

Coastal Zones of India



Space Applications Centre - ISRO, Ahmedabad

Coastal Zones of India

(Sponsored by Ministry of Environment & Forests, Govt. of India)

Space Applications Centre, ISRO

Ahmedabad

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जयन्ती नटराजन
Jayanthi Natarajan



MESSAGE

राज्य मंत्री (स्वतंत्र प्रभार)
पर्यावरण एवं वन मंत्रालय
भारत सरकार
नई दिल्ली-110 003

MINISTER OF STATE (INDEPENDENT CHARGE)
ENVIRONMENT & FORESTS
GOVERNMENT OF INDIA
NEW DELHI-110 003

Coastal Zones, the area of interaction between land and sea, are highly dynamic entities subject to waves, tides, currents, winds, in addition to anthropogenic activities. Because of the economic benefits that accrue from access to ocean navigation, coastal fisheries, tourism and recreation, human settlements are often more concentrated in the coastal zones than elsewhere. About 40% of the world's population lives within 100 Km of the coast. As the population density and economic/industrial activities in the coastal zones increase, pressure on coastal ecosystem increase. Coastal zone being very fragile, it needs to be monitored regularly.

India has a long coast line of about 7500 km including that of its island territories. The coastal zone of India is under increasing pressure due to rapid urbanization, tourism development, discharge of waste effluents, municipal sewage, over exploitation of coastal resources and continued development in hazard prone areas.

The Ministry of Environment and Forests (MoEF), Govt. of India had issued CRZ notification in February 1991 to regulate the activities in the coastal zones, since then the activities in the CRZ are being monitored and regulated. Subsequently, MoEF has issued a new CRZ notification in January, 2011.

Space Application Centre (SAC) has earlier mapped the entire Coastal Zones of India using Satellite data. These maps have been extensively used in implementing CRZ during the past 20 years. Recently, SAC in collaboration with a large number of scientific organizations & universities of the country has carried out, at the behest of MoEF, a detailed scientific investigation/inventory of the entire coastal zones of India. It includes i) inventory of the coastal land use along with demarcation of HTL/LTL and ESAs ii) mapping and monitoring of coral reefs and mangroves iii) impact of sea level rise on the Indian coastal environment and iv) development of Coastal Zone Information System (CZIS).

The present book is an outcome of the National Project "Coastal Zone Studies" on the above aspects of Indian Coastal Zones sponsored by the MoEF under its National Natural Resources Management Systems (NNRMS) Programme.

I congratulate the national team of the scientists led by Dr. Ajai, Space Application Centre, Ahmedabad and Dr. G. V. Subrahmanyam, Advisor, MoEF and his team for carrying out such an important study for the entire Indian coast. This study assumes greater significance in the context of the recent CRZ notification 2011.

I am sure this book will be highly useful not only to the coastal zone managers and the authorities involved in CRZ implementation but also to the scientific community working in the coastal environment and climate change studies.

Jayanthi Natarajan
(Jayanthi Natarajan)

तिथ्यरक्षित चटर्जी
Dr. Tishya Chatterjee



सचिव
भारत सरकार
पर्यावरण एवं वन मंत्रालय
Secretary
Government of India
Ministry of Environment and Forests

Preface

Coastal Zone is one of the most fragile and dynamic ecosystems having interface of sea and land. Interactions between various natural processes and human activities are important factors in the coastal areas. The Coastal Zone in India assumes importance because of high population pressure, development of various industries and spurt in recreational activities, exploitation of renewable and non renewable natural resources, discharge of waste effluents and municipal sewage etc. Periodic storms and cyclones as well as erosion further adds to the problems in the coastal areas.

Inventory and regular monitoring of Indian Coastal Zones are indispensable due to its dynamic nature. The Ministry of Environment and Forests (MoEF), Govt. of India has been regulating the activities in the Indian Coastal Zone through the CRZ notification issued in 1991. Recently, in January 2011, MoEF has issued a new CRZ notification for regulating the Indian coastal zones.

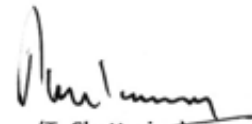
One of the basic requirements in implementing the CRZ notification is the availability of spatial information for the entire Indian Coastal Zone. Space Applications Centre (SAC), ISRO has earlier mapped the entire coastal zones of India using satellite data of 1989 - 92 timeframe. These maps have been extensively used by the state environment departments and MoEF in providing environmental clearances and in implementing CRZ notification during the last 20 years.

In view of the dynamic nature of coastal zones, Space Applications Centre, at the behest of the Ministry of Environment & Forests has carried out a detailed inventory of the entire Coastal Zone of the country using recent satellite images. The findings of the studies carried out on i) mapping of coastal land use along with the HTL/LTL, ii) inventory and monitoring of coral reefs and mangroves iii) impact of sea level rise and iv) development of coastal zone information system, are presented in this book.

I congratulate the national team of the scientists led by Dr. Ajai, Group Director, Space Applications Centre, Ahmedabad and Dr. G.V. Subrahmanyam, Advisor, MoEF and his team for such an important study for the entire coast of the country.

I hope that the spatial information generated for the entire Indian Coastal Zone by SAC will be useful to the scientific community for carrying out research in the field of coastal environment and to State environment departments and the MoEF in implementing the CRZ notification.

December 23, 2011


(T. Chatterjee)


जहाँ है हरियाली।
वहाँ है खुशहाली।।

पर्यावरण भवन, सी.जी.ओ. कॉम्प्लेक्स, नई दिल्ली-110 003 फोन : 24360721, 24361896, फैक्स : (011) 24362746
PARYAVARAN BHAWAN, CGO COMPLEX, NEW DELHI-110 003, Ph. : 24360721, 24361896, Fax : (011) 24362746
E-mail : t.chatterjee@nic.in, titichatterjee@gmail.com

भारतीय अन्तरिक्ष अनुसंधान संगठन
अन्तरिक्ष विभाग
भारत सरकार
अन्तरिक्ष भवन
न्यू बी ई एल रोड, बेंगलूर - 560 231, भारत
दूरभाष : +91-80-2341 5241 / 2217 2333
फैक्स : +91-80-2341 5328



Indian Space Research Organisation
Department of Space
Government of India
Antariksh Bhavan
New BEL Road, Bangalore - 560 231, India
Telephone: +91-80-2341 5241 / 2217 2333
Fax : +91-80-2341 5328
e-mail : chairman@isro.gov.in

Dr. K. Radhakrishnan
Chairman

Preface

Coastal zones represent diverse ecosystems and support highly productive habitats such as mangroves, mudflats and other marine species. India has a coast line of 7,500 km which is intersected by rocky outcrops and shores with stretches of sandy beaches. It supports over 25% of countries population within 100 km of the coastline. As a consequence of anthropogenic and socio-economic factors the coastal zones of India are subjected to enormous pressures. Moreover, industrial development and unsustainable growth have resulted in degradation of coastal zones and surrounding ecosystems.

Dynamic nature of the coastal zones necessitates regular monitoring in order to realize integrated management plans for sustainable conservation of coastal areas. Towards this, Space Applications Centre, ISRO, in collaboration with a large number of organizations, has carried out a detailed inventory for the entire coast of India using recent satellite data. This includes studies on coastal land use mapping, inventory of vital coastal habitats, impact of sea level rise and development of coastal zone information system.

I compliment the team for having created a rich database on such an important subject. I am sure that the information generated and presented in this book on the Indian coastal zones will be of immense use to the coastal zone managers, researchers and also for ecological conservation in the country.


20/6/12
(K. Radhakrishnan)

भारत सरकार
अन्तरिक्ष विभाग
अन्तरिक्ष उपयोग केन्द्र
आंबावाडी विस्तार इकाई पर,
अहमदाबाद-380015. (भारत)
दूरभाष: +91-79-6912000, 6915000
फैक्स :



Government of India
Department of Space
SPACE APPLICATIONS CENTRE
Ambawadi Vistar P.O.
Ahmedabad-380 015. (India)
Telephone : +91-79-6912000, 6915000
Fax :

Rangnath R. Navalgund
Director

Preamble

Coastal zones are highly dynamic area of interaction between terrestrial and marine processes. Although, coastal zones constitute about 10% of the land area, these are densely populated, sustaining as much as 60% of the world's population.

The processes of erosion and sedimentation, periodic storms and cyclones and sea level changes continuously modify shoreline. The entire stretch of coastal zone along 7,500 km long coast line of India assumes its importance because of high productivity of its ecosystems, exploitation of natural resources, industrial and port development, discharge of waste effluents and increased tourism activities.

During the past three decades, Space Applications Centre (ISRO), Ahmedabad along with a large number of collaborating agencies has developed methodologies for extraction and dissemination of reliable and quick information from remote sensing data pertaining to the various aspects of coastal zone of India. It includes the delineation of high tide line and low tide lines, shore line changes, coastal land uses, landforms and the critical/vital habitats.

A national project on 'Coastal Zone Studies' was taken up by Space Applications Centre (ISRO) at the behest of Ministry of Environment and Forests (MoEF), Government of India. The project addressed the various aspects of the Indian coastal zone, including preparation of base-line information on CRZ, inventory of coastal land use including Ecologically Sensitive Areas (ESA) for the entire Indian coast on 1:25,000 scale.

Mangroves and Coral Reef areas of the Indian coast have been mapped on 1:25,000 scale at dominant community and eco-geomorphological level respectively, using Resourcesat LISS-IV/LISS III data of the period 2004-07. Models have been developed for assessing health of mangroves as well coral reefs. All the spatial data generated for the Indian Coast has been put into 'Coastal Zone Information System'. The query shells are developed for retrieval of thematic information and automatic map generation. Coastal processes have been studied and approach has been developed to assess coastal vulnerability due to predicted sea level rise.

I compliment the entire team of scientists from both ISRO and other organizations for carrying out this national level task diligently. I do hope, the above information is vital for implementing the CRZ Notification, monitoring CRZ violations and providing environmental clearance by MoEF & State Environment Departments. In addition, these spatial information will be of immense use to the researchers and environmentalists working in the field of coastal habitat, coastal zone management, coastal vulnerability and studying the impact of climate change.

October 14, 2011

(Rangnath R. Navalgund)

भारत सरकार
अन्तरिक्ष विभाग
अन्तरिक्ष उपयोग केन्द्र
आंध्रप्रदेश विस्तार इकाई पर,
अहमदाबाद-380015. (भारत)
दूरभाष: +91-79-6912000, 6915000
फैक्स :



Government of India
Department of Space
SPACE APPLICATIONS CENTRE
Ambawadi Vistar P.O.
Ahmedabad-380 015, (India)
Telephone : +91-79-6912000, 6915000
Fax :

Dr. Ajai
Group Director
Marine, Geo and Planetary Sciences Group

Ph : 079 - 26914141
Fax : 079 - 26915825
Email : ajai@sac.isro.gov.in

Acknowledgement

Coastal Zone, the area having influence of both marine and terrestrial processes, is one of the most fragile, dynamic and productive ecosystem. The coastal zone has been receiving increased attention due to pressure of population, developmental activities, trade and transport and presence of vital and critical habitats. The loss of biodiversity, severe coastal erosion, sedimentation in ports and harbours, industrial pollution are some of the major concern to the coastal zone managers. In India, the CRZ notification 2011, governs/regulates the activities in the coastal area of the country. Maps prepared by Space Applications Centre on 1:25,000 scale using satellite data of 1989-91 time frame has been extensively used by the state environment departments and the Ministry of Environment and Forests (MoEF), Government of India in implementation of CRZ in the country.

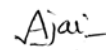
In view of the dynamic nature of the coastal zone, a project on mapping and monitoring of the Indian Coastal Zone, using the latest satellite images, was taken up by Space Applications Centre at the behest of MoEF. The project envisaged: i) CRZ (land use/land cover) mapping of the entire Indian coast on 1:25,000 scale ii) mapping of vital critical habitats such as mangroves (on dominant community level) and coral reefs (on eco morphological level) iii) development of model to monitor the health of these two habitats iv) development of coastal zone information system and v) study the impact of sea level rise on the coast. The project has been successfully executed by SAC in collaboration with 22 important organizations of the country.

We would like to place on record our deep sense of gratitude to Dr. R.R. Navalgund, Director, SAC for his encouragement and guidance in carrying out this national project. We express our thanks to the Director's and Scientific team of each of the collaborating agencies for their valuable contributions in carrying out the project. We are thankful to Shri A.S. Kirankumar, AD, SAC, Dr. V.S. Hegde, Scientific Secretary ISRO and Director EOS, Dr. J.S. Parihar, Deputy Director, EPSA, SAC and Dr. K. Ganesh Raj, Dy. Director (Applications), ISRO H.Q. for their guidance, support and help.

We are very much thankful to Dr. G.V. Subrahmanian, Advisor, Dr. Jag Ram, Director and Dr. Harendra Kharakwal, Scientist, MoEF for their continuous support in executing this project.

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Ahmedabad
October 20, 2011


(Ajai)

National Team

Team Leader: Dr. Ajai
Dr. Shailesh Nayak

SAC, Ahmedabad

V. Tamilarasan
H.B. Chauhan
Anjali Bahuguna
M.C. Gupta
A.S. Rajawat
Nandini Ray Chaudhury
Tanumi Kumar
R.S. Rao
Satadru Bhattacharya
Ratheesh Ramakrishnan
R.J. Bhandari
Manik Mahapatra

IESWM, Kolkata

Somenath Bhattacharyya
Kakoli Sen Sarma
Abhijit Hor
Tanusree Basak
Madhumita Das
Aniruddha Sengupta
Shyamal Mondal
Sayak Chakraborty

Central Agricultural Research Institute, Port Blair

S. Dam Roy

BISAG, Gandhinagar

T.P. Singh

Forest Survey of India (FSI), Dehradun

Subhash Ashutosh
Raj Kumar

INCOIS, Hyderabad

S.S.C. Shenoi
T. Srinivasa Kumar
R.S. Mahendra
Prakash Chandra Mohanty
Hrushikesh Bisoyi
Sumisha Velloth

CESS, Thiruvananthapuram

M. Baba
M. Samsuddin
K.K. Ramachandran
T.N. Prakash
Misilul Khamar
Anil Kumar P.
G. Renoy

GEER, Gandhinagar

C.N. Pandey
B.H. Patel
Sachin Chavan
Rakesh Patel

Madurai Kamraj University, Madurai

A.K. Kumarguru

IRS, Anna University, Chennai

M. Ramalingam
K. Srinivasan
P. Radhakrishnamoorthy
V. Franklin

**M.S. Swaminathan Research
Foundation (MSSRF), Chennai**

V. Selvam
L. Gnanappazham

**Annamalai University,
Annamalainagar**

Thangaradjou
K. Sivakumar
T. Balasubramanian

**Bharathidasan University,
Tiruchirapalli**

S.M. Ramasamy
C.J. Kumanan
J. Saravanel

**Andhra University,
Visakhapatnam**

K. Nageswara Rao
P. Subraelu

APSRAC, Hyderabad

K. Mruthyunjaya Reddy
A.V. Subba Rao
G.V. Padma
G. Sreedevi

KRSAC, Bangalore

M.H. Balakrishnaiah

V. Shreedhara
M.E. Vijayakumar
C.J. Yogesh
M.C. Jayaprakash
Chandrakanth Lingdal

ORSAC, Bhubaneswar

A.K. Mohapatra
P. Kumar
N.C. Das
S. Devi
S. Padhi

MRSAC, Nagpur

A.K. Sinha
D.M. Kolte
R.K. Deshkar

MS University, Vadodara

Nikhil Desai
Dharmendra G. Shah
Uday Bhonde
Sweta Bhatt
Shreestuti Tattu

CEPT, Ahmedabad

Anjana Vyas

M.G. Science Institute, Ahmedabad

Alpana Shukla
Kosha Trivedi

MoEF, New Delhi

G.V. Subrahmanian
Jag Ram
Harendra Kharkwal

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1. Introduction

The coast is a unique environment where land, sea and atmosphere interact and interplay continuously influencing a strip of spatial zone defined as coastal zone. In other words, coastal zones are the areas having the influence of both marine and terrestrial processes. Coastal zones are the most fragile, dynamic and productive ecosystem and are quite often under pressure from both anthropogenic activities and natural processes. It supports a large amount of floral and faunal biodiversity. Coastal Zone is endowed with a very wide range of habitats such as coral reefs, mangroves, sea grasses, sand dunes, vegetated stungle, mudflats, salt marshes, estuaries, lagoons etc., which are characterized by distinct biotic and abiotic processes.

Boundaries of the coastal zones are defined in different ways depending on the focus of interest and availability of data. Typically, a combination of distance-to-coast and elevation data is used. Different countries use different distance criteria for defining the coastal zone. In India, 500 m distance from the high tide line (landward) is taken for demarcating the coastal zone.

Total coast line of the world is 35, 6000 km and the coastal area covers more than 10% of the earth surface. Because of the economic benefits that accrue from access to ocean navigation, coastal fisheries, tourism, recreation and industrialization, human settlements are often more concentrated in the coastal zone than elsewhere. About 40% of the world's population lives within 100 km of the coast. About 10% of the world's population resides in low elevation coastal zone (<10 m) making their lives highly vulnerable to coastal disasters. About 35% of Indians live within 100 km of the country's coast line measuring 7517 km.

Coastal zones in India assumes importance because of high productivity of its ecosystems, concentration of population, exploitation of renewable and nonrenewable natural resources, discharge of waste effluents and municipal sewage, industrialization and spurt in recreational activities. Coastal zones are continuously changing because of the dynamic interactions between the ocean and land. Erosion and accretion, inundation due to sea level rise and storm surge, shifting of shoreline caused by natural or anthropogenic forces, such as

construction of artificial structure, port and harbors leads to changes in the coastal zone and its environment.

Thus, regular monitoring of coastal zone is indispensable. Moreover, preparation of a suitable coastal zone management plan as well as implementation of regulations in the coastal zone require spatial information on the coastal land use and land forms along with high tide and low tide lines, the inventory and status of coastal habitats and information on ESAs (Ecologically Sensitive Areas).

Remote sensing techniques have been extensively used in inventory, monitoring and management of natural resources in the coastal areas. Due to its repetitive, multispectral and synoptic nature, satellite Remote Sensing (RS) has proved to be extremely useful in providing information on various aspects of the coastal environment, viz. coastal wetlands, coastal landforms, shoreline changes, tidal boundaries (high/low), brackish water areas, suspended sediment dynamics, coastal currents, vital coastal habitats etc. Coastal habitats of the entire Indian coast were mapped earlier on 1:250,000 /1:50,000 scale using multispectral satellite data (Nayak et al. 1992). Similarly, satellite data has successfully been used to map the Indian coast including the delineation of High Tide Lines (HTL) and Low Tide Lines (LTL) on 1:25000 scale for Regulation of the Coastal Zones. RS data has also been used for mapping the mangroves at dominant community level and for mapping coral reefs at eco-morphological levels.

A large number of studies pertaining to different aspects of Indian coastal environment have been carried out using RS & GIS technology. Some of the organizations in India have been using satellite data operationally to create information on coastal zones of the country. Forest Survey of India has been using satellite data to regularly monitor the mangroves of the Indian coast. Institute for Ocean Management (IOM), Anna University; ICMAM Project Directorate of MoES; M.S. Swaminathan Research Foundation; Centre for Earth Science Studies, Thiruvananthapuram; Institute of Wetland Management and Ecological Design, Kolkatta; State Remote Sensing Centres of Gujarat, Maharashtra, Karnataka and Orissa; National Remote Sensing Centre, Hyderabad, etc. have worked on the Indian coast using RS data in studying the existing landuse and changes in the landuse/landcover pattern, shoreline

management studies, coastal processes and mapping of critical habitats such as coral reefs, sea grass, mangrove. IOM and ICMAM have generated models for coastal zone management using RS & GIS technologies.

Space Applications Centre (ISRO), Ahmedabad has carried out extensive studies for the entire Indian coastal zone. It includes mapping and monitoring of vitital coastal habitats such as mangroves and coral reefs. Spatial inventory of mangroves and coral reefs have been made by Space Applications Centre (SAC) using satellite data of 1989-91 time frame. Coastal land use and landforms have been mapped for the entire coastal zones of the country using satellite data of 1989-91 time frame. These maps on 1:25,000 scale assumed greater significance in view of the CRZ notification brought out by MoEF in January 1991. These CRZ maps which depicted HTL (High Tide Line) and LTL (Low Tide Line) along with the coastal land uses have been extensively used for implementing CRZ notification in the country. Shoreline of the country have also been mapped based on satellite data.

The above spatial inventory is based on the satellite images of 1989-91 time frame. As the coastal zones are highly fragile and dynamic in nature, it was felt necessary to revisit and make a spatial inventory of the above mentioned aspects of coastal environment/zones using recent satellite data. Accordingly, Space Applications Centre along with 22 organisations/Universities and academia of the country has carried out the task of coastal zone mapping using IRS (Indian Remote Sensing Satellite) data of 2004-06 time frame. It includes the following major elements: i) mapping and monitoring of the coastal land use for the entire Indian coast at 1:25,000 scale using satellite data of 2004-06 time frame and development of methodology to map the coastal zone at local level (1:5000 scale), ii) to map the coastal vital/critical habitats, namely, mangroves at community level and Coral Reefs at eco-morphological level on 1:25,000 scale using multidecade satellite data, iii) development of models to assess health of mangroves and coral reefs, iv) development of Coastal Zone Information System (CZIS) for the entire Indian coast using digital database of coastal thematic maps, v) development of conceptual frame work for integrated coastal zone management and vi) to understand coastal processes and develop methods to assess impact of predicted sea level rise on coastal environment. The details on the above studies have been elaborated in this book. Inventory and monitoring of coastal zones, the 'Ecologically Sensitive Area' (ESA)

landforms / landuse etc are discussed in chapter two. Mangroves, its zonation at community level and health models are presented in chapter three. Spatial inventory of coral reefs and its ecomorphological zonations are discussed in chapter four. Details of the health models for coral reefs are also given in chapter four. Information on the selected Marine Protected Areas (MPAs) are presented in chapter five. Chapter six deals with coastal zone information system which has been developed for the entire coast of India. Climate change, the associated sea level rise and its likely impact on the coastal landforms and environment are discussed in detail in chapter seven. Conceptual frame work for integrated coastal zone management are presented in chapter 8.

2. Coastal Land Use

Coastal landuse is one of the most desired information for assessing the status of natural resources and the coastal environment. It is also a pre requisite for zonations of the coast as well as for making a sustainable coastal zone management plan. A variety of spatial databases have already been generated at SAC for the Indian coast using satellite data. These include coastal wetland maps for the entire Indian coast at 1:250, 000 (using satellite data of 1986), 1:50,000 (satellite data of 1990-93) and 1:25, 000 (using satellite data of 1988-90) scales, coastal landuse maps on 1:25,000 scale based on satellite data of 1989-91 time frame, mangrove and coral reef maps. Spatial data for these themes have been integrated in to Coastal Zone Information System (CZIS) developed at SAC. As a large amount of developmental activities have taken place in many parts of the Indian coast affecting the coastal habitats, degrading the coastal/marine resources and hence a fresh mapping on coastal land use and ESAs (Ecologically Sensitive Areas) is required on 1: 25,000 scale using the latest satellite data.

Implementation of coastal zone management plans require mapping at local/cadastral level i.e. 1:4000/8000. Resourcesat and Cartosat 1 and 2 along with IKONOS can be used for local level mapping. Stereo viewing capabilities of Cartosat can greatly help in generating local level information.

Coastal zone mapping has been done at two scale: i) on 1:25000 scale for inventory and monitoring of the entire Indian coast and ii) local level mapping at 1:5000 scale for selected areas .

Land Use and land Cover Changes (LUCC) may influence carbon fluxes and green house gas emissions, and modify land surface characteristics which may influence the climatic processes. The land-cover modification and conversion may alter the properties of the ecosystems, biodiversity and their vulnerability to climate change. Changes such as clearing of forests for use in agriculture or settlements are associated with change in the carbon stocks. Thus the study of land use changes in coastal areas is essential for understanding the global environmental changes. In addition, efforts have been made to develop models

for predicting changes in coastal hotspots on the basis of past and current trends in landuse land /cover changes.

Inventory and Monitoring

Entire Indian coast upto 500 m from HTL has been mapped at 1:25,000 scale using primarily Resourcesat-1 LISS-IV data. Cartosat and LISS-III data has also been utilized (one-time) for selected regions. As far as possible data of low tide condition were used as most of the coastal wetlands get maximum exposure during low tidal condition. The satellite data of December-February was chosen in most cases to take care of reproductive cycle of vegetation present in wetland areas. Around 1000 scenes of Resourcesat-1 LISS-IV precision geo-coded products at 1:25,000 scale cover the entire Indian coast. WGS 84 datum and UTM projection were used while mapping coastal land use. Digital database of existing coastal thematic maps were used as base maps.

The land use/land cover and land forms have been mapped on 1:25, 000 scale using Resourcesat-1 LISS-IV/LISS III data of 2004-2006 time period. Digital data was downloaded and displayed on image processing work stations/high end desktop PC and visual interpretation was employed with on – screen digitization. The classification system used in the present landuse inventory (Nayak et al. 1992) is given in table 2.1:

Table 2.1: Classification System for Coastal Wetland and land use mapping

	Level I	Level II	Level III
1	Wetland		
1.1		Mudflat /tidal flat	
1.1.1			Sub - tidal
1.1.2			Inter - tidal
1.1.3			High tidal
1.1.4			High tidal with Salt - encrustation
1.2		Beach / Patch	
1.3		Spit	
1.4		Bar/barrier/ island	
1.5		Shoals	

1.6		Beach ridge	
1.7		Rocky coast	
1.8		Rock exposure	
1.9		Mangrove	
1.9.1			Very Dense
1.9.2			Dense
1.9.3			Sparse
1.9.4			Degraded
1.10		Salt-marsh/Marsh vegetation	
1. 10.1			Dense
1. 10.2			Moderately dense
1. 10.3			Sparse
1.11		Algae	
1.11.1			Dense
1.11.2			Moderately dense
1.11.3			Sparse
1.12		Sea grass	
1.12.1			Dense
1.12.2			Moderately dense
1.12.3			Sparse
1.13		Mud with vegetation	
1.14		Sand with vegetation	
1.15		Scrub	
1.15.1			Dense
1.15.2			Sparse
1.15.3			Degraded
1.16		Coral reef	
1.16.1			Fringing
1.16.2			Platform
1.16.3			Patch
1.16.4			Atoll
1.16.5			Coral Lagoon
1.16.6			Coral pinnacle
1.16.7			Coralline shelf
1.16.8			Coral head

2	Water bodies		
2.1		Estuary	
2.2		Creek	
2.3		Lagoon	
2.4		Bay	
2.5		Pond/lake	
2.6		Oxbow lake	
2.7		Meanders	
2.8		Cooling pond	
2.9		Water treatment plant	
2.10		River/stream	
2.11		Canal	
2.12		Waterlogged	
2.13		Reservoir / tank	
3	Barren/ wasteland		
3.1		Mining areas/dumps	
3.2		rock outcrops/gullied /eroded/barren land	
3.3		Brick kiln	
3.4		Sandy area	
4	Shore land		
4.1		Saline area	
4.2		Coastal dunes	
4.2.1			Dune with vegetation
4.2.2			Dune without vegetation
5	Built-up land		
5.1		Habitation	
5.1.1			Habitation With vegetation
5.2		Open/vacant land	
5.3		Industrial area	
5.4		Waste dumping	
5.5		Transportation	
5.5.1			Roads
5.5.2			Railways
5.5.3			Port/Harbour/jetty

5.5.4			Waterways
5.5.5			Airport
6	Agricultural land		
7	Forest (Non-tidal)/ Plantation		
8	Other features		
8.1		Aquaculture ponds	
8.2		Salt pans	
8.3		Cliff	
8.4		Seawall/Embankment	

		High waterline	—————
		Low waterline	- - - - -
		CRZ Boundary	
		District Boundary	—————
		State Boundary	— . — . .

For preparation of coastal land use/land cover maps, a minimum mapable unit of 2mm x 2mm was considered. At 1:25, 000 scale the minimum area of 0.25 ha (equal to 2 x 2 mm) could be mapped.

The High tide line (HTL) is one of the important features in the coastal area which is required to delineate the Coastal zone or the CRZ. It has been defined as the extent up to which the highest of high tide reaches during spring tides. On a satellite image, the distinct tonal discontinuity along with the geomorphic feature and landforms are used in delineating the HTL. This tonal discontinuity is due to the effect of water leaving its mark on the land. Apart from this, the

presence of mangroves, mudflats, beach and other geomorphic features are also used while delineating HTL on satellite images. It is difficult to map LTL from satellite imagery except where the image is of lowest of low tide conditions. In such cases the land-water boundary is delineated. A buffer zone of 500 m from HTL is marked on the map to indicate CRZ extent. Various wetland categories are delineated between HTL and land-water boundary/LTL and the coastal landuse categories in the adjoining strip of 500 m based on the interpretation key. Land use categories for area outside 500 m strip are delineated up to the boundary of the respective map sheet on 1:25, 000 scales.

Ground truths are carried out for validation and accuracy assessment of the maps. Plate numbers 2.1 to 2.5 (given at the end of the book) show different coastal features as seen on the ground. Detailed collection of field data is often not possible because of difficulty of traversing and navigating in coastal areas. Each 1:25000 scale map covers an area bounded by 7.5' x 7.5'. Various base map details such as village, town, district and state boundaries are transferred on to the interpreted map. Necessary corrections in the preliminary maps are carried out after field check. Final maps are prepared after including base information. Standard colour coding scheme finalised by Space Applications Centre (SAC) have been used in preparation of final maps. A sample map is shown in Figure 2.2. Classification accuracy has been estimated using random sampling method. Approximately 10 percent of the numbers of total maps were selected and classification accuracy check was carried out by selecting random points on each map. Edge matching of adjoining maps ensured the continuity of maps. Statewide database was generated using these maps and seamless mosaics were prepared (Figure 2.1).

Coastal zone maps for the entire Indian coast on 1:25,000 scale were prepared. These maps depict the ecologically sensitive areas (ESAs) and the HTL, LTL in addition to the coastal landuse and landforms.

State-wise Coastal land Use Maps

The details of the landuse classes mapped and their spatial distributions for each of the maritime states are discussed below:

Gujarat

The Gujarat coast lies between $20^{\circ} 00'$ - $24^{\circ} 45'$ N latitudes and $68^{\circ} 00'$ - $73^{\circ} 30'$ E longitudes. Maps on 1:25,000 scales have been prepared for the entire Gujarat coast. Diu & Daman are geographically associated with Gujarat and hence clubbed with Gujarat.

Gujarat is having longest shoreline of 1600 km among all the maritime states of India. The Gujarat coast is having two gulfs, namely, Gulf of Kachchh and Gulf of Khambhat. Total seven estuaries exist in Gulf of Khambhat and delivering large amount of water and sediments, whereas in Gulf of Kachchh riverine inputs are very little. Gujarat coast provides a wide variety of coastal features due to its varied physiography, geomorphology and coastal processes. It has distinct variation in the wetland landform categories due to climate, substrate constituent and topography. Large industrial investment all along the coast is altering the coastal land use and land cover.

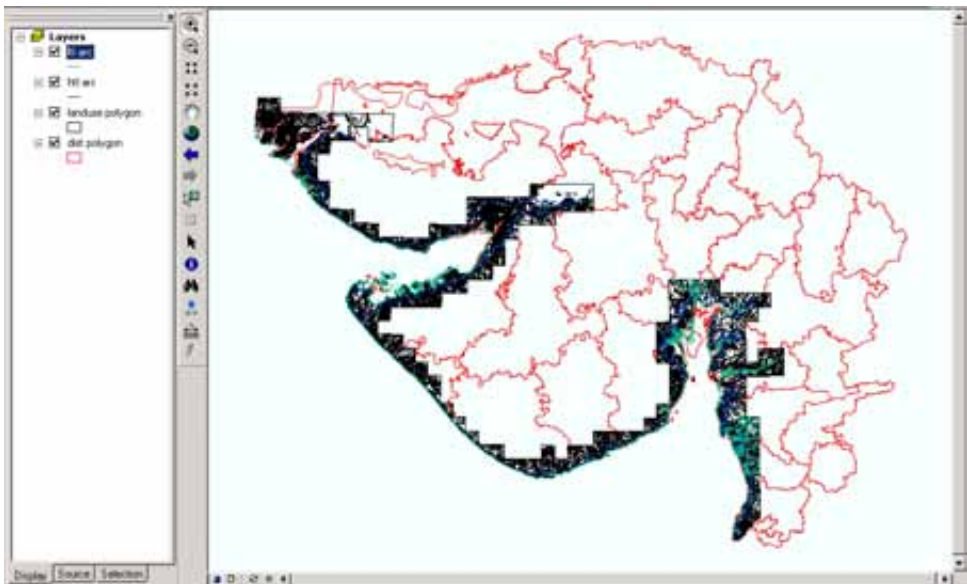


Fig. 2.1: Coastal Landuse mapping for Gujarat state

Western most part of Gujarat coast, known as Kori Creek, is a part of lower Indus deltaic plain and is characterised by network of tidal creeks and small overbank splays that houses large block of mangrove on a sand/silt substrate. Coastal wetlands of the Rann of Kachchh broadly comprise high tide mudflats

with or without salt encrustation, salt marsh vegetation and mangrove around the Kori creek area. The shoreline of Gulf of Kachchh has extensive mudflats and is highly indented with a number of cliffy rocky islands. It is indented by coral reefs at many places. Saurashtra coast is less indented and moderately straight. From Gopnath point to Diu towards the west numerous cliffs, mudflats, beaches, estuaries and embayments are seen. Near Mahua row of dunes are observed. From Diu onwards, sandy beaches, numerous spits, bars, bays, marshes and small estuaries predominates. The coastal flora of Saurashtra is a mixture of saline and inland type. The coast around Gulf of Khambhat is indented by estuaries and consisting of extensive mudflats, dunes and sporadic presence of sandy beaches. All these landforms are the result of high-tidal range in the Gulf of Khambhat. The South Gujarat coast is comparatively uniform and broken by few indentions. Narrow sandy beach is present between Mindhola and Purna rivers and extends up to Daman. Heavy minerals, quartz and mica make up the beach sand. Along the estuaries of the Mindhola, the Purna, the Ambica, the Auranga and the Damanganga mudflats are with marsh and mangrove vegetation. Numerous small tidal creeks also occur along the coast. South of Auranga estuary, the coast is rocky.

Figure 2.3 provides the coastal landuse distributions for Gujarat state. Total area covered by Mudflat is 5504.41 sq km. Industrial development along the coast is very fast and it occupies 192.21 sq km. Gujarat is a major salt producer in India and salt pan occupies 1115.60 sq km (Table 2.2).

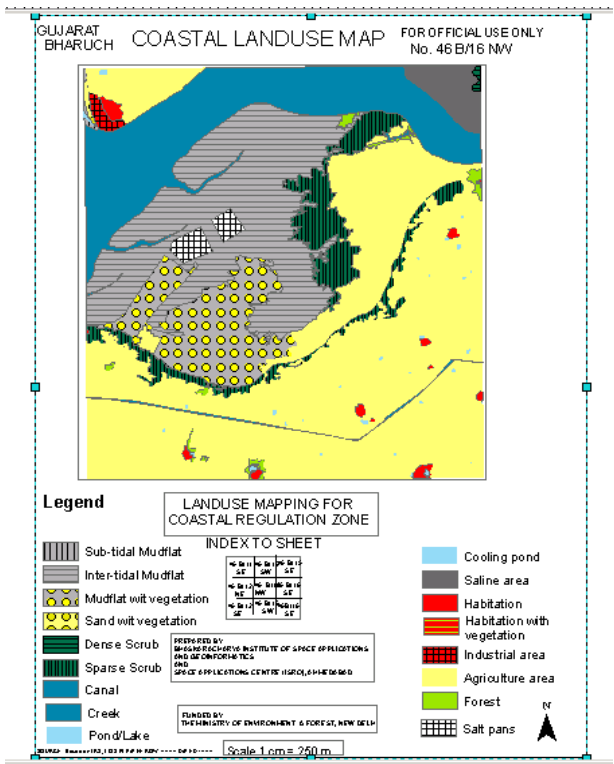


Fig. 2.2: Sample Coastal Landuse map, Gujarat coast

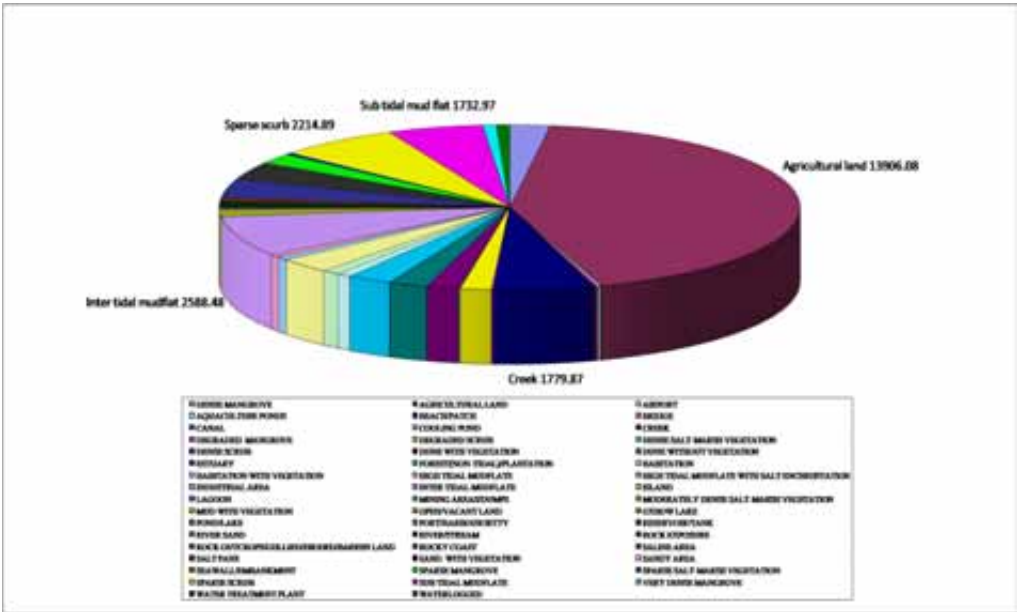


Fig. 2.3: Coastal land use distribution of Gujarat

Table 2.2: Coastal landuse area of Gujarat

S. No.	Land-use class	Area in sq. km
1	Dense Mangrove	732.20
2	Agricultural Land	13906.08
3	Airport	9.68
4	Aquaculture Ponds	64.45
5	Beach/Patch	85.87
6	Bridge	0.25
7	Canal	13.73
8	Cooling Pond	2.88
9	Creek	1779.87
10	Degraded Mangrove	29.78
11	Degraded Scrub	563.52
12	Dense Salt-Marsh Vegetation	18.25
13	Dense Scrub	588.95
14	Dune With Vegetation	0.49
15	Dune Without Vegetation	69.70
16	Estuary	9.66
17	Forest(Non-Tidal)/Plantation	816.39
18	Habitation	256.57
19	Habitation With Vegetation	316.72
20	High Tidal Mudflat	947.11
21	High Tidal Mudflat With Salt Enchrustation	235.85
22	Industrial Area	192.21
23	Inter Tidal Mudflat	2588.48
24	Island	2.12
25	Lagoon	0.01
26	Mining Areas/Dumps	7.53
27	Moderately Dense Salt-Marsh Vegetation	234.20
28	Mud With Vegetation	164.43
29	Open/Vacant Land	6.84
30	Oxbow Lake	0.01
31	Pond/Lake	104.71
32	Port/Harbour/Jetty	1.54
33	Reservoir/Tank	150.14
34	River Sand	10.96
35	River/Stream	297.87
36	Rock Exposure	0.07
37	Rock Outcrops/Gullied/Eroded/Barren Land	178.25
38	Rocky Coast	8.09
39	Saline Area	1226.87
40	Salt Pans	1115.60

41	Sand With Vegetation	8.66
42	Sandy Area	40.60
43	Seawall/Embankment	0.21
44	Sparse Mangrove	634.83
45	Sparse Salt-Marsh Vegetation	111.86
46	Sparse Scrub	2214.89
47	Sub Tidal Mudflat	1732.97
48	Very Dense Mangrove	248.41
49	Water Treatment Plant	0.68
50	Waterlogged	241.13
	Total Area	32593.17

Maharashtra

The Maharashtra coast lies between $15^{\circ} 45'$ - $20^{\circ} 00'$ N latitudes and $68^{\circ} 00'$ - $73^{\circ} 30'$ E longitudes. A total of 95 maps on 1:25,000 scale cover the entire Maharashtra coast.

The Maharashtra coast is characterised by pocket beaches flanked by rocky cliffs of Deccan basalt as we go from North to south, estuaries and the patches of the mangroves along it. Beaches of the Maharashtra coast are small, crescent shaped and flanked by promontories. They are termed as pocket beaches as they are pocketed between headlands. They are delineated southwest of Dahnu, Andhari, north of Alibag, Vadamirya and Rajapur creek. Long and linear beaches are observed near Guhaghar and Malvan. Mudflats are found mainly along the estuaries and bay. They are broad at the mouth and gradually tapered down. They are observed near Thane creek, Panvel creek, and Vasai creek, along the bank of Kundalika river and along the Rajapur creek. Mangroves are mainly observed along the intertidal region of estuaries and creeks. Large patches of mangroves are observed along the Panvel creek, Vasai creek, Thane creek and Dharamtar creek, along the estuaries of Vasisth, Savitri and Kundlika. Coastal dunes are found with *Casurina* plantation near Malvan and Devgarh. Table 2.3 provides the areas under different coastal landuse classes for Maharashtra. Area covered by mudflat is 300.76 sq km, Habitation with vegetation occupies 1049.75 sq km, Rock outcrop / Barren area occupies 911.81 sq km and Forest / Plantation occupies 3250.88 sq km. Figure 2.4 shows the land use distributions for Maharashtra.

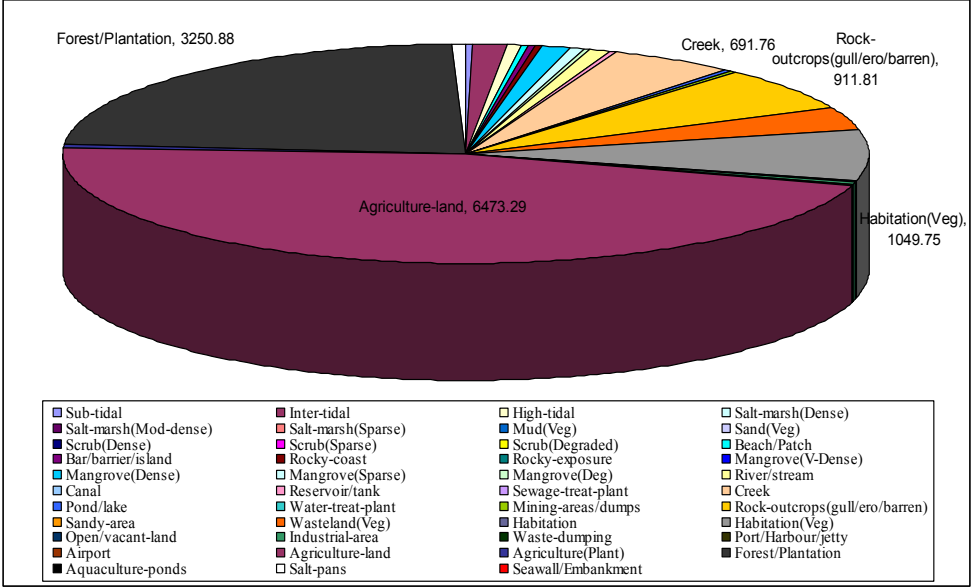


Fig. 2.4: Coastal land use distribution of Maharashtra

Table 2.3: Coastal landuse area of Maharashtra

S. No.	Land-use class	Area in sq. km
1	Sub-tidal	29.77
2	Inter-tidal	209.91
3	High-tidal	61.08
4	Salt-marsh (Dense)	2.01
5	Salt-marsh (Mod-dense)	3.51
6	Salt-marsh (Sparse)	5.49
7	Mud (Veg)	0.74
8	Sand (Veg)	2.2
9	Scrub (Dense)	0.64
10	Scrub (Sparse)	9.86
11	Scrub (Degraded)	0.03
12	Beach/Patch	44.2
13	Bar/barrier/island	1.49
14	Rocky-coast	43.57
15	Rocky-exposure	0.46
16	Mangrove (V-Dense)	28.54
17	Mangrove (Dense)	150.63
18	Mangrove (Sparse)	76.86
19	Mangrove (Deg)	31.39

20	River/stream	110.7
21	Canal	0.33
22	Reservoir/tank	32.26
23	Sewage-treat-plant	1.01
24	Creek	691.76
25	Pond/lake	59.02
26	Water-treat-plant	0.34
27	Mining-areas/dumps	17.96
28	Rock-outcrops (gull/ero/barren)	911.81
29	Sandy-area	0.48
30	Wasteland (Veg)	462.29
31	Habitation	9.77
32	Habitation (Veg)	1049.75
33	Open/vacant-land	20.71
34	Industrial-area	70.48
35	Waste-dumping	0.39
36	Port/Harbour/jetty	0.8
37	Airport	6.72
38	Agriculture-land	6473.29
39	Agriculture (Plant)	61.5
40	Forest/Plantation	3250.88
41	Aquaculture-ponds	6.17
42	Salt-pans	67.05
43	Seawall/Embankment	3.16
	Total Area	14011.01

Goa

The Goa coast has long, linear and wide beaches on the northern side and rocky cliffs mainly along the southern part (Figure 2.5). Beaches are observed at north of Cape Rama to Vasco Da Gamma, near Kalanghut, Near Ubhadanda and NW of Mapuca. Mudflats occur along the Mandovi estuary and Marmgoa Bay. Coastal dunes are found with Casurina plantation near Madgaon and Kalanghut. Table 2.4 shows Coastal landuse classes of Goa. Mudflat 20.52 sq km, Forest plantation occupies 1669.96 sq km, Habitation with vegetation occupies 262.15 sq km and wasteland occupies 204.38 sq km (Figure 2.6).

Coastal Landuse Mapping (1:25,000 Scale)



IRS LISS IV Image, 13 March 2006

- These maps depicts land use, landforms ESAs , HTL and LTL
- Will be used for CRZ/CMZ Implementation

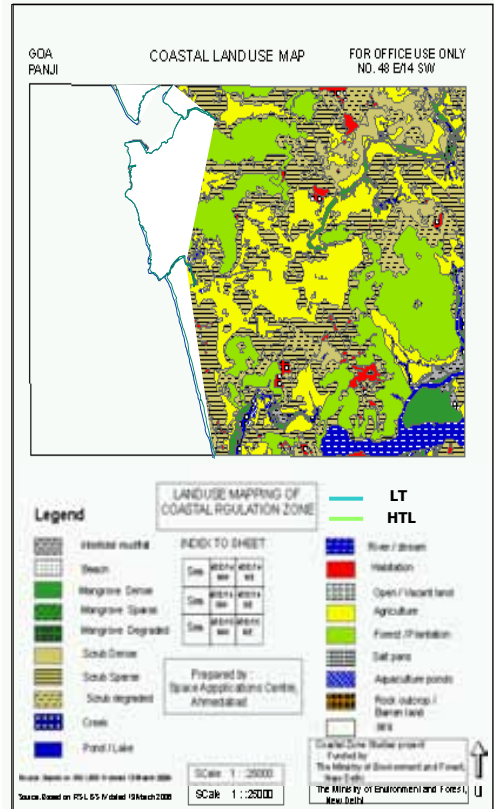


Fig. 2.5: Sample map showing Coastal Landuse mapping of Goa coast

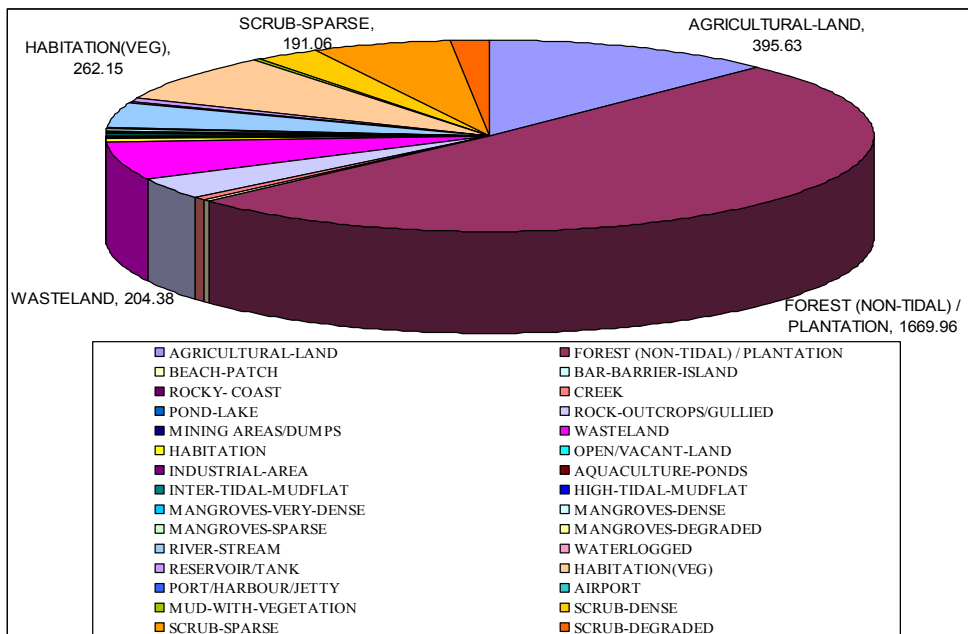


Fig. 2.6 Coastal land use distribution of Goa

Table 2.4 Coastal landuse area of Goa

Sr. No.	Land-use class	Area in sq km
1	Agricultural-land	395.63
2	Forest (non-tidal) / plantation	1669.96
3	Beach-patch	5.5
4	Bar-barrier-island	1.34
5	Rocky- coast	0.39
6	Creek	15.19
7	Pond-lake	8.1
8	Rock-outcrops/gullied	116.22
9	Mining areas/dumps	0.84
10	Wasteland	204.38
11	Habitation	17.49
12	Open/vacant-land	14.41
13	Industrial-area	2.13
14	Aquaculture-ponds	1.75
15	Inter-tidal-mudflat	13.12
16	High-tidal-mudflat	7.4
17	Mangroves-very-dense	4.53

18	Mangroves-dense	17.77
19	Mangroves-sparse	3.69
20	Mangroves-degraded	5.48
21	River-stream	135.15
22	Waterlogged	5.39
23	Reservoir/tank	17.83
24	Habitation(veg)	262.15
25	Port/harbour/jetty	5.03
26	Mud-with-vegetation	3.39
27	Scrub-dense	96.31
28	Scrub-sparse	191.06
29	Scrub-degraded	51.67
	Total Area	3274.00

Karnataka

The northern coast of Karnataka is rocky while the southern coast has long linear beaches. The coastal zone is narrow except around the estuaries. It has long, narrow and straight beaches at Surathkal, Panamburu Manura and near Coondapur as well as small crescent shaped pocket beaches observed at Ullal, Surathkal, Malpe and Udupi. Also, spectacular spits are observed near Bengare, north of Chitrapa near Coondapur and near Kolluru. Double spits are observed near Honavar, shallow lagoons near Coondapur and the Kalinadi are observed. Mudflats and small patches of mangroves also exist. Mangroves are sparsely distributed in the estuarine area of Mulki, Sita, Swarna, Chakra, Haldi and Kolluru and Agnashani. Good patches of mangroves are present in the Kali Nadi estuary. Rocky coast is observed near the Ankola to Karwar coast at numerous locations. Northern part of Karwar coast is rocky and without vegetation. They form high cliffs, which are protruded into the sea. Wave interacts with them and provides material, which forms the beaches. Stabilised sand dunes are noticed along the Coondapur coast near Bijadi/Tekkatte and Kotatattu. They are observed along the coast near Kumta and also below the Tadri creek. Table 2.5 provides the details of the coastal landuse classes for Karnataka. Mudflat occupies 9.9 sq km, Forest/plantation occupies 1734.89 sq km and Habitation with vegetation occupies 679.94 sq km (Figure 2.7). Developmental activities have led to reduction in mangrove area particularly around Coondapur region.

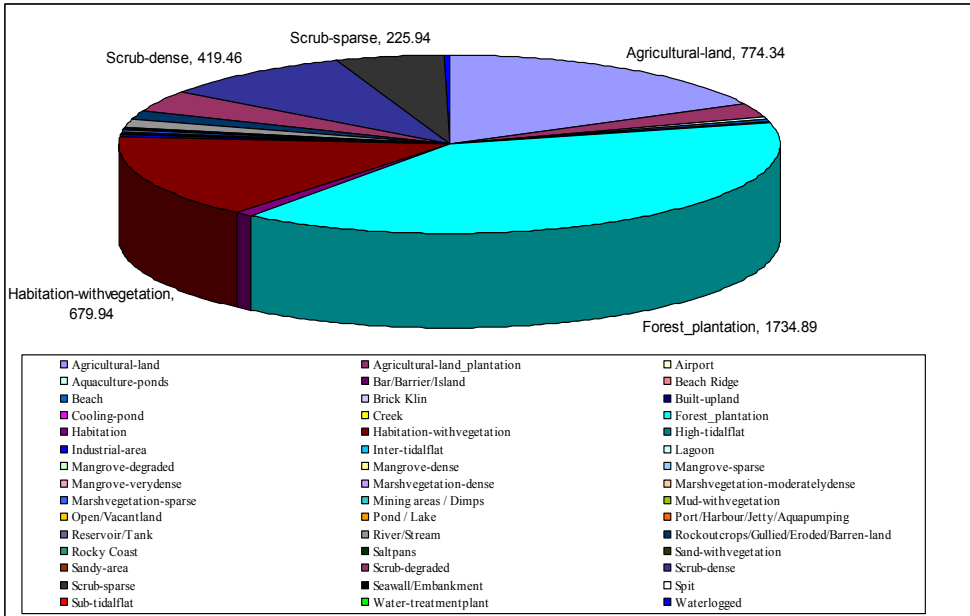


Fig. 2.7: Coastal land use distribution of Karnataka

Table 2.5: Coastal landuse area of Karnataka

S. No.	Land-use class	Area in sq km
1	Agricultural-land	774.34
2	Agricultural-land plantation	113.52
3	Airport	1.39
4	Aquaculture-ponds	23.82
5	Bar/Barrier/Island	1.42
6	Beach Ridge	0.03
7	Beach	17.2
8	Brick Klin	0.08
9	Built-upland	4.32
10	Cooling-pond	0.11
11	Creek	6.06
12	Forest-plantation	1734.89
13	Habitation	37.84
14	Habitation-with vegetation	679.94
15	High-tidalflat	0.07
16	Industrial-area	5.37
17	Inter-tidalflat	2.88
18	Lagoon	5.76

19	Mangrove-degraded	0.2
20	Mangrove-dense	2.52
21	Mangrove-sparse	3.52
22	Mangrove-very dense	2.11
23	Marsh vegetation-dense	4.78
24	Marsh vegetation-moderately dense	9.03
25	Marsh vegetation-sparse	9.58
26	Mining areas / Dimps	2.05
27	Mud-with vegetation	2.95
28	Open/Vacant land	7.67
29	Pond / Lake	1.68
30	Port/Harbour/Jetty/Aqua pumping	1.59
31	Reservoir/Tank	7.93
32	River/Stream	68.67
33	Rock out crops/Gullied/Eroded/Barren-land	64.93
34	Rocky Coast	1.93
35	Saltpans	1.99
36	Sand-with vegetation	2.22
37	Sandy-area	2.56
38	Scrub-degraded	172.04
39	Scrub-dense	419.46
40	Scrub-sparse	225.94
41	Seawall/Embankment	0.35
42	Spit	1.2
43	Sub-tidal flat	6.95
44	Waterlogged	9.93
Total Area		4442.83

Kerala

The Kerala coast is famous for its beautiful beaches, estuaries and lagoons. The coastline is more or less linear, at places it is offset by the presence of promontories. Another characteristic feature of Kerala coastal zone is high population density, 2362 persons /sq km resulting in a more or less urbanized coastal zone. The Kerala coast extends from Manjeswaram in north to Pozhiyur in the south. Well developed sandy beaches are in Chittari, Kappad, Ponnani, Calicut, Cochin, Alleppey and Kovalam. The beach consists of sands of different fractions along with broken molluscan shells. In addition to this,

crescent shaped pocket beaches are observed at Ezhimals, Dharmadom, Tellicherry, Kadur point and Ealthur. Spits are seen at the estuarine of Vambanad, Asthamudi, Shiriys, Bypore and Veli. At some places during the lean season opening of small estuaries got blocked by the growth of the spits. Cliff and rocky coasts are observed at many places on the Kerala coast. The rocky shores are made up of laterites or Precambrian crystalline such as Khondalites or Charnockites. Some of the prominent rocky coasts are near Bekal, Ezhimala, Azhikode and Kadalur point in the north and Vizhinjam, Varkala and Tangasseri in the south. The mangrove vegetation in the coastal area of Kerala is very sparse and thin. The Kerala coast has a number of islets or islands. Most of them are populated. Locally the islands are called thuruths. Man made thuruths are also common. The Vembanad, the Asthamudi, and Kakavvayi estuaries show more islands. The islands in the Vembanad estuary in central Kerala are large in size compared to the islands in the Kavvayi estuary. The major islands are Wellington, Kumbalam, Nettur, Madavana, Cheppanam and Perumbalam. Dharmadm, a large island with mangroves is situated in the northern Kerala. Fig 2.8 shows the distribution of the various coastal landuse classes in Kerala state and the area under different classes are given in table 2.6. Mudflat occupies 41.61 sq km and Habitation with vegetation occupies 4903.70 sq km (Figure 2.8).

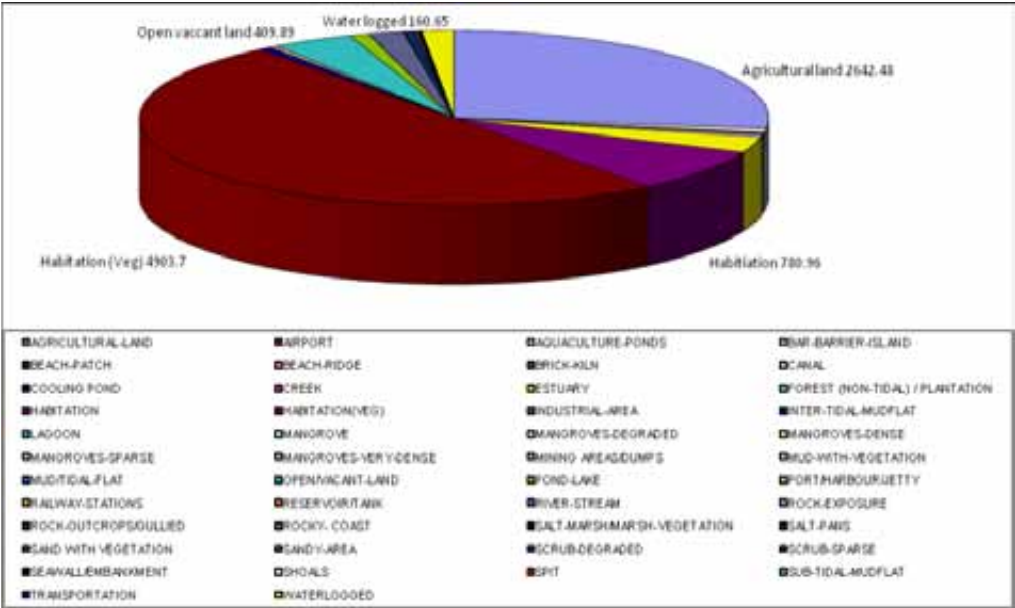


Fig. 2.8: Coastal land use distribution of Kerala

Table 2.6: Coastal landuse area of Kerala

S. No.	Land-use class	Area in sq km
1	Agricultural-land	2642.48
2	Airport	3.98
3	Aquaculture-ponds	73.26
4	Bar-barrier-island	6.69
5	Beach-patch	28.92
6	Beach-ridge	0.002
7	Brick-kiln	0.88
8	Canal	43.85
9	Cooling pond	0.05
10	Creek	3.48
11	Estuary	288.34
12	Forest (non-tidal) / plantation	0.86
13	Habitation	780.96
14	Habitation(veg)	4903.70
15	Industrial-area	7.96
16	Inter-tidal-mudflat	38.77
17	Lagoon	0.10
18	Mangrove	4.42
19	Mangroves-degraded	1.45
20	Mangroves-dense	1.82
21	Mangroves-sparse	2.67
22	Mangroves-very-dense	1.97
23	Mining areas/dumps	5.08
24	Mud-with-vegetation	34.37
25	Mud/tidal-flat	2.79
26	Open/vacant-land	409.84
27	Pond-lake	98.67
28	Port/harbour/jetty	0.56
29	Railway-stations	2.60
30	Reservoir/tank	0.07
31	River-stream	172.98
32	Rock-exposure	3.73
33	Rock-outcrops/gullied	49.87
34	Rocky- coast	0.63
35	Salt-marsh/marsh-vegetation	0.95
36	Salt-pans	0.09
37	Sand with vegetation	0.86

38	Sandy-area	15.24
39	Scrub-degraded	0.41
40	Scrub-sparse	7.94
41	Seawall/embankment	11.55
42	Shoals	1.78
43	Spit	0.43
44	Sub-tidal-mudflat	0.05
45	Transportation	0.07
46	Waterlogged	160.65
	Total Area	9817.83

Tamil Nadu

The Tamil Nadu coast is nearly 950 km long. About 46 rivers, draining a total catchment of about 171,000 sq km empty along this coastline. These rivers bring considerable sediments, as they traverse long distance, affecting the shore processes very significantly. The composition of mud is sandy at Pichavaram and Nagapatinam and clayey at Pattikudi, Pamban near Rameshwaram, Vedaranyam, Pt. Calimare and Muttupet. Sandy beaches are made up of fine/coarse/medium grained brown sand particles, broken molluscan shells, shingles and pebbles. Sandy beaches are mapped at Ennore, south of Chennai, from covelong to Mahabalipuram from Manakkanam to North Pondicherry, South Cuddalore, near Kollidam along the Rameshwaram coast. At Vattakatti, Rasthakadu and Muttam beach consist of black sand with red sand patches. Red sand forms a very thin layer over black sand. Black sand consists of heavy minerals like magnetite, ilmenite, garnet, monozite etc. A well developed spit is observed at the mouth of the Pulicat Lake. Small spits are observed at south of Mahabalipuram, Kollidan, south Rajmatam etc. Coral reefs on Tamil Nadu coast are located near Rameshwaram (Palk Bay) and in the Gulf of Mannar. A solitary fringing reef is present in the Palk Bay, from Pambam to Rameshwaram. Patch reefs namely Kursad, Tivu, Kovi Tivu, Manali Tivu and Musal Tivu are present in the Gulf of Mannar. Well developed mangrove forests are observed at Pichavaram in Cuddalore, Vedaranyam, Point Calimere, Muttupet, Chatram and Tuticorin. *Avicennia sp.* dominates where soil is sandy mud and *Excoecaria* and *Rhizophora* dominate where soil is clayey muddy. The Pulicat lagoon is the second largest lagoon in India. Apart from this, there are a number of small lagoons on the Tamil Nadu coast. Well developed coastal dunes are observed along the coast of Ennore,

Mahabalipuram, from Manakkanam to Pondicherry, Cuddalore to Pichavaram, from Karaikal to Velangani, Vedaranyam to Manamelnkudi, and Pudupattanam to Tondi. Table 2.7 gives areas of different coastal landuse classes for Tamil Nadu. The coastal dunes are stabilized and covered by *Casurina*, coconut, *Palmyra* and *Prosopis*. Mudflat occupies 222.94 sq km, Reservoir/tanks occupies 1007.85 sq km, Dune with vegetation 362.00 sq km and Habitation with vegetation occupies 1185.45 sq km (Figure 2.9).

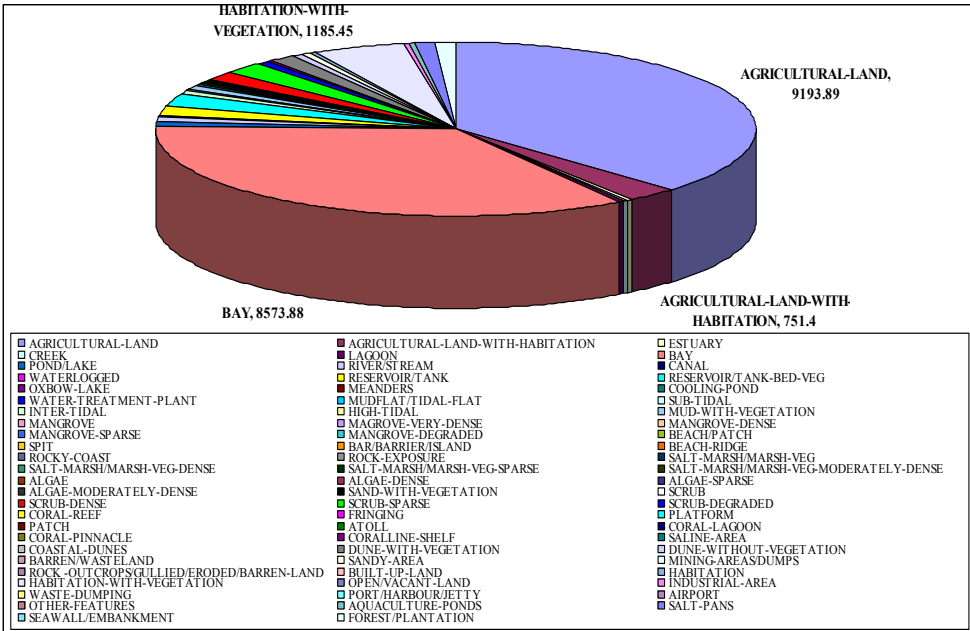


Fig. 2.9: Coastal land use distribution in Tamil Nadu

Table 2.7: Coastal landuse area of Tamil Nadu

Area Calculation (Category wise Table)

S. No.	Land-use class	Area in Sq km
1	Agricultural-land	9193.89
2	Agricultural-land-with-habitation	751.40
3	Estuary	10.86
4	Creek	62.46
5	Lagoon	105.70
6	Bay	8573.88
7	Pond/lake	216.01
8	River/stream	225.29
9	Canal	61.12
10	Waterlogged	27.97

11	Reservoir/tank	384.72
12	Reservoir/tank-bed-veg	623.13
13	Oxbow-lake	0.12
14	Meanders	0.39
15	Cooling-pond	0.26
16	Water-treatment-plant	0.47
17	Mudflat/tidal-flat	9.31
18	Sub-tidal	15.51
19	Inter-tidal	97.52
20	High-tidal	100.60
21	Mud-with-vegetation	162.05
22	Mangrove	0.05
23	Mangrove-very-dense	7.56
24	Mangrove-dense	17.51
25	Mangrove-sparse	32.22
26	Mangrove-degraded	7.83
27	Beach/patch	47.35
28	Spit	0.14
29	Bar/barrier/island	8.26
30	Beach-ridge	1.71
31	Rocky-coast	2.71
32	Rock-exposure	0.57
33	Salt-marsh/marsh-veg	4.53
34	Salt-marsh/marsh-veg-dense	46.08
35	Salt-marsh/marsh-veg-sparse	35.12
36	Salt-marsh/marsh-veg-moderately-dense	52.55
37	Algae	0.08
38	Algae-dense	0.02
39	Algae-sparse	0.00
40	Algae-moderately-dense	0.04
41	Sand-with-vegetation	138.53
42	Scrub	0.22
43	Scrub-dense	361.56
44	Scrub-sparse	598.41
45	Scrub-degraded	90.16
46	Coral-reef	0.04
47	Fringing	1.13
48	Platform	3.10
49	Patch	1.96
50	Atoll	0.16
51	Coral-lagoon	2.16
52	Coral-pinnacle	0.16

53	Coralline-shelf	61.59
54	Saline-area	0.35
55	Coastal-dunes	0.29
56	Dune-with-vegetation	362.00
57	Dune-without-vegetation	158.94
58	Barren/wasteland	2.69
59	Sandy-area	85.47
60	Mining-areas/dumps	7.43
61	Rock - outcrops/gullied/eroded/ barren - land	28.70
62	Built-up-land	0.12
63	Habitation	89.24
64	Habitation-with-vegetation	1185.45
65	Open/vacant-land	51.13
66	Industrial-area	62.38
67	Waste-dumping	4.28
68	Port/harbour/jetty	5.55
69	Airport	5.60
70	Other-features	0.06
71	Aquaculture-ponds	30.93
72	Salt-pans	293.35
73	Seawall/embankment	0.05
74	Forest/plantation	263.46
	Total Area	24783.64

Andhra Pradesh

The coastline of Andhra Pradesh is long and smooth with inundation only in the extreme south (in saltwater lagoon Pulicat lake) and between the Godavari and the Krishna delta. Andhra Pradesh coast shows three distinct segregation of coast based on their relief, nature of the material and type of vegetation: Rocky coast (North of Godavari delta), Vegetated coast (Deltas of Godavari and Krishna and inter delta region) and sandy coast (South of Krishna delta upto Pulicat lake). The coastal area north of the Godavari delta comprises of tidal creeks, small patches of coastal wetlands at the mouth of rivers and inlets. The residual hills and ridges are close to the sea and some of ridges extend beyond the coast in to the sea. The rocky outcrops are observed in this area. Headland bay and small beaches are seen in the Vishakhapatnam district. Though the rivers, Bahuda, Vamsadhara, Gosthani, Sarda are flowing in this region, but it does not have any major delta. The deltaic type of coastal area between Godavari and Krishna and interdeltaic region comprises of bay, tidal

creeks, mudflats, spits, mangroves swamps and marshes. Inter tidal mudflats are extensive to the east of Coringa. A number of tidal creeks dissect mudflats. Mangrove swamps occurs in abundance in the intertidal mudflats on both sides of creeks. Encroachment in mangrove area for agriculture and aquaculture and industrial pollution is making adverse impact on the mangrove of this area. Narrow beaches are found on the delta fronts except on both sides of the Vainateyam and the Vasisth- Godavari mouths. A spectacular spit has been developed at Kakinada. A bay has been developed between the shoreland and the spit. Large block of dense mangrove can be seen near Coringa. Beaches, sand dunes and dune sands are widely distributed in the region of south of Krishna delta up to the Pullicat lake. It mainly occurs between Suryalanka to Tutipalem, Kuruvatipalem, durgarajupatanam and the Shriharikota Island. Sandy plain has spread over a wide area in Chirala Vetapalem and chinagunjam. Sand dunes occurred at Vetapalem, Krishnapatanam, Kotapalem and Gopallapalem. Sparse and scattered mangroves are found in the intertidal and high tidal mudflats at the mouth of the river zone. Marsh vegetation is also seen on the islands of the rivers. Fig. 2.10 shows the coastal landuse distribution in Andhra Pradesh. Mudflat occupies 399.2 sq km, Aquaculture ponds occupy 1535.67 sq km and Habitation with vegetation occupies 698.72 sq km (Table 2.8).

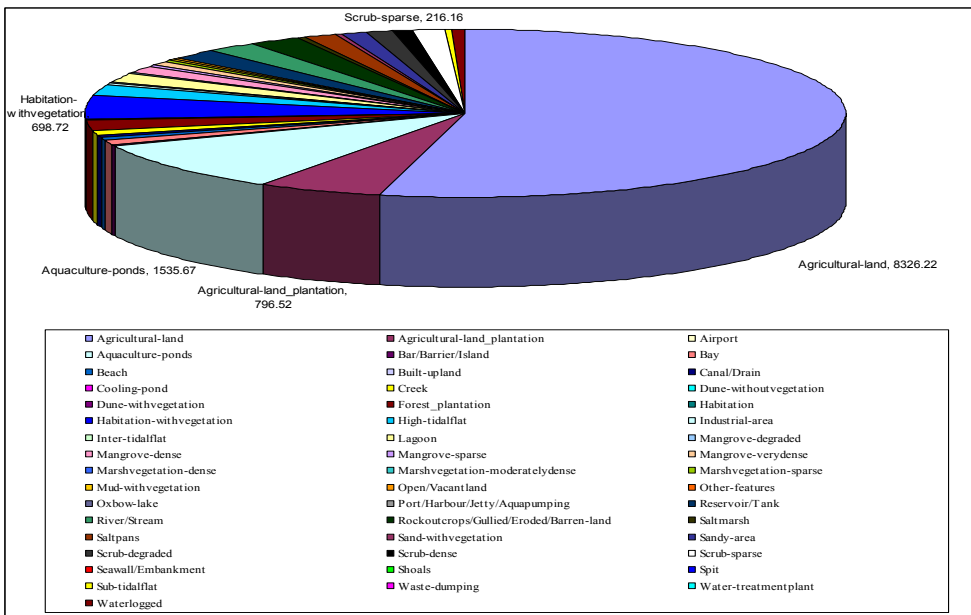


Fig. 2.10: Coastal land use distribution of Andhra Pradesh

Table 2.8: Coastal landuse area of Andhra Pradesh

S. No.	Landuse class	Area in sq km
1	Agricultural-land	8326.22
2	Agricultural-land_plantation	796.52
3	Airport	4.64
4	Aquaculture-ponds	1535.67
5	Bar/Barrier/Island	7.68
6	Bay	145.82
7	Beach	74.27
8	Built-upland	9.49
9	Canal/Drain	92.57
10	Cooling-pond	7.23
11	Creek	97.13
12	Dune-without vegetation	1.46
13	Dune-with vegetation	2.67
14	Forest_plantation	298.49
15	Habitation	71.47
16	Habitation-with vegetation	698.72
17	High-tidal flat	319.89
18	Industrial-area	35.69
19	Inter-tidal flat	39.42
20	Lagoon	278.15
21	Mangrove-degraded	59.91
22	Mangrove-dense	188.89
23	Mangrove-sparse	54.95
24	Mangrove-very dense	110.59
25	Marsh vegetation-dense	7.7
26	Marsh vegetation-moderately dense	6.92
27	Marsh vegetation-sparse	50.72
28	Mud-with vegetation	54.57
29	Open/Vacant land	9.28
30	Other-features	19.22
31	Oxbow-lake	0.05
32	Port/Harbour/Jetty/Aquapumping	14.39

33	Reservoir/Tank	299.58
34	River/Stream	331.6
35	Rock out crops/Gullied/Eroded/Barren-land	339.73
36	Salt marsh	45.41
37	Saltpans	222.94
38	Sand-with vegetation	40.68
39	Sandy-area	180.69
40	Scrub-degraded	167.99
41	Scrub-dense	103.44
42	Scrub-sparse	216.16
43	Seawall/Embankment	0.2
44	Shoals	10.75
45	Spit	10.33
46	Sub-tidal flat	39.89
47	Waste-dumping	1.49
48	Water-treatment plant	0.71
49	Waterlogged	78.75
	Total Area	15510.73

Orissa

The Orissa coast is mainly depositional in nature, formed by Mahanadi and the Brahmani- Baiterani deltas. Orissa coast has some of the excellent mangroves. Another notable feature is the Chilka lake. Wide expanse of fine grained soft clay and silt constitute this category and observed on the Balasore coast, near Devi estuary and near Chilka lagoon. Vast stretch of subtidal mudflats are observed from Dhamra river to Chandipur. Sandy beaches are well marked along the coastline from the Bahuda estuary near Andhra Pradesh border to the Devi mouth and mouth of Mahanadi to Dhamra river. The sandy beach of the southern coast of Orissa is enriched with rare minerals like monazite, ilmenite, zircon, rutile, sillimanite etc. The sandy beach of Puri is a tourist attraction. Muddy coast of Orissa consists of more sand particles and is non-sticky in nature. Spits are well developed along the coastline near major estuaries. The mangrove occurring near the mouth of the Mahanadi river have creek network of the Luna, the Jambu, the Kharnasi, the Khola and the Batighar jora creek.

These creeks are almost parallel to the coast. The mangrove vegetation includes tree, scrub and palm species. Important species in this locality includes *Avicennia spp.*, *Acrosticum spp.* and *Phoenix spp.* The Brahmani and Baitarani rivers and their distributaries and creeks provide a congenial ecological niche for the growth of mangrove vegetation. The mangrove of Bhitarkanika which is the second largest mangal formation in the Indian subcontinent, harbour high concentration of typical mangrove species and a wide spectrum of genetic diversity. Important mangrove species includes *Avicennia Alba*, *A. officinalis*, *Excoecaria agallocha*, *Heritiera minor*, *Sonneratia apetala*, *Rizophora mucronata*, *R. candlena* etc. The mangroves of Balasore Coast are quite different from other deltaic area due to absence of fresh water inflow except in the Dhamra river mouth. The salinity level remains very high except during rainy season. The species are mainly *Avicennia Alba*. The Chilka lake on the Orissa coast is the largest lagoon in the country. It is connected to the Bay of Bengal by a long and narrow channel. Fig 2.11 shows Coastal landuse distribution in Orissa. Mudflat occupies 229.26 sq km, Lagoon occupies 733.30 sq km, Forest occupies 569.10 sq km and Habitation with vegetation occupies 1133.56 sq km (Table 2.9).

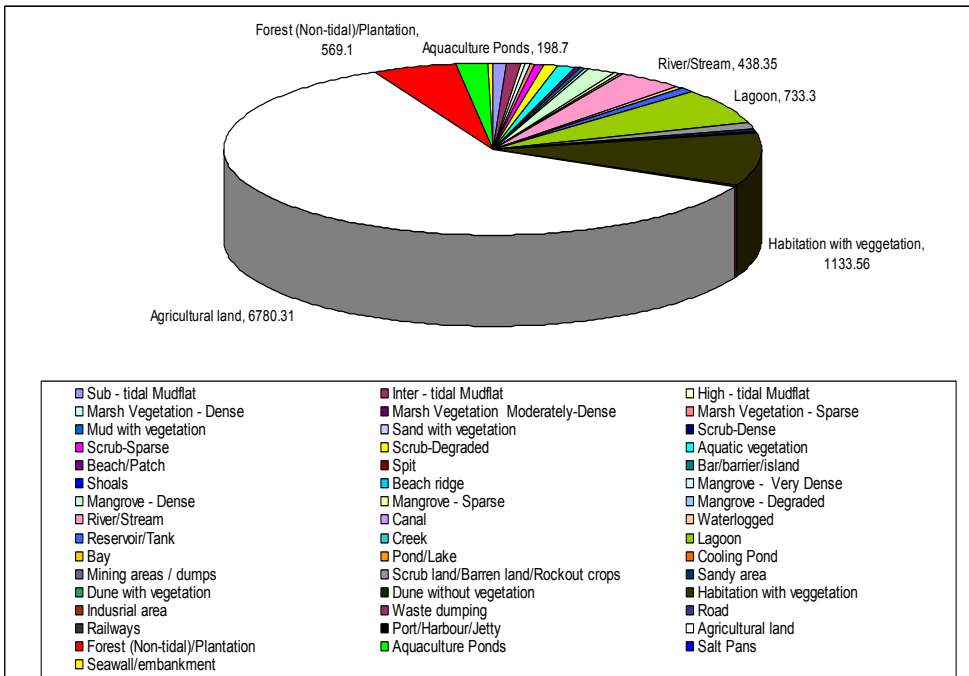


Fig. 2.11: Coastal land use distribution of Orissa

Table 2.9: Coastal landuse area of Orissa

S. No.	Landuse class	Area in sq km
1	Sub - tidal Mudflat	85.27
2	Inter - tidal Mudflat	95.56
3	High - tidal Mudflat	48.43
4	Marsh Vegetation - Dense	4.09
5	Marsh Vegetation Moderately-Dense	27.67
6	Marsh Vegetation - Sparse	19.11
7	Mud with vegetation	0.99
8	Sand with vegetation	4.52
9	Scrub-Dense	2.26
10	Scrub-Sparse	62.75
11	Scrub-Degraded	91.63
12	Aquatic vegetation	113.55
13	Beach/Patch	43.77
14	Spit	5.3
15	Bar/barrier/island	18.64
16	Shoals	0.86
17	Beach ridge	1.22
18	Mangrove - Very Dense	37.68
19	Mangrove – Dense	167.53
20	Mangrove – Sparse	36.98
21	Mangrove - Degraded	30.35
22	River/Stream	438.35
23	Canal	8.2
24	Waterlogged	66.71
25	Reservoir/Tank	79.02
26	Creek	15.36
27	Lagoon	733.3
28	Bay	10.95
29	Pond/Lake	2.24
30	Cooling Pond	1.41
31	Mining areas / dumps	1.48
32	Scrub land/Barren/land/Rockout crops	105.03
33	Sandy area	53.16
34	Dune with vegetation	13.61
35	Dune without vegetation	16.89
36	Habitation with vegetation	1133.56
37	Industrial area	14.97

38	Waste dumping	2.39
39	Road	10.7
40	Railways	3.63
41	Port/Harbour/Jetty	4.71
42	Agricultural land	6780.31
43	Forest (Non-tidal)/Plantation	569.1
44	Aquaculture Ponds	198.7
45	Salt Pans	19.11
46	Seawall/embankment	19.31
	Total Area	11200.36

West Bengal

The Coastal area of West Bengal is well connected by road, rail and water ways and thickly populated. The main occupation is the cultivation and fishing. High tide mudflats are well noticed near Khajuri and NE of Kanthi. In some areas the inter-tidal mudflats are being used for the development of salt pans. Sandy beach has been noticed in few patches where as vast extension of muddy beach is found along the Hooghly estuarine area and the Sundarbans. The mangroves in the West Bengal coast mainly colonies in the Sundarban area which is the largest single block of tidal halophytic mangroves of the world. Topographically Sundarban area exhibits number of anastomosing distributaries. The rivers; the Bartala, the Muri Ganga, The Saptamukhi, the Thakuran matta, the Ichhamati, the Kalinadi, the Harinbari, the Bidya and the Gosaba rivers mostly carry the fresh water from the upper reaches. The Padma river of Bangladesh also contributes considerable amount of fresh water. These rivers along with their distributaries form a number of islands at the mouth of the Bay. The mangroves are also described as the flora of formative islands and the flora of riverbanks and the swamp forests. The common plant species of the formative islands includes a few tree species like *Avicennia spp.*, *Sonneratia spp.* and *Excoecaria agallocha*. The flora of river bank and the swamp forests constitute major mangrove occurrences on them. The major species of the dense mangrove forest include *Heeritiera fomes*, *Rhizophora apiculata*, *R. mucronata*, *Bruguiera gymnorhiza*, *B. parviflora*, *Ceriops decandra*, *Sonneratia apetala*, *S. caseolaris* and *Avicennia spp.* *Nypa fruticans* is the major species found on the creek side and found on the sparse categories. *Phonix paludosa* almost cover all the tidal zones of the Sunderbans but exploitation of this species prevents its rapid growth and deteriorates its

density from the major parts of the Sundarbans. The Sundarban area is fed with numerous rivers which form network of creeks. These are always affected by daily tides. The creeks are erosive in nature and have been affected by cyclones and storm surges. These creeks are gradually filled with sediments from the upper reaches. Figure 2.12 provides the coastal landuse distribution for West Bengal. Mudflat occupies 28.34 sq km, Aquaculture ponds 478.46 sq km and Habitation with vegetation occupies 3255.25 sq km (Table 2.10).

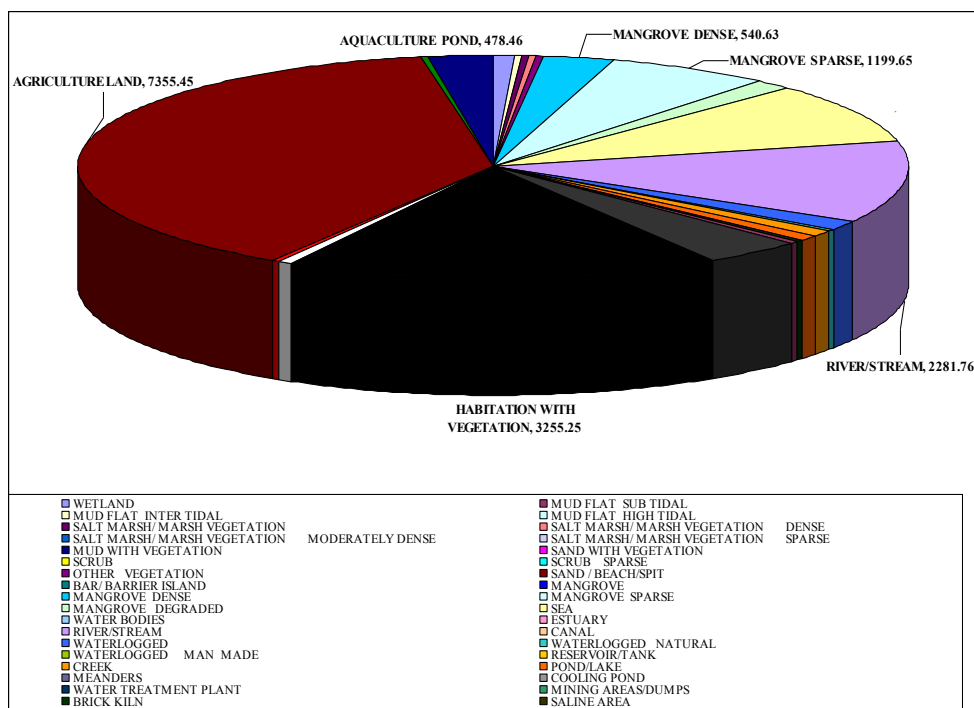


Fig. 2.12: Coastal land use distribution of West Bengal

Table 2.10: Coastal landuse area of West Bengal

S. No.	Landuse Class	Area in sq km
1	Mud flat sub tidal	3.31
2	Mud flat inter tidal	22.18
3	Mud flat high tidal	2.85
4	Salt marsh/ marsh vegetation	83.63
5	Salt marsh/ marsh vegetation dense	5.1
6	Salt marsh/ marsh vegetation Moderately dense	5.15

7	Salt marsh/ marsh vegetation sparse	2.6
8	Mud with vegetation	34.13
9	Sand with vegetation	0.09
10	Scrub	0.17
11	Scrub sparse	0.15
12	Other vegetation	16.84
13	Sand / beach/spit	19.89
14	Bar/ barrier island	0.73
15	Mangrove dense	540.63
16	Mangrove sparse	1199.65
17	Mangrove degraded	292.63
18	Sea	1698.47
19	Water bodies	0.17
20	Estuary	0.04
21	River/stream	2281.76
22	Canal	13.44
23	Waterlogged	283.19
24	Waterlogged natural	6.35
25	Waterlogged man made	0.63
26	Reservoir/tank	0.33
27	Creek	165.43
28	Pond/lake	152.36
29	Meanders	17.39
30	Cooling pond	0.22
31	Water treatment plant	0.13
32	Mining areas/dumps	0.34
33	Brick kiln	35.6
34	Saline area	29.01
35	Coastal dune with vegetation	18.43
36	Coastal dune without vegetation	5.53
37	Coastal dune with habitation	34.06
38	Habitation	752.41
39	Habitation with vegetation	3255.25
40	Open/vacant land	73.63

41	Industrial area	60.88
42	Road	6.34
43	Railways	6.1
44	Port/harbour/jetty	10.53
45	Airport	0.12
46	Golf club	1.16
47	Agriculture land	7355.45
48	Forest (non-tidal) / plantation	36.7
49	Aquaculture pond	478.46
50	Seawall/ embankment	0.8
	Total Area	19010.44

Andaman & Nicobar Islands

The Andaman and Nicobar group consist of more than 350 islands and the land area is about 8500 sq km. The Andaman groups of islands are the emerged part of a mountain chain and lie on a ridge which extends south-ward from the Irrawaddy delta areas of Burma. They have been divided into north, middle, south and little Andaman. In addition to main islands, the Andamans have a number of offshore islands e.g. Ritchie's archipelago (on the east of the main land), North Sentinel (west of the mainland), Coco island (north of the mainland) etc. and several coral pinnacles or patch reefs without any sizable island at all. The Nicobar groups of islands are high islands forming part of an emerged mountain chain, continuing that of the Andamans. Linear and narrow sandy beach make up of the coast of almost all the islands and the mainland of Andaman and Nicobar group of islands. Prominent and wider beach surrounds the entire little Andaman island. Sandy beaches vary from island to island in their size. The sand particles in the beaches are with traces of the organic parts and broken shells. Coral reefs of the Andaman and Nicobar group of islands are of fringing type, often separated from the shore by a lagoon. Almost all the islands of the Andaman and Nicobar group have narrow, linear and fringing type of reefs. On the Andaman and Nicobar islands, there are many small tidal estuaries, long inlets and the lagoons which support a dense and diverse mangrove flora. The tidal creeks of Andaman and Nicobar islands often form the outlets to the rain-fed stream that flow from the interior and carry silt to the shore to form muddy plains facilitating the spread and regeneration of

mangroves. Figure 2.13 shows coastal landuse distribution in the Andaman and Nicobar Islands. The islands alone account for about 18% of the country’s total mangrove area. The mangrove flora of the Andaman group of islands comprises of 27 species and that of Nicobar group of islands comprises of 10 species. The dominant mangrove species are *Rhizophora mucronata* and *R. stylosa* and the co-dominant is *Bruguiera gymnorrhiza*. Mudflat occupies 7406.36 sq km, Forest occupies 6441.58 sq km and Corals occupies 950.73 sq km (Table 2.11).

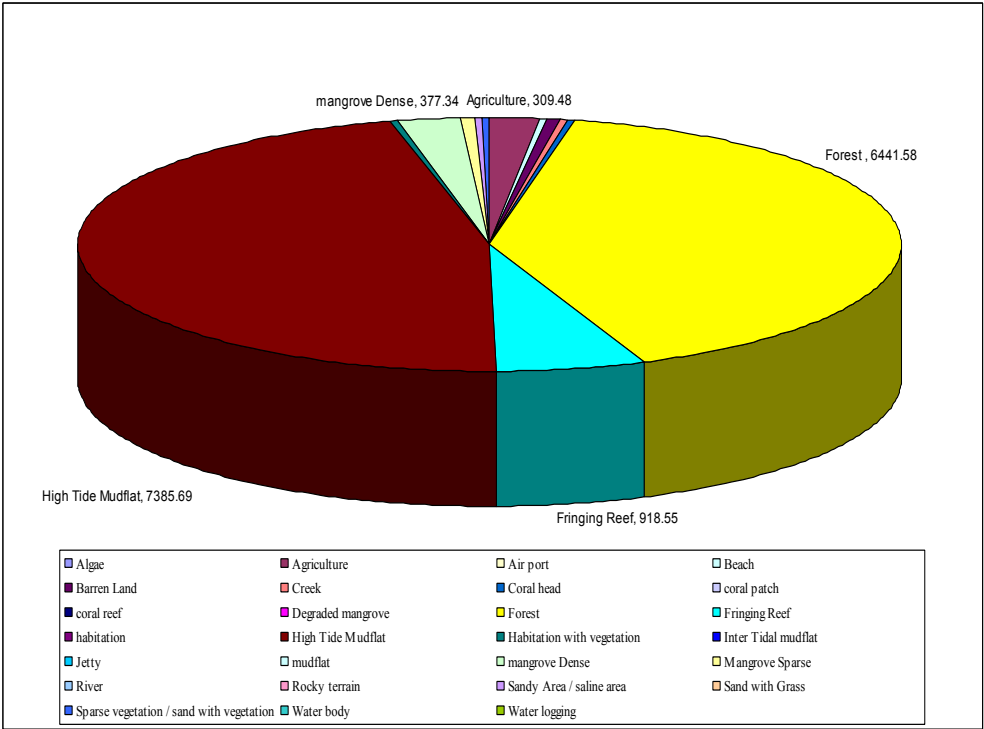


Fig. 2.13: Coastal land use distribution of Andaman and Nicobar Islands

Table 2.11: Coastal landuse area of Andaman and Nicobar Islands

S. No.	Landuse class	Area in sq
1.	Algae	9.31
2.	Agriculture	309.48
3.	Air port	0.37
4.	Beach	40.01
5.	Barren Land	77.03
6.	Creek	52.15

7.	Coral head	23.95
8.	coral patch	8.11
9.	coral reef	0.12
10.	Degraded mangrove	23.77
11.	Forest	6441.58
12.	Fringing Reef	918.55
13.	Habitation	1.68
14.	High Tide Mudflat	7385.69
15.	Habitation with vegetation	32.92
16.	Inter Tidal mudflat	20.67
17.	Jetty	0.13
18.	Mudflat	2.76
19.	mangrove Dense	377.34
20.	Mangrove Sparse	103.70
21.	River	4.32
22.	Rocky terrain	0.98
23.	Sandy Area / saline area	34.82
24.	Sand with Grass	0.24
25.	Sparse vegetation/sand with vegetation	18.23
26.	Water body	1.81
27.	Water logging	20.10
	Total Area	15909.82

Lakshadweep Islands

The coral islands in the Arabian Sea were previously called as the Laccadive, Minicoy and the Amindivi islands. The territory officially named Lakshadweep in November 1973. It consists of a chain of well developed coral reefs. They lie about 200-470 km off the Kerala coast within the geographic limits of 10^0 - 12^0 N latitudes and 71^0 - 74^0 E longitudes. The Minicoy Island is southernmost island separated from the rest of islands by a stretch of a sea that is about 180 km wide and is known as the Nine degree channel. Almost all the atoll have NE-SW orientation with low lying islands on the east, a broad well developed reef on the west, with a lagoon in between, connected to the open ocean by one or more channels. The width of the lagoons varies from 1 to 4 km and most of the lagoons also have coral atolls arising from the lagoon floor.

There are about 27 islands, a number of sunken banks, open reefs and sand banks. Out of these only 10 are inhabited. Other islands are small and exist as satellite of the inhabited islands. The geographic area of the islands is 32 sq km. The main occupation of the people is fishing, turtle hunting, pearl oyster and cowrie collection, depending upon the lagoons. Coconut cultivation and coir twisting are the other major occupations. Coconut is only economically important plant of the islands and different varieties are found. Sandy beach characteristically makes up the coast of all the Lakshadweep islands. Sand is medium to coarse grained and coralline in nature. Sandy beach is discontinuous on the Baliyapaniyam, the Cheriyananiyam and the Perumal par reef. The Chetlat island is enclosed with the beach of its entire eastern side. The Bitra, the Kiltan, the Kadmat, the Amini, the Bangaram, the Tinnakara, the Parali, the Agatti, the Pitti, the Valiyakara and the Cheriyaakara islets of the Suheli par are entirely surrounded by the beach. Beach is continuous on the eastern side and discontinuous on the western side and devoid of beach in the extreme north of the Kavaratti Island. The Minicoy has a J-shaped beach circling the entire island. Geographically, the Lakshadweep groups of coral islands are considered to be a continuation of the Aravalli system of rocks of Rajasthan and Gujarat through the bank of Gulf of Khambhat and through Agaria banks further south. Their tops are built up of coral reefs from the late Tertiary times. Accumulation of coral is being continued even now. The lagoons vary considerable in size bottom type and geomorphology. Small lagoons (of the Chetlat, the Kiltan, the Amini and the Kadmat islands) are virtually filled with sediments with a depth of 1-25 m. Large lagoons (the Bitra, the Bangaram, the Suheli par and the Minicoy) are comparatively deep with depth about 10-16 m, with central part of the lagoon is deep. The margins of the lagoons are characterised by gravel and coarse sand. Shallow sandbanks bordering the reef are also covered by coarse sediments. The central region of the deeper lagoon is usually covered by fine sand and silts. Sand consist of entirely pure calcium carbonate, with very little silica, alumina or iron. The calcium carbonate from the sand has various uses such as in the manufacturing of cement and glass and also in the chemical and paper industry. Figure 2.14 shows the coastal land use class distribution in Lakshadweep Islands. Lagoon occupies 476.45 sq km, Habitation occupies 8.74 sq km and Habitation with vegetation occupies 12.09 sq km (Table 2.12).

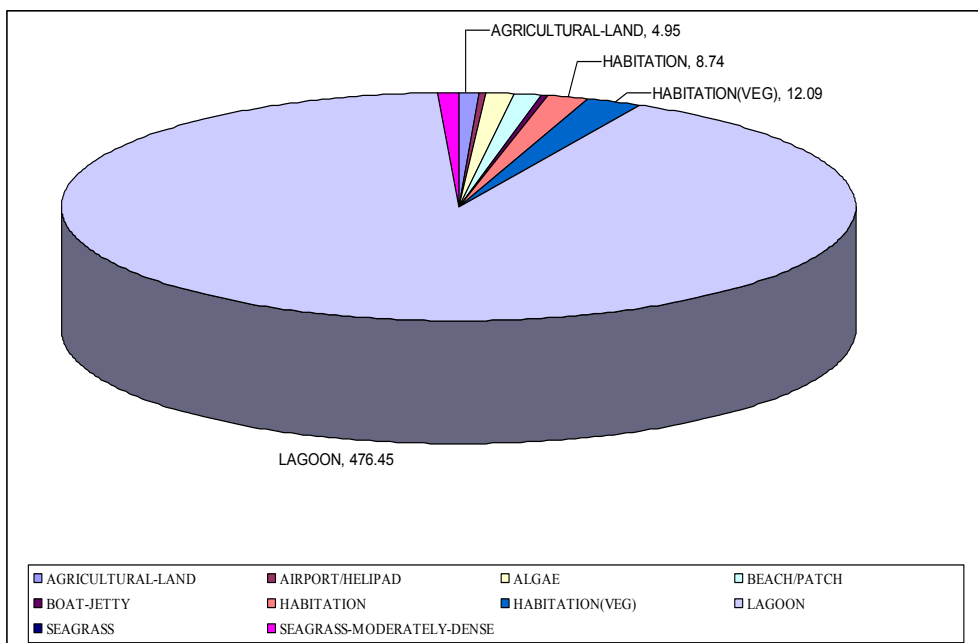


Fig. 2.14: Coastal land use distribution of Lakshadweep Islands

Table 2.12: Coastal landuse area of Lakshadweep Islands

S. No.	Landuse class	Area in sq km
1	Agricultural-land	4.95
2	Algae	5.78
3	Beach/patch	7.04
4	Boat-jetty	0.05
5	Habitation	8.74
6	Habitation(veg)	12.09
7	Lagoon	476.45
8	Seagrass	0.37
9	Seagrass-moderately-dense	4.09
	Total Area	519.79

Local level mapping at 1:5,000 scale

Coastal Landuse mapping on 1:25,000 scale are used for preparation of the management plan at district/regional level. With the availability of the high spatial resolution CARTOSAT data, local level maps at cadastral scale can be prepared which can be used by local administration for implementing Coastal Regulation Zone. Preparation of local level map is a two step process:

- Development of methodology to prepare coastal zone maps at 1:5000 scale (cadastral level) using CARTOSAT/LISS-IV data.
- Delineation of HTL and LTL and coastal wetland/landuse categories using CARTOSAT/LISS-IV data.

These maps have been prepared for the selected areas as given in table 2.13.

Table 2.13: Study Area for local level mapping

Sr. No.	State	Area
1	Gujarat	Hazira & Dahej
2	Maharashtra	Navi Mumbai
3	Karnataka	Mangalore
4	Kerala	Cochin
5	Tamilnadu	South Chennai
6	Andhra Pradesh	Visakhapatnam
7	Orissa	Paradeep
8	West Bengal	Digha

As far as possible data of low tide condition have been used as most of the coastal wetlands get maximum exposure during low tidal condition. The satellite data of pre and post monsoon was used and December-February was chosen in most cases to take care of reproductive cycle of vegetation present in wetland areas. Cartosat/IKONOS/LISS-IV data of 2004-2008 was used for the analysis. Data with WGS 84 datum and UTM Projection were procured.

Each scene of Cartosat 1/LISS-IV was brought to 1:5000 scale. The entire mapping was done using visual interpretation technique. HTL and LTL were first delineated using the tonal discontinuity feature in the satellite data. Coastal wetland and land use features were delineated using the basic elements of visual interpretation like tone, texture, shape, size and association. The categories were classified using the classification system developed at the Space Applications Centre (Nayak, et al., 1992) and is given in Table 2.14. Cadastral maps for each area were procured from concerned agencies and were overlaid on the satellite data and maps. Base maps at 1:5000 scale were generated using CARTOSAT data and GPS. Each map covers 1.25' x 1.25'

area. Minimum mapping unit used is 2 mm x 2 mm. Ground truth was carried out for selected areas. Classification accuracy of maps was ascertained by randomly selecting points on maps. Each point was visited on ground and accuracy was ascertained using confusion matrix. Thus local level CRZ Maps on Cadastral scale of 1:5000 scale for all the study areas were prepared.

Cadastral maps for each of the areas were procured from concerned agencies and were overlaid on the satellite data and maps. Base maps at 1:5000 scale were generated using Cartosat data and GPS. Each map is 1.25' x 1.25'. Minimum mapping unit is 2 mm x 2 mm. Ground truth was carried out for selected areas. Classification accuracy of maps was ascertained by randomly selecting points on maps. Each point was visited on ground and accuracy was ascertained using confusion matrix. Thus local level CRZ Maps on Cadastral scale of 1:5000 scale for all the study areas were prepared.

Table 2.14: Classification System for Coastal Landuse/Landcover Mapping

	Level I	Level II	Level III
1	Wetland		
1.1		Mudflat /tidal flat	
1.1.1			Sub - tidal
1.1.2			Inter - tidal
1.1.3			High tidal
1.1.4			High tidal with Salt - encrustation
1.2		Beach / Patch	
1.3		Spit	
1.4		Bar/barrier / island	
1.5		Shoals	
1.6		Beach ridge	
1.7		Rocky coast	
1.8		Rock exposure	
1.9		Mangrove	
1.9.1			Very Dense
1.9.2			Dense
1.9.3			Sparse
1.9.4			Degraded
1.10		Salt-marsh/Marsh vegetation	
1. 10.1			Dense

1. 10.2			Moderately dense
1. 10.3			Sparse
1.11		Algae	
1.11.1			Dense
1.11.2			Moderately dense
1.11.3			Sparse
1.12		Sea grass	
1.12.1			Dense
1.12.2			Moderately dense
1.12.3			Sparse
1.13		Mud with vegetation	
1.14		Sand with vegetation	
1.15		Scrub	
1.15.1			Dense
1.15.2			Sparse
1.15.3			Degraded
1.16		Coral reef	
1.16.1			Fringing
1.16.2			Platform
1.16.3			Patch
1.16.4			Atoll
1.16.5			Coral Lagoon
1.16.6			Coral pinnacle
1.16.7			Coralline shelf
1.16.8			Coral head
2	Water bodies		
2.1		Estuary	
2.2		Creek	
2.3		Lagoon	
2.4		Bay	
2.5		Pond/lake	
2.6		Oxbow lake	
2.7		Meanders	
2.8		Cooling pond	
2.9		Water treatment plant	
2.10		River/stream	
2.11		Canal	
2.12		Waterlogged	
2.13		Reservoir / tank	
3	Barren/ wasteland		
3.1		Mining areas / dumps	

3.2		rock outcrops/gullied /eroded/barren land	
3.3		Brick kiln	
3.4		Sandy area	
4	Shore land		
4.1		Saline area	
4.2		Coastal dunes	
4.2.1			Dune with vegetation
4.2.2			Dune without vegetation
5	Built-up land		
5.1		Habitation	
5.1.1			Habitation with vegetation
5.2		Open/vacant land	
5.3		Industrial area	
5.4		Waste dumping	
5.5		Transportation	
5.5.1			Roads
5.5.2			Railways
5.5.3			Port/Harbour/jetty
5.5.4			Waterways
5.5.5			Airport
6	Agricultural land		
7	Forest (Non- tidal)/ Plantation		
8	Other features		
8.1		Aquaculture ponds	
8.2		Salt pans	
8.3		Cliff	
8.4		Seawall/Embankment	

Local level mapping out puts:

LISS III, LISS IV, Cartosat-1 and merged product is shown in Fig. 2.15 for Hazira industrial area of Gujarat. The classification system used for 1:25000 scale were used to maintain the consistency. This classification system was further modified at level IV. For example, residential area in urban is further classified as commercial, industrial, recreational, vacant plots, public utilities mixed built up and in rural area: it is further classified in to rural group of buildings, rural settlements and rural single building.

Preparation of local level map using CARTOSAT data



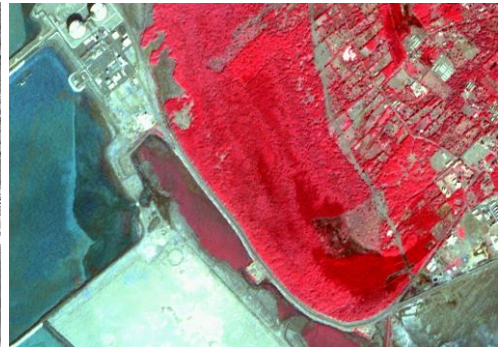
L3 Hazira



L4 Hazira



Cartosat_Hazira



Merge (L4 + Carto) Hazira

Fig. 2.15: LISS III, LISS IV, Cartosat 1 and merged product for Hazira, Gujarat

This will help in identifying fishermen's settlements. Roads along the coastal areas can be very well demarcated using high resolution data. This helps in demarcating the CRZ boundary with better accuracy in urban as well as rural areas. Thin vegetation line along the coastal stretch (such as Casurina), which was not possible to delineate using medium resolution data, could be delineated using Cartosat1 data. Small jetties, used by local fisherman, could also be easily delineated. Different tidal marks (diurnal, weekly etc.) on the image can be demarcated using high resolution data in addition to demarcating the highest of high tide line.

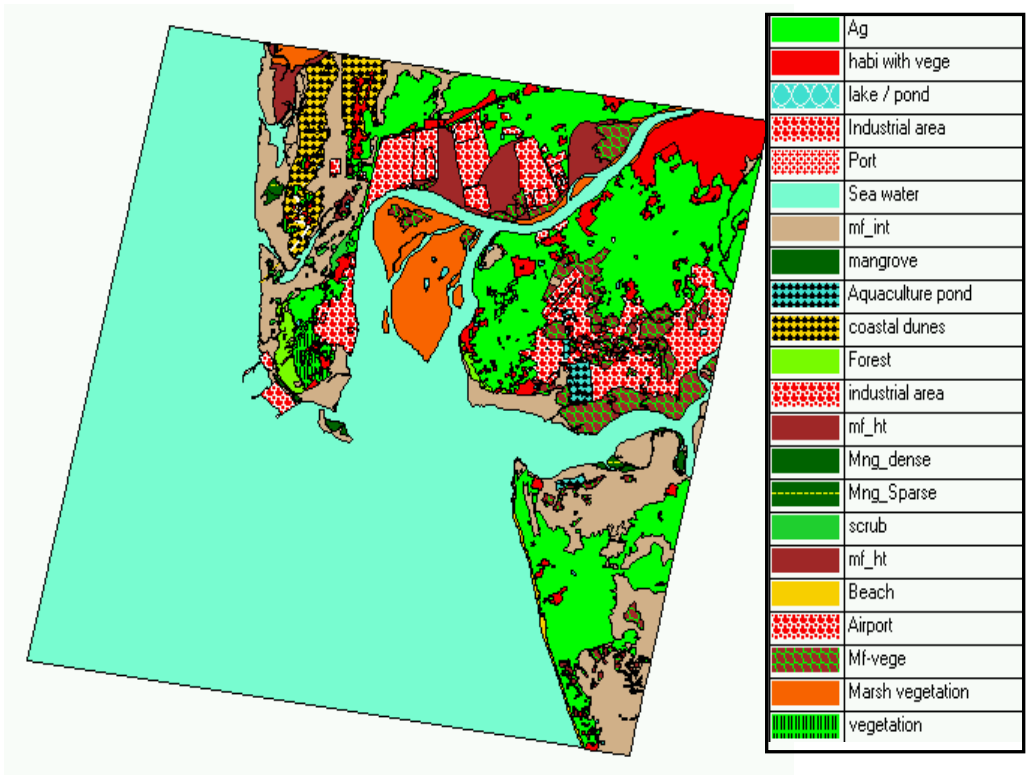


Fig. 2.16: Classified CARTOSAT image of the Hazira region Gujarat

Local level coastal landuse maps of Hazira region of Gujarat and Vishakhapatnam region of Andhra Pradesh are given in Figures 2.16 and 2.17 respectively. Level IV information of certain categories like commercial area or public utility area in urban area is possible to delineate using CARTOSAT data. Legend for Vishakhapatnam area is given in Figure 2.18.

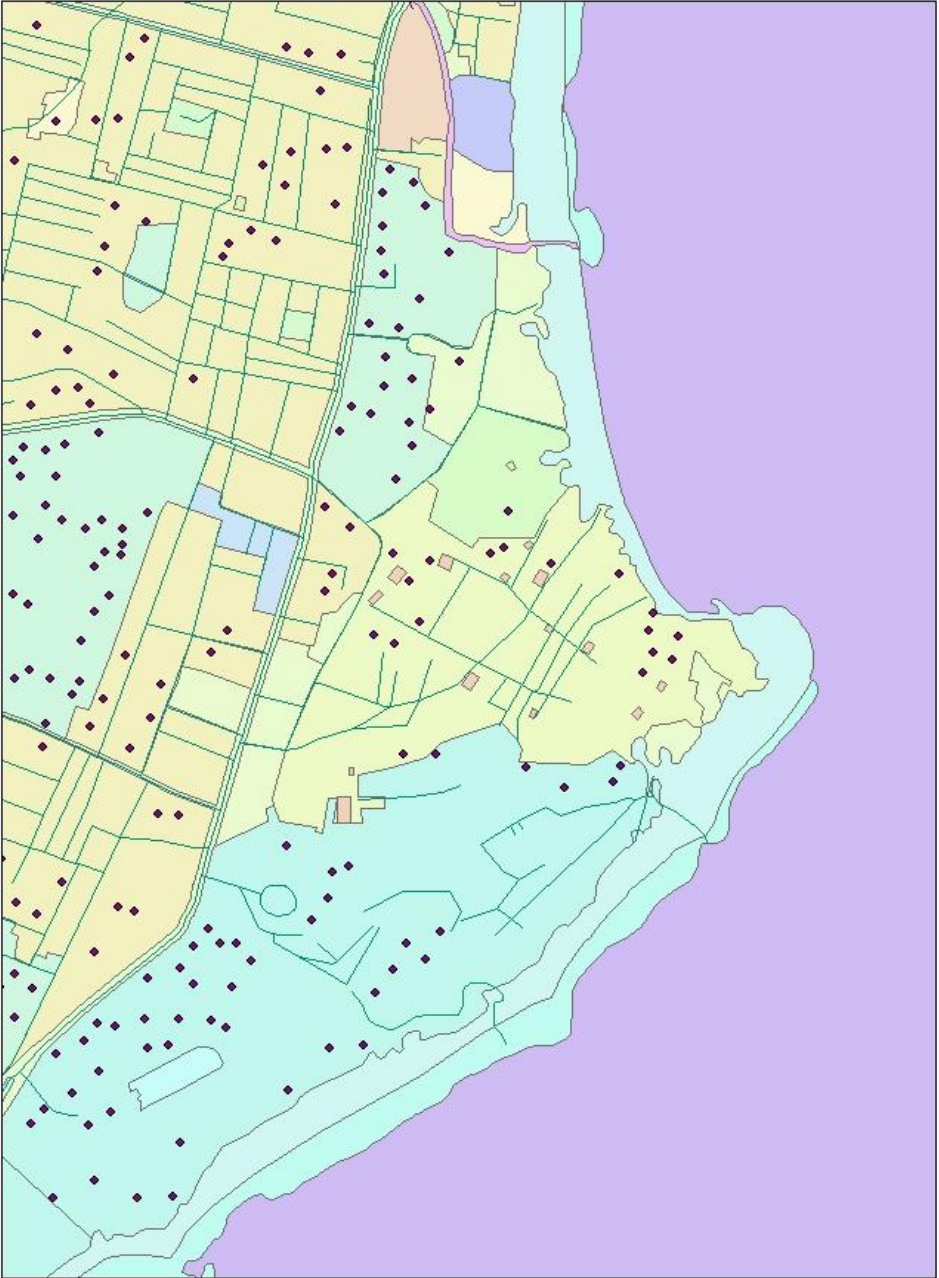


Fig. 2.17: Part of Vishakhapatnam Landuse map on 1.5000 scale using CARTOSAT data

Legend

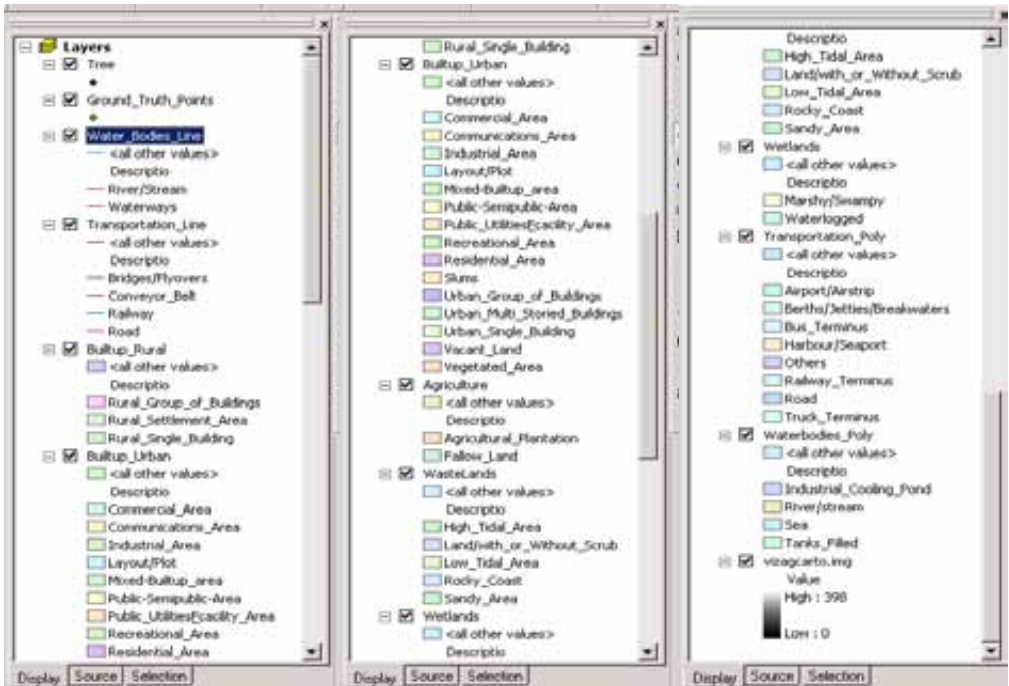


Fig. 2.18: Legend for Vishakhapattanam Landuse map on 1.5000 scale using CARTOSAT data

Monitoring Coastal Land-Use/Land Cover Changes (LUCC) and Status of Coastal Ecosystems

Coastal land forms are unique and dynamic in nature and are vulnerable to the excessive anthropogenic pressure. Monitoring coastal Land Use/Land Cover is important for making coastal zone management plan. The following tasks are required to be performed for this work:

- Mapping Land use-Land cover changes in coastal zone and identifying hotspots of land cover changes
- Studying changes in coastal habitats
- Studying the relationship between anthropogenic pressure, LUCC and its impacts on the vital coastal habitats (coral reefs and mangroves)

- Predicting the changes in coastal habitats/identify hotspots due to LUCC

Monitoring of coastal Land Use/Land Cover has been done for the following areas:

- Gulf of Kachchh (Selected regions), Gujarat Coast
- Dahej, Gujarat Coast
- Hazira, Gujarat Coast
- Mangalore, Karnataka Coast
- Chennai, Tamilnadu Coast
- Visakhapatnam, Andhra Pradesh Coast

Details of the satellite data used for this study are used:

- Landsat TM/MSS (at 10 year interval)
- IRS LISS III (1996-2001)
- Resourcesat LISS-III (2005-2008)
- Resourcesat LISS-IV (2004-2006)
- Resourcesat-1 AWiFS, Pre and Post monsoon (2005-2008)
- Cartosat/IKNOS (for critical areas)

In addition, other data utilized for this study are:

- Climatic, physical and biological parameters collected in the CZIS component
- Socio-economic data (past and present)
- Past land-use land-cover data from past cadastral/revenue maps

Details of the approach used are discussed below

Data Preparation

Land use/Land cover maps at 1:25, 000 scale were generated using multi date satellite data for the period 1975-2008 for the Gulf of Kachchh and 1996-2008 for other study areas. These maps are given in Figures 2.19 - 2.22. During

1975-2000 maps were generated at 10 years interval and for remaining years they were prepared using data for each period.

Coastal land use-land cover changes were studied using satellite data (existing and current). From 1975 to 1995 changes for every 10 years were studied. However, during 1995 - 2000, changes were studied for every five years. 2001 onward maps were prepared on a yearly basis and annual changes were recorded. In critical areas mapping at detailed scale (1:25,000/1:12,500) was carried out. Old topographical maps were used to compare changes.

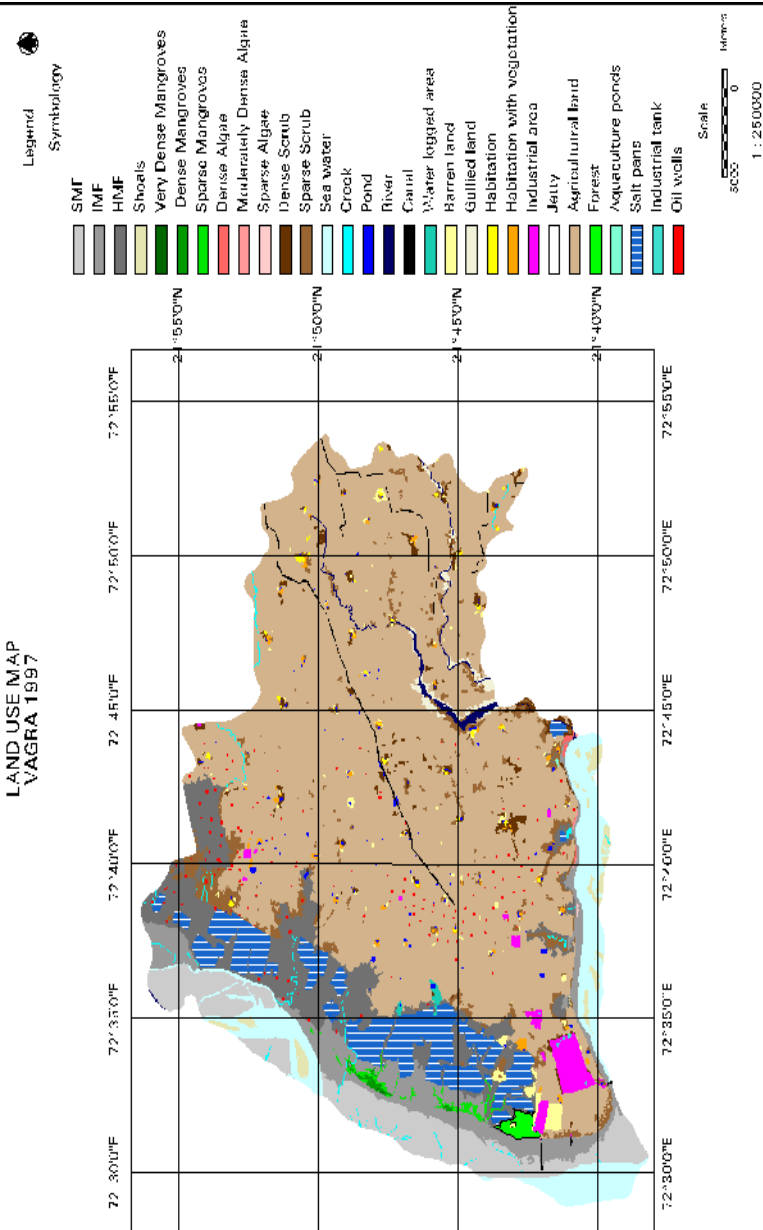
Submergence and Emergence, rate of sedimentation, role of coastal processes were also studied. Erosional/depositional aspect of the coast was also studied using RS data. Since the spatial Information was not available for the period before 1975, therefore the existing literature on the pattern of land use land cover was used to generate maps in the desired form. Intensification of anthropogenic and agricultural activities was also generated in map form. Current condition was obtained using current satellite data. NDVI/vegetation indices were generated from satellite data for the period 1986 onwards.

The newly generated spatial data on current LU/LC was overlaid and linked to the past data to understand the causes and rate of LU/LC changes. Areas which have undergone rapid land cover changes are the areas affected by either land conversion or modification. And these are the areas which are most vulnerable to future changes.

Pattern and trend of changes in weather parameters and socio-economic profiles were also integrated with changes in land use-land cover (Figure 2.23 - 2.24). This is important as land use decisions are based on opportunities and constraints affected by both biophysical and socio-economic drivers. Predicting future land use change requires methodologies that integrate understanding of the processes affected by these drivers). Therefore, this helped in identifying hot spots of land cover changes. Different thematic codes were assigned to different processes of change and for each change patch, a description of the nature of the change, date, causes, impacts etc. were included. Predictive models for land use/cover changes were generated.

Shifts occurring in the coastal habitats were studied based on the changes that have occurred. Coastal vegetation diversity and type were taken as indicator to study the effect of anthropogenic activities on the coast, e.g., a previously mangrove covered area converted to marsh vegetation or saline area indicates not only the degradation in the extent and condition of the mangrove habitat but also the change in the composition of species, change in the geomorphological setting e.g., freshwater influence mangrove habitat to purely tidal, normally flushed tidal area to highly saline and thus unsuitable for the growth of mangrove vegetation, etc.

Dahej, Gujarat Coast



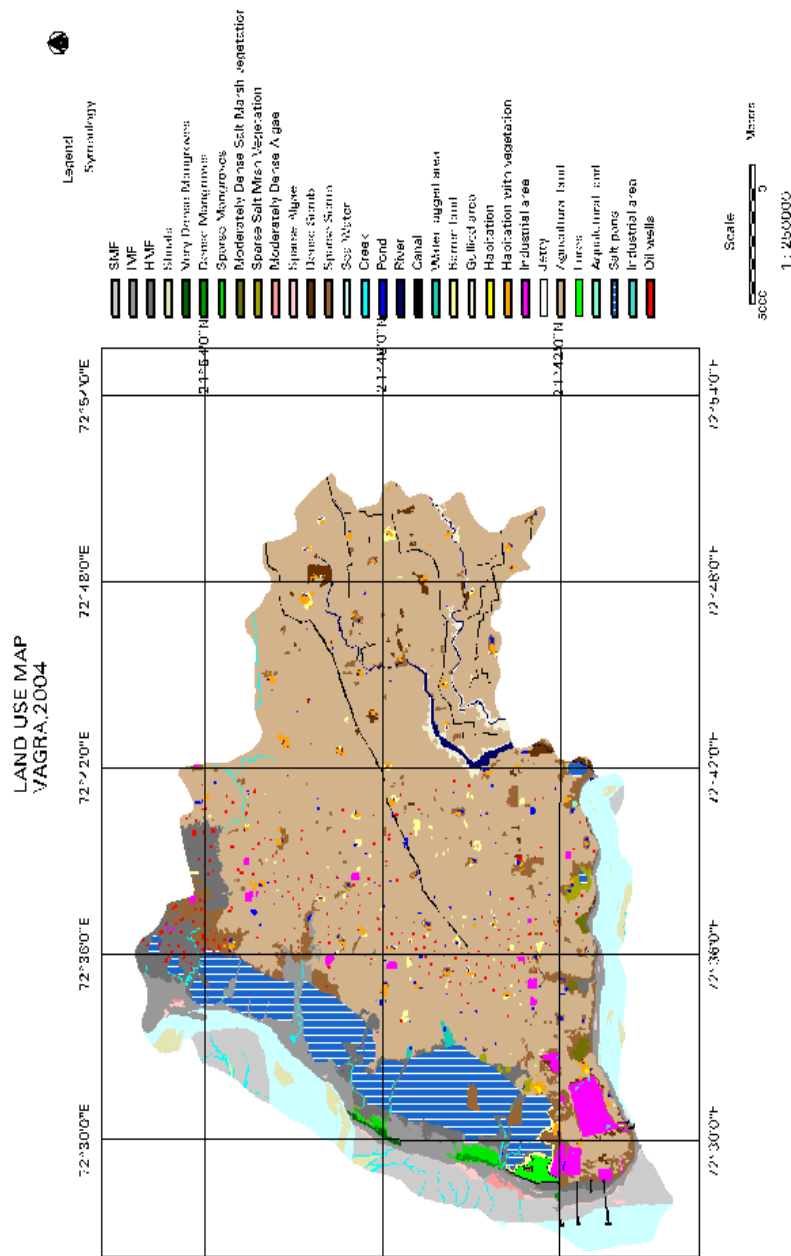
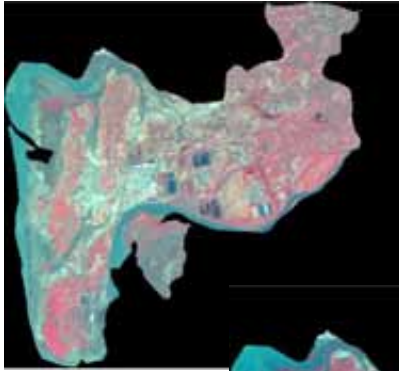
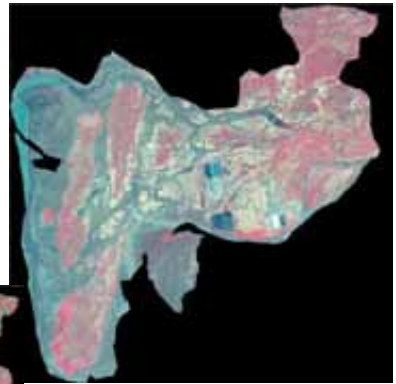


Fig. 2.20: Landuse map of Vagra Taluka, Bharuch district, Gujarat using 2004 data

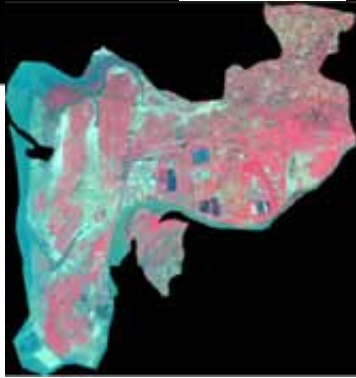
Hazira, Gujarat Coast



L3 - 12 Feb 1999



TM - 12 Jan 1987



L4 - 06 Nov 2004

Fig. 2.21: TM, LISS III and LISS IV images of the Chorasi taluka area

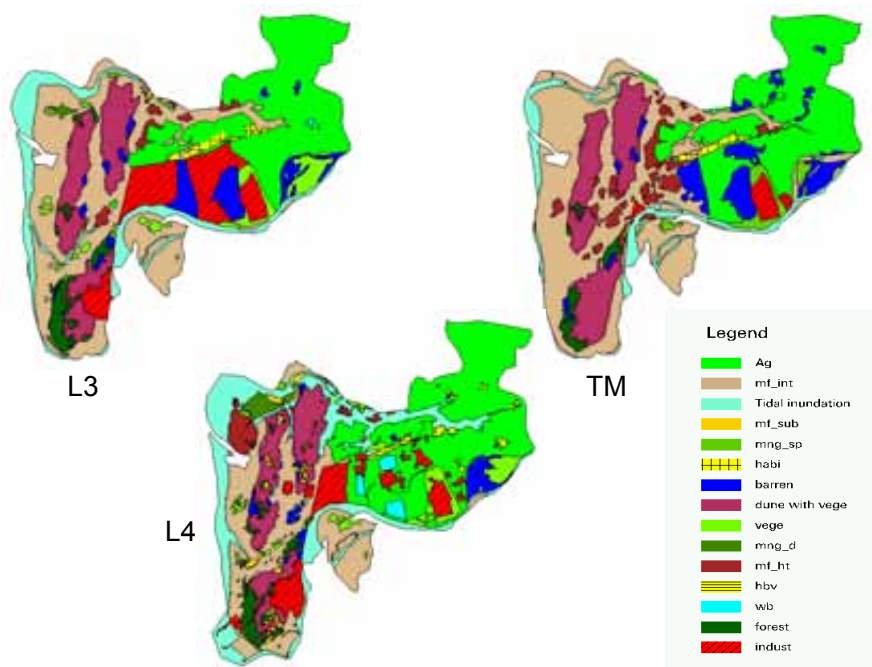


Fig. 2.22: Land use/Land cover maps prepared from TM, LISS III and LISS IV images of the Chorasi taluka, Hazira, Surat

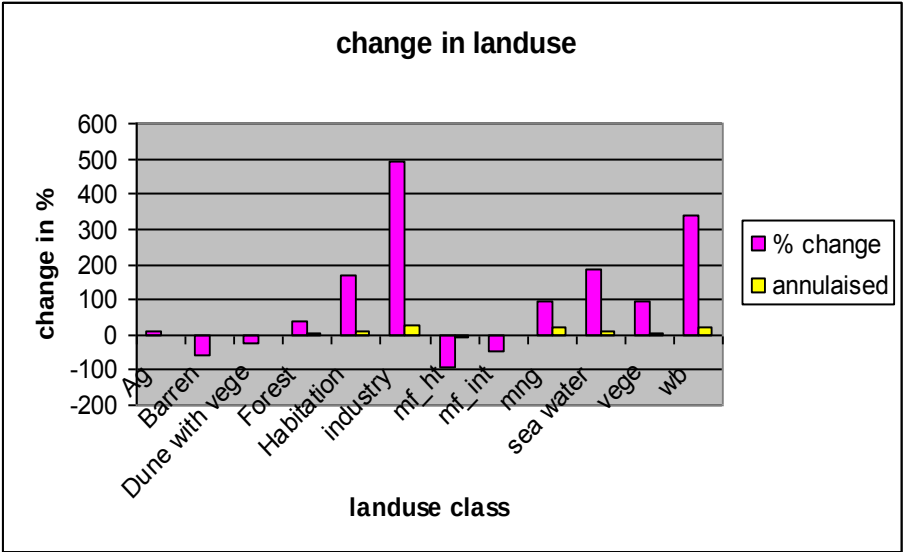


Fig. 2.23: comparison of area percent change in coastal landuse and wetland

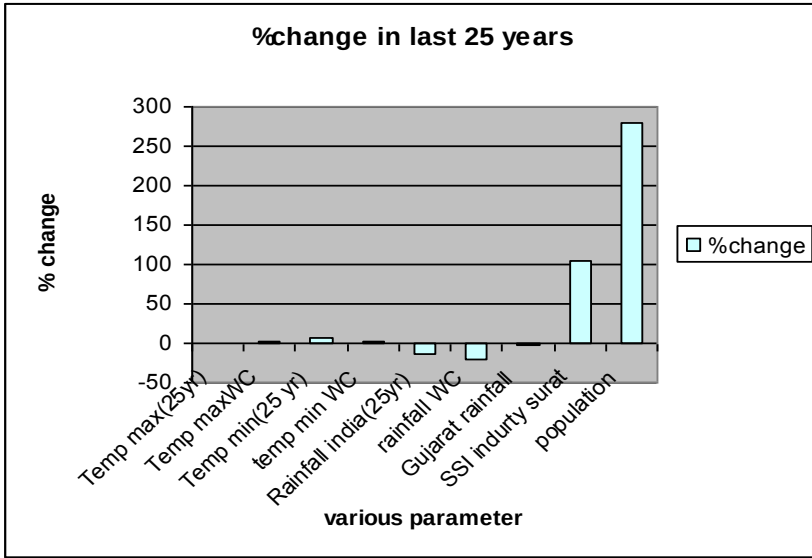


Fig. 2.24: Percent change in various parameters affecting landuse
Changes during last 25 years

Model Development:

Dynamic simulation model based on object-orientated representation has been used in this study. Differential and partial differential equations are generally used as mathematical tools for this type of models. Modelling of interconnections and interactions of components and sub-components for studying interacting dynamic systems do not yield satisfactory results in complex systems like natural and ecological systems. This type of systems functions via many interacting mechanism, which define and control them. However, the forces which change or control the systems arise from very primitive interaction within individual components.

Theory of cellular automata is a concept to represent the idea that a computing machine could reproduce itself or even complex machine. This idea is further attempted for variety of natural systems to the economics. Camera (1996) have attempted cellular automata for the fourth category of systems and concluded that for simulating spatial phenomena cellular automata shows promising results. Cellular automata modelling of dynamic systems conceptualise cell structure to explain the phenomena. It consider cell of a line in case of one-

dimensional and grid in case of multi-dimensional phenomena. In satellite remote sensing, a pixel can be considered as a basic unit (cell) for application of cellular automata. For structure or system analysis, this computational scheme is similar to numerical manipulation of the partial differential equations. Basic difference here is that each cell allows only two states option for considering change, i.e. change or no change. Thus, transition function does not assume the algebraic form, but may be deterministic or stochastic. Cellular automata simulation can have large number of variables (one per cell) compared to differential equations. This permits more detailed and efficient dynamic modelling of spatial system. This approach also provides a model representation closer to the real physical system by removing macroscopic and microscopic representation.

Following models have been used:

1. Processes acting upon land and give resultant effect on land (Ind1), and
2. Impact of man-made structure on the coastal processes (Ind2)

1. Processes acting upon land and give resultant effect on land (Ind1):

A cellular automaton has been used and the parameters measured and processes identified in the previous exercise have been used for the development of model of processes acting upon land. LISS III image of 19 February 1999 of Chorasi Taluka has been selected for this analysis. For applying criteria in the programming procedure, pre define classes were identified and classification of the test area has been carried out. Giving different input time, model was run and landuse change maps for different time frame were generated (Figure 2.25). It can be noted that how the barren area was converted either in the agriculture or habitation and high tide area convert in to the either agriculture or industrial area.

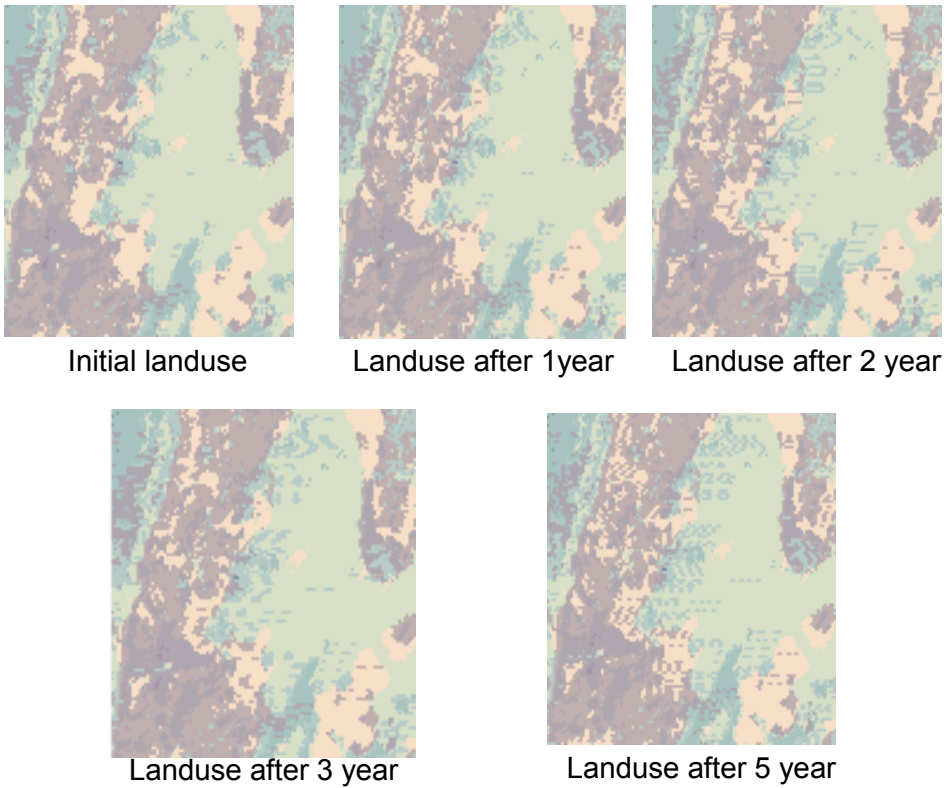


Fig. 2.25: Part of classified image of Chorasi Taluka, Surat District showing change in landuse at different time-scale after running the model Ind1

2. Impact of man-made structure on the coastal processes (Ind2):

For studying the impact of man-made structure on the coastal processes, first prerequisite is the identification of precise location of man-made structure on the image. This has been accomplished by generating 5 x 5 similarity matrix using the input data. This matrix is compared with each pixel. Thus, location of manmade structure was identified. Once this is identified, and current direction is known, leeward and upward direction has been decided. The rates of erosion or deposition calculated above were applied and output scenario for different years were generated (Figure 2.26).

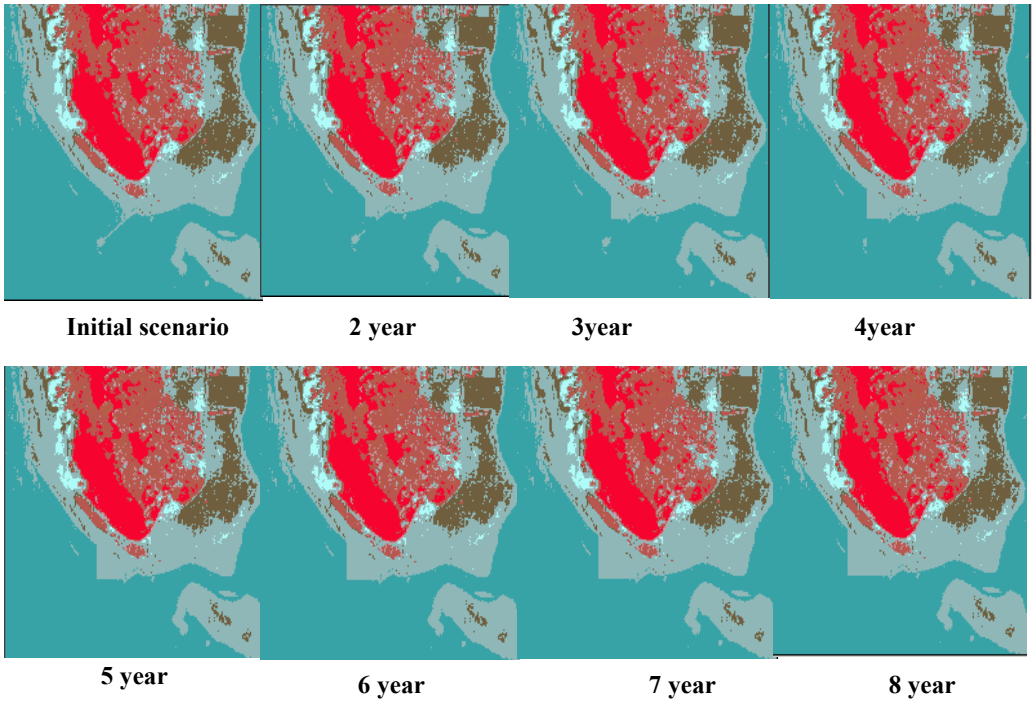


Fig. 2.26: Different output scenario for Model Lnd21

Observations and Results for Landuse Landover changes:

Landuse changes (category wise) during 1987 to 2003 were calculated from the classified images. Agriculture area has increased from 4406 ha to 4880 ha. Industrial area has increased from 288 ha to 1711 ha, during the same period. Habitation area has increased from 32 ha to 330 ha and high tidal mudflats have decreased from 407 ha to 64 ha. This change may be due to reclamation of mudflat area in to agriculture or industrial area. In addition to this other non spatial data like census, rainfall, temperature, industrial development were used for finding out the major drivers of the Landuse change. It is evident from the data that population increase due to industrial development (Anthropogenic parameters) are driving the change in this area. Using this inputs the models 'Ind1' and 'Ind2' were prepared and future scenario for different time frame were generated.

3. Mangroves

Mangroves are salt tolerant plants that occur along inter-tidal zones of rivers and seas in the form of narrow strips or as extensive patches in estuarine habitats and river deltas of tropical and sub-tropical regions. They occur between 32°N and 38°S latitudes, mostly on the eastern coasts of Africa, Australia, Asia and America. Sheltered environment with brackish influx, estuarine and deltaic muddy soils, good rainfall (1000 mm - 3000 mm) and temperature between 26°C - 35°C are considered as ideal habitats for luxuriant growth of mangroves. Mangrove forests are usually characterized by uniform type of trees and shrubs and the species diversity decreases with increasing latitudes. According to a trend analysis conducted on available data by FAO, some 15.2 million hectares of mangroves are estimated to exist worldwide as on 2005, down from 18.8 million hectares in 1980. The most extensive mangrove area is found in Asia, followed by Africa and North and Central America. According to Finlayson and Moser (1991) the total mangrove area of the world is about 14 million hectares: out of these, the old world tropical mangroves, i.e., the Indo-Pacific tropical zones and tropical Australia have the most dominant and important mangroves in respect of species diversity, richness, abundance and succession.

The most dominant and single largest mangrove chunk of the world is situated in the Ganga–Brahmaputra–Meghna deltaic regions or estuarine mouths of both India and Bangladesh (Naskar and Mandal, 1999). West Bengal has the maximum mangrove cover in India, followed by Gujarat and then Andaman and Nicobar islands.

Characteristics of Mangroves

Mangroves are notably different from other halophytic and mesophytic plant species, as they survive in a hostile environment, an interface between land and sea marked with fluctuations in salinity, storms and tidal surges and recently human induced biotic pressures like pollution. The biota exhibits a wide variety of adaptations in terms of morphology, anatomy, physiology, development of seed and seedlings, physiognomy and succession mechanisms.

Prop roots, knee roots, plank buttresses and pneumatophores, sclerophyllous leaves with sunken stomata, and vivipary are some of the common adaptations. The roots possess pneumatopores or lenticels for the purpose of gaseous exchange. The control of tissue water potential through specialized leaves and stems, exclusion of salt through rhizo-filtration, excretion of salts through salt glands, and the ability to deposit salt in older leaves, barks and pneumatophores help the plants to acquire high level of salt tolerance (Tomlinson, 1986).

The exact number of mangrove species is still a matter of debate and ranges from 50 to 70 according to different classification systems (Tomlinson, 1986; Saenger et al., 1983; Lugo and Snedaker, 1975; Aksornkoae et al., 1992), with the highest species diversity found in Asia, followed by eastern Africa.

Significance of Mangroves

Mangroves are recognized widely for their ecological and economic functions. Mangrove wetlands play an important role in stabilizing shorelines and protect the coast by acting as barriers against storm surges and heavy tides. They are self-generating and self-perpetuating littoral formations, playing a major role in the global cycle of carbon, nitrogen and sulphur. They act as sink for sediments and detritus draining from coastal catchments and help in the tertiary assimilation of wastes. Mangrove swamps are also source of nutrients and supports highly productive marine food chains. Mangroves serve as unique habitats for wild animals like tiger and harbour large number of birds, larvae and juveniles of fishes significant to the fishery resources. They contribute to the livelihood of coastal folks in terms of forest produce and fishery resources. Mangrove forests are also valued as potential recreation site for fishing, boating, bird watching, sightseeing and photography.

Distribution of Mangroves

Mangroves mostly grow within the sheltered inter tidal flat deltaic lands, funnel shaped bays, broad estuarine mouths, shallow or frequently tidal inundated coastlines (Thom, 1982). Each of these habitats has a unique environmental setting created by factors like geomorphology of the coast,

climate, tidal amplitude and duration and quantity of freshwater inflow and the salinity quotient caused by mixing up of the freshwater with the sea water. On the macro-scale, geomorphic setting of the mangrove wetlands of the east coast of India is different from those of the west coast. Steep slopes, rises, promontories and drowned estuaries characterize the west coast of India, while the east coast shows a sequence of delta formations (Ahmad, 1972). This vast expanse of deltaic soil and mud-flats favors luxuriant growth and diversity of species. According to Jagtap *et al.* (1994), the mangrove flora of India consists of 50 species, of which 37 species are reported from east coast and 20 from the west coast. Species such as *Pemphis acidula* is endemic to islands of Gulf of Mannar of Tamil Nadu, *Scyphyphora hydrophyllacea* is endemic to Godavari mangroves of Andhra Pradesh and *Nypa fruticans* is present only in Sunderbans.

Along the east coast the tidal amplitude, volume and intensity of fresh water inflow decreases from north to south affecting the soil characteristics, mainly, salinity, moisture content, chemical composition, texture and nutrient availability. Correspondingly, the species diversity and extent of mangroves also decreases which is clearly evident as Sunderbans of West Bengal harbours around 30 true mangrove species while Pichavaram and Muthupet of Tamil Nadu records only 13 species. Furthermore, within the sheltered habitats, the species form distinct communities due to their strong dependence on specific environmental gradients like temperature, tidal frequency, sedimentation processes, freshwater availability, wave and storm surges, and physico-chemical soil properties. The distinct zonation pattern, in which each zone comprising of one or two dominant species or an assemblage of a particular group of species is clearly noticeable within short transects from the coast towards the landward side.

Threats to Mangroves

Despite the ecological and economic significance of mangroves they are considerably under pressure from human activity. The main threats to mangroves are described below.

Plantations and young plants are being damaged by the attachment of barnacles to their stem. Insect attack also causes considerable damage to the leaves of various species of mangroves like *Rhizophora mucronata*, *Avicennia alba* and *Sonneratia alba*. Other species also have been found to be attacked by fungus. This problem is affecting the mangroves of Goa, Orissa and Andhra Pradesh but to a little extent.

Reduction in the quantity and periodicity of fresh water flowing into mangrove wetlands affects the density as well as diversity of the mangroves through increasing water and soil salinity. This problem mainly affects the highly saline sensitive species like *Sonneratia apetala*, *Xylocarpus granatum*, *Heritiera fomes* and *Nypa fruticans* and has shown its impact in the Krishna mangroves (Andhra Pradesh), in the mangrove of Jagatsinghpur and Baleshwar districts (Orissa) and in the Sundarbans of West Bengal.

Conversion of mangrove areas for human habilitation, aquaculture, agriculture and other developmental activities are also a major threat to mangroves, especially in Orissa and Maharashtra. Unauthorized felling and cutting of branches of mangroves for firewood purpose is still reported sometimes but the damage caused by this practice is not much significant.

Barge movement in Zuari and Mandovi rivers of Goa carries ores to Marmugao port, resulting in the strong wave action due to which young regeneration/saplings get uprooted. This also leads to erosion on the river banks. However, other mangrove wetlands not having barge movement do not face threat from this problem.

Inadequate infrastructure for protection also poses some difficulties in mangrove protection but the threat to mangrove wetlands because of this problem is very limited.

In Maharashtra, losses of habitat, human interference, pollution, Kharland bunding, aquaculture, grazing, commercial use, etc. are some of the threats affecting the mangrove forests. Due to these factors several thousand hectares of mangrove have been cleared. The major problem is the lack of participation of local people and awareness about the importance of mangroves. The

following conservation strategies are suggested: germplasm preservation, protection and preservation of value-added species, sustainable land-use, etc.

To overcome all these threats a number of actions can be taken into consideration. Periodical monitoring of fresh water flow along with diversion of fresh water in the upstream will be helpful in designing programmes to prevent damage of salinity sensitive species of mangrove. A proper mangrove management policy which should offer people with viable alternatives for their dependency on mangroves for fuel wood, fencing, fodder etc is needed. A sustainable method of mangrove harvesting should also be evolved. Enrichment of the old plantations should be taken up at regular intervals of time by the forest department. Eco-tourism should be supported and encouraged in the mangrove wetlands. Awareness programmes for students and villagers should be organized to make them aware of the uses and need for conservation of mangroves. A clear policy on landuse around mangrove wetlands can play an important role in the conservation of mangroves which are facing degradation threat especially in Maharashtra and Orissa. More grass root level institutions like Luna Jungla Samrakshna Samitis (Mahanadi and Devi mouth villages of Orissa) should be formed for participatory management of mangroves and their restoration. Demarcation of the revenue lands, forest areas and mangroves has to be clearly established for better results in mangrove conservation.

General Classification of Mangroves

Classification of mangroves is mainly based on the tidal flow, soil salinity and the nature of community. Regional scale classification of Indian mangrove wetlands can be based on the classification system developed by Thom (1982), which is mainly based on three groups of dynamic factors, namely (a) geo-physical attributes (changes in sea-level, climatic conditions and tidal properties of a region), (b) geomorphic parameters (sedimentation, dominance of particular process – wave or river, tidal or river, etc. and micro-topography of the wetland) and (c) biological properties. Based on this, Indian mangroves can be classified into tidal-dominated, river-dominated, drowned bedrock valley type and carbonate platform on low energy coast types of mangroves.

According to Lugo and Snedaker (1974), further classification of mangrove wetlands into smaller units based on micro-topographical features with respect to mean sea-level, frequency of tidal inundation into the areas and appearance of forests is possible. According to this system six community types could be identified, each having its own set of environmental variables such as soil, depth, salinity and tidal flushing rates. Each of these community types possesses its own range of primary production, litter decomposition and carbon export, along with differences in nutrient cycling rates and factors that determine the role of mangroves on the bio-production of adjacent water bodies.

Following the classification of Tomlinson (1986), mangroves may be divided into three groups according to their morphological and physiological adaptations, viz., major elements (strict or true mangroves, which are found exclusively in the mangrove habitat), minor elements and mangrove associates.

3.1 Mapping at Community Level

In spite of ecological and economical significance, mangroves are endangered ecosystems. The major threats to these wetlands are conversion of mangrove habitats for agriculture, industrial development, human settlement, salt extraction and shrimp farming. Reduction in freshwater flow and excessive extraction of wood for fuel also add up to the severe degradation of mangroves. This has necessitated the need for a constant surveillance; in this regard, remote sensing is a practical alternative to field-based surveys and is being successfully used over the years for mangrove mapping at primary level, especially in differentiating mangroves from other vegetative covers (State of Forest Report, 2001, 2003).

In recent years, there are new initiatives to understand the spatial relationship between mangroves and their immediate environment, viz., ‘community zones’ (Tomlinson, 1994; Hogarth, 1999), using advanced digital image processing techniques (Bahuguna and Nayak, 1996; Blasco *et al.*, 1998). These mangrove zones exhibit unique spectral signatures and earlier studies at select sites by Nayak and Bahuguna (2001) revealed the potential of remote sensing data in

discerning and mapping these communities effectively. Indian Remote Sensing Satellite (IRS) data has been extensively used to map mangroves and other coastal vegetation for the entire Indian coastline. Large data base on spatial extent of mangroves have been created on 1: 25,000, 1: 50,000 and 1: 250,000 scale using IRS data of 1990-93 timeframe (Nayak and Bahuguna 2001).

The present study envisages mapping of mangroves at community level on 1:25,000 scale for all maritime states/Union territory harbouring mangroves.

These are Andhra Pradesh, Goa, Maharashtra, Orissa, Karnataka, Kerala, Puducherry, Tamil Nadu (excluding Puducherry), Gujarat, West Bengal, Andaman and Nicobar islands

IRS P6 LISS-III and LISS-IV data of the year 2005 - 2007 during the period from October – March have been utilized for discerning mangrove communities of the coasts of Andhra Pradesh, Goa, Maharashtra, Orissa, Karnataka, Kerala and Puducherry. Table 3.1.1 shows the key parameters of IRS P6 LISS-III and LISS-IV sensors. As mangrove forests are tide inundated, care was taken to utilise low tidal data sets of coastal regions. For delineating fringe mangroves along narrow creeks and new plantation areas, Quick bird data available from Google Earth Services was also utilized.

Table 3.1.1: Key parameters of IRS P6 LISS-III and LISS-IV Sensors

		LISS-IV		LISS-III	
		Mono Mode	MX Mode		
Spatial Resolution	Band 2 (green)	5.8 m	5.8 m	23.5 m	
	Band 3 (red)				
	Band 4 (NIR)				
	Band 5 (SWIR)				
Swath-width	all Bands	70 km	23.9 km	140 km	
Radiometric Resolution/ Quantization	all Bands	7 bit rescaled	7 bit	7 bit	
Spectral Coverage	Band 2 (green)	620-680nm	520-590 nm	520-590 nm	
	Band 3 (red)		620-680 nm	620-680 nm	
	Band 4 (NIR)		770-860 nm	770-860 nm	

Band 5 (SWIR)

1550-1700 nm

Methodology

IRS P6 LISS-III data is considered as the primary data source for digital data analysis. Digital values are converted to spectral radiance based on the equations and calibration coefficients obtained from sensor calibration details available in the metadata

$$L_{\text{rad}} = \{ [\text{DN} / \text{max grey}] \times [L_{\text{max}} - L_{\text{min}}] \} + L_{\text{min}}$$

Where, DN = Digital number of each pixel; max grey = 255 for LISS-III

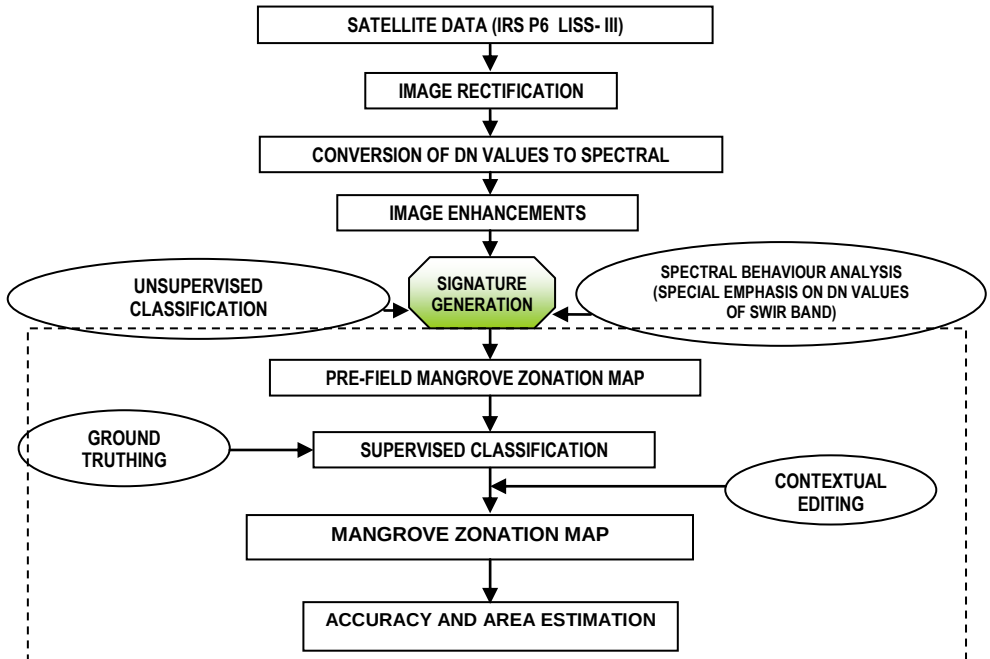


Fig. 3.1.1: Methodology for Mangrove Community Mapping

As there was only scanty information available regarding community zonation, so to start the work, geo-referenced spectral radiance images were subjected to unsupervised classification using the commonly used Iterative Self-Organising Data Analysis (ISODATA) classifier. The ISODATA method uses minimum

spectral distance to assign a cluster for each candidate pixel. Depending upon the scene characteristics arbitrary clusters are specified with a convergence threshold of 0.99. The clusters thus obtained were colour coded for better visual discrimination and pre-field classification maps were prepared.

From the field observations, elevation of land, level of salinity and duration of tidal inundation were found to be the predominant factors influencing the species composition. The false colour composite developed from digital data is able to discern the major communities to a considerable extent. To identify the subtle differences in species composition, classified outputs developed from ISODATA classifier are also made use of in ground truthing. Ground truth points are selected in such a way to sufficiently represent all the digitally discernible communities. Geographical coordinate information, species composition and dominance, influence of tidal inundation and digital view of each selected reference point are also collected. Based on the ground truth information, supervised classification is performed with sufficient training sets for each community. Mangrove community classes thus obtained is evaluated critically with the ground information and expert knowledge. Short wave infra red band of IRS LISS-III with a spatial resolution of 23.5 m is effectively used for differentiating mangroves from adjacent other vegetative covers. Contextual editing is performed wherever necessary to improve the classification accuracy. Area statistics is drawn based on final classification.

Classification System

A merged classification system involving both geomorphological as well as ecological characteristics of the habitat (Table 3.1.2) is ideal for habitat mapping as both the characteristics strongly influence the radiance recorded by a remote sensing instrument. Though a direct geomorphological classification is not attempted in this study, mangrove community zonation is quite visible based on definite environmental gradients. Depending on the dominance of species present in these zones and its crown cover density, mangrove community classes are delineated and assigned class names in the order of dominance. Mangrove communities with more than three mangrove species are classified as mixed mangrove communities.

Table 3.1.2: Geomorphological zones and ecological classes of mangrove habitat

Geomorphological zones		Ecological classes	
Onshore areas	Beach	Muddy Sandy	Fringe tidal mangroves
Deltaic complex	Estuarine mouth	Inter-tidal mudflat	<i>Avicennia</i> pure (3 species) <i>Aegialitis</i> (only in Sunderbans & Mahanadi)
	Mid estuary (creeks and canals more)	Inter-tidal mudflat	<i>Rhizophora</i> , <i>Bruguiera</i> , <i>Ceriops</i> , <i>Sonneratia</i> , <i>Aegiceras</i> , <i>Xylocarpus</i>
	Inner estuary	Inter-tidal mudflat	<i>Rhizophora</i> , <i>Bruguiera</i> , <i>Heritiera</i> , <i>Carberrra</i> , <i>Cynometra</i> , <i>Excoecaria</i> , <i>Phoenix</i> , <i>Xylocarpus</i>
	Outer estuary	High-tidal mudflat	<i>Dalbergia</i> , <i>Derris</i> , <i>Excoecaria</i> , <i>Acrostichum</i> , <i>Pongania</i> Marsh vegetation Saline blanks
Bay Complex	Mouth	Inter-tidal mudflats	<i>Rhizophora</i> , <i>Bruguiera</i> , <i>Ceriops</i> , <i>Sonneratia</i> , <i>Xylocarpus</i>
	Middle zone	High-tidal mudflats	<i>Avicennia</i> , <i>Phoenix</i> , <i>Lumnitzera littoralis</i> , <i>Heritiera littoralis</i> , <i>Nypa</i>
	Inner zone	High-tidal mudflats	<i>Avicennia</i> , <i>Nypa</i> , <i>Acrostichum</i> , <i>Thespesia</i> , <i>Derris</i> Marsh vegetation Saline banks
Gulf Complex	Seaward zone	Sub-tidal Mudflat	Algae
	Inner zone	Inter-tidal mudflat	<i>Rhizophora</i> , <i>Sonneratia</i> , <i>Avicennia</i> , <i>Ceriops</i> , <i>Bruguiera</i>
	Outer zone	High-tidal mudflat	<i>Avicennia</i> , Salt marsh vegetation Grass/ <i>Acanthus</i> Saline blanks
Offshore area	Continental shelf		Algae/ seaweeds
	Islands		Mangroves Sand vegetation
	Coral reefs		Algae/seaweeds/ seagrass

Zoning also includes condition assessment in the form of density-wise classification of the communities. Mangroves have been classified in four

density classes, viz., very dense (> 70 % cover), moderately dense (40-70 % cover), dense (10-40 %) and degraded (< 10 % cover).

Statewise Mangrove Distributions: Area and Community

Andhra Pradesh

Andhra Pradesh, lying between the latitude $12^{\circ}37'$ and $19^{\circ}55'$ N and longitude $76^{\circ}45'$ and $84^{\circ}46'$ E is the largest state of the eastern coast of India. It has a geographic area of $275,069 \text{ km}^2$, constituting 8.37 % of the total area of the country. Physiographically the state can be divided into 3 distinct regions, viz., (i) the hilly region having Nallamalai and Erramalai hills of the Rayalaseema and the Eastern ghats, (ii) the plateau having an altitude of 100 m to 1000 m spread mainly over the Telengana region, and (iii) the deltas of rivers between the Eastern Ghats and the sea coast. The state has a coastline of about 1014 km and major estuaries, viz., the Godavari and the Krishna, which form deltas in the coastal areas of Andhra Pradesh. The estuarine deltas comprise of bays, tidal creeks, extensive tidal mud-flats, spits, bars, mangrove swamps, marshes, bridges, swale areas and coastal alluvial plains. Climate is hot and humid, except in western plateau where humidity is low. Annual rainfall in the northern part ranges from 1100 mm to 1250 mm and in the southern part it is around 500 mm.

Andhra Pradesh has a recorded forest area of 44372 km^2 , which is 16.13 % of the total geographical area of the state (State of Forest Report, 2005). Though around 40 rivers flow through the state yet Krishna and Godavari deltaic regions harbour extensive mangroves that account for the major share of mangrove forests of Andhra Pradesh. These eastward flowing rivers bring along nutrients from the Eastern and Western Ghats and Deccan plateau and empty these into the sea, thereby, nourishing the estuarine habitats. Besides these, mangroves are mainly confined to Nellore and Guntur districts on the east coast and as few patches on the intertidal mud-flats at the mouth of Sarada river in Visakapatnam. About 600 km^2 of mangrove area in the state has been notified as reserved forests which include mangrove covers, mud-flats and water bodies.

Godavari mangroves

River Godavari, the second longest river in India with its vast expanse of estuarine delta formed between the major tributaries of Gautami and Vasishta makes the bed for a variety of mangrove species. Again, this river is the border line between the mangroves of Sunderbans and Mahanadi delta and the mangroves of rest of the peninsular India (Anonymous, 1984). Considering the ecological significance and biological diversity of Godavari estuarine mangroves of East Godavari district, Coringa Reserved forest, Coringa Reserved forest Extension and Bhairavapalem Reserved forest were delimited as Coringa Wildlife Sanctuary in the year 1978.

Compared to other deltaic mangroves, Coringa has a unique geomorphological setting that protects it from heavy sea surges and maintains a healthy and species rich ecosystem by freshwater flushes through intricate channels from upstream. Towards the north it is surrounded by the Kakinada Bay which has a long narrow sand spit that extends to about 16 km on the eastern side separating the bay from the open sea. Gautami-Godavari and their tributaries, namely, Coringa, Gaderu, Matlapalem and Pillarava empty large amount of freshwater into Kakinada Bay throughout the year. In addition, these water bodies are subjected to considerable tidal action especially during non-monsoon period from January till the onset of monsoon during July, giving rise to luxuriant fringe mangroves with rich species diversity.

Towards the south of Coringa Wildlife Sanctuary, reserved forests of Rathikaluva, Masantippa, Matlatippa, Balusitippa, Kottapalem and Kandikuppa also harbour luxuriant mangrove vegetation.

Coringa Reserved forest (RF)

A distinct zonation of tree species is observed in Godavari estuarine mangroves. Species like *Avicennia alba* and *Sonneratia apetala* are found to be the early colonizers and they exist along the open coast. *Avicennia alba* is seen as pure stands near Coringa and Matlapalem canal mouths facing Kakinada bay. Lying in the low tidal zone, they trap the sediments and help in land formation. Pure patches of *Avicennia officinalis* are noted in many areas towards landward side, especially between Matlapalem and Coringa creeks with an average height of about 7-9 m. *Excoecaria agallocha* is quite

widespread throughout the sanctuary occurring either as pure patches or in association with *Avicennia marina*. *Myriostachya wightiana* and *Fimbristylis ferruginea* are found to border the creeks of Coringa river. Towards the landward side in certain areas *Excoecaria agallocha*, *Lumnitzera racemosa* and *Avicennia marina* are found to grow together. In degraded areas *Suaeda maritima* and *S. nudiflora* are found as extensive patches along with *Excoecaria agallocha* and *Acanthus ilicifolius*. Other than true mangroves, mangrove associates like *Acanthus ilicifolius*, *Dalbergia spinosa*, *Thespesia populneoides*, *Hibiscus tiliaceus*, *Clerodendrum inerme* and climbers like *Ipomea tuba*, *Sarcolobus carinatus*, *Caesalpinia crista* and *Derris trifoliata* are observed along the fringes of Coringa river.

Coringa RF Extension

Kakinada bay occupies almost half the area of this reserved forest towards the northern side and thick mangrove vegetation of Matlapalem and Gaderu comprises the southern part. *Excoecaria agallocha* and *Avicennia marina* are the dominant species. Towards the eastern side of Gaderu river where there is tidal inundation, species like *Rhizophora apiculata*, *Rhizophora mucronata* etc. are found along with *Avicennia* species. *Sesuvium portulacastrum*, a succulent perennial herb is found abundantly in the sandy clayey soil of Gaderu bay side along with other true mangroves species of *Avicennia* and *Bruguiera*. Very distinct pure patches of *Avicennia marina*, known for its wide range of tolerance to salinity are observed in the seaward channels towards east coast. Salt marshes like *Suaeda maritima*, *Suaeda monoica*, *Salicornia brachiata* and grasses like *Myriostachya wightiana*, *Aeluropus lagopoides*, *Porteresia coarctata*, *Fimbristylis ferruginea* are also encountered.

Bhairavapalem RF

Excoecaria agallocha, *Avicennia marina*, *Avicennia officinalis* and *Aegiceras corniculatum* are the common mangrove species found in this reserved forest. Along the creeks where there is constant inundation, species like *Rhizophora apiculata*, *R. mucronata*, *Bruguiera gymnorhiza*, *Bruguiera cylindrica*, *Ceriops decandra* are found to occur abundantly. Other species like *Derris trifoliata*, *Sarcolobus carinatus*, *Clerodendrum inerme* etc. are also observed.

Rathikalava RF

Avicennia marina, *Avicennia officinalis* and *Excoecaria agallocha* are the dominant species. Along the creeks where there is frequent tidal inundation *Rhizophora apiculata*, *Rhizophora mucronata*, *Xylocarpus molluccensis*, *Bruguiera gymnorrhiza* are found. In degraded areas, marsh vegetation comprising mainly of *Suaeda maritima*, *Salicornia brachiata* exists. *Clerodendrum inerme*, *Lumnitzera racemosa*, *Thespesia populneoides*, *Hibiscus tiliaceus* etc. are also located in this RF.

Masanitippa RF

In Masanitippa R.F. luxuriant growth of 5-6 m tall *Rhizophora apiculata* and *Rhizophora mucronata* trees are seen. Other mangrove species like *Avicennia marina*, *Excoecaria agallocha*, *Ceriops decandra*, *Sonneratia apetala*, *Lumnitzera racemosa*, *Ceriops decandra*, *Bruguiera gymnorrhiza*, *B. cylindrica* are also observed along the creeks. Towards the south-eastern part outside Masanitippa R.F. and towards the Bay of Bengal thick mangrove patches comprising of *Avicennia officinalis*, *Avicennia marina* along with *Excoecaria agallocha* are found. Growth of *Prosopis juliflora* along sandy shores is also noticed.

Matlatippa RF

Pure and extensive patches of *Excoecaria agallocha* are found on the western side. Mangrove associates like *Acanthus ilicifolius*, *Derris trifoliata*, *Dalbergia spinosa*, *Sarcolobus carinatus* and grasses like *Myriostachya wightiana* and *Porteresia coarctata*, and herbs like *Ipomoea pes-caprae* are found on degraded areas towards the northern side. Eastern side of this RF is dominated by *Avicennia officinalis* and *Avicennia marina*.

Kottapalem RF

In the eastern part of Kottapalem RF adjoining the sandy beaches, mangrove density is comparatively low and invasion of *Prosopis juliflora* is noticed. Pure patches of *Excoecaria agallocha* is found to exist towards north-eastern part of the RF and it is also found to occur along with *Avicennia marina* as vast expanse. Degraded mangrove patches comprising of a mixture of species, namely, *Acanthus ilicifolius*, *Clerodendrum inerme*, *Avicennia marina*, *Suaeda* sp. and *Salicornia* sp. are recorded near aquaculture ponds and sandy shores.

Balusitippa RF

Luxuriant growth of *Avicennia marina* and *Excoecaria agallocha* is present along the Gautami Godavari river. Similarly, towards the western side near Balusitippa, vast expanse of pure patches of *Avicennia marina* and *Excoecaria agallocha* are found growing adjoining the tributary of Gautami Godavari. In this RF towards the southern part, all along the Gautami Godavari river healthy mangroves typical to the Godavari delta, viz., trees of height 7-8 m with moderately dense crown cover (40-70 %) belonging to *Avicennia officinalis* and *Avicennia marina* are recorded.

Kandikuppa RF

Because of its ecological setting with a sandy beach protection on the eastern side and many intricate water channels for tidal influx, Kandikuppa RF shelters a wide variety of mangroves like *Rhizophora apiculata*, *Rhizophora mucronata*, *Excoecaria agallocha*, *Lumnitzera racemosa*, *Bruguiera gymnorrhiza*, *Ceriops decandra* etc. which exist as a community. Patches of *Avicennia officinalis*, *Avicennia marina* and *Excoecaria agallocha* are also found inter-dispersed with ‘mixed mangroves’ in this RF.

Mangrove Communities of Coringa and adjoining RFs

Spectral profile analysis of digital data of IRS P6 LISS-III substantiated with extensive ground truthing resulted in classifying the mangrove vegetation of Coringa and adjoining areas into eight communities. Community classification was mainly done based on dominance of occurrence of species and crown cover density. Three species of *Avicennia*, namely, *Avicennia alba*, *Avicennia officinalis* and *Avicennia marina* form distinct patches in the Godavari delta region. These eight communities together account for 170.62 km² of mangrove vegetation (Table 3.1.3).

Avicennia alba – Moderately Dense

In the extreme seaward side facing Kakinada bay and frequently inundated by tidal flux lies pure patches of *Avicennia alba* with a crown density of 40-70 % (moderately dense). These patches form a distinct zone.

Avicennia marina - Moderately Dense

Adjoining to *Avicennia alba* zone and towards inside and also along the eastern coast where there is tidal influence through creeks extensive pure patches of *Avicennia marina* (moderately dense) is seen that clearly demonstrates its preference for high saline conditions.

Avicennia officinalis - Moderately Dense

Patches comprising of pure *Avicennia officinalis* trees occur throughout Coringa- Kandikuppa area though larger patches of tall trees with crown density 40-70 % are found more towards stabilized land, mainly between Matlapalem and Coringa creeks and also towards Rathikaluva, Masantippa and Kandikuppa RFs.

Excoecaria agallocha – Moderately Dense

Pure patches of *Excoecaria agallocha* (moderately dense) form the most dominant zone in the Matlapalem-Coringa area. It is also found to occur gregariously towards the landward side and in elevated areas (2.6 m and above).

Avicennia marina - Excoecaria agallocha - Moderately Dense

Patches comprising mainly of *Avicennia marina* - *Excoecaria agallocha* are found to be the most widespread community except in the southern part of Kandikuppa, where the mangroves are frequently flushed by tidal currents. *Avicennia marina* - *Excoecaria agallocha* community accounts to 64.75 km² area and 38.05 % of the total Coringa mangroves (Figure 3.1.2).

Mixed mangroves

A group of three or more true mangroves and associated species is referred here as “Mixed mangroves”. An assemblage of mangrove species comprising mainly of *Aegiceras corniculatum*, *Ceriops decandra*, *Bruguiera gymnorhiza*, *Bruguiera cylindrica*, *Lumnitzera racemosa* etc. are found along the creeks of Matlapalem and Coringa. The presence of *Lumnitzera racemosa* and *Bruguiera* sp. is indicative of freshwater influence from Matlapalem and Coringa rivers, while in the eastern part of Gaderu river, *Rhizophora* sp. mainly *Rhizophora apiculata* abundantly growing along the creeks with other mangroves indicates the species affinity for saline conditions. This area

consists of intricate network of creeks that carry tidal water from Bay of Bengal to the western part of the Sanctuary.

Table 3.1.3: Mangrove Communities of Coringa and Adjoining Reserved forests

Mangrove Communities	Area in Hectares
Mixed mangroves – Degraded	1618.73
Mixed mangroves – Sparse	1610.74
Mixed mangroves - Moderately Dense	1798.11
<i>A. marina</i> - <i>E. agallocha</i> - Moderately Dense	6475.15
<i>A. officinalis</i> - Moderately Dense	3316.72
<i>E. agallocha</i> - Moderately Dense	1067.70
<i>A. marina</i> - Moderately Dense	1029.60
<i>A. alba</i> - Moderately Dense	100.09
Total	17016.84

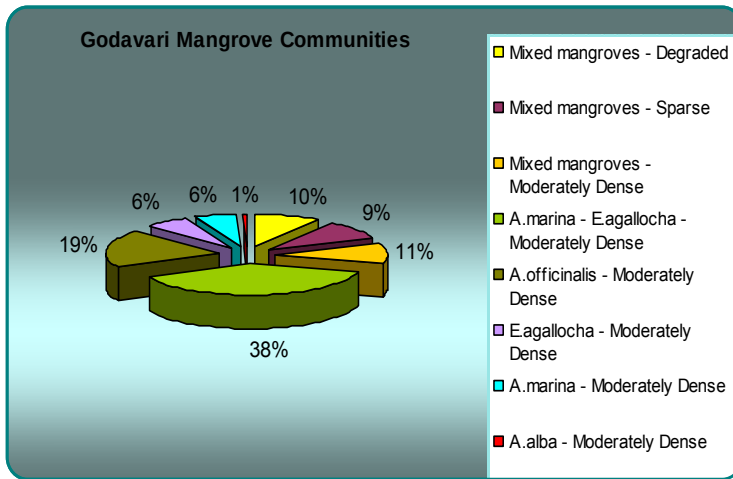


Fig. 3.1.2: Percentage-wise distribution of Godavari mangrove communities

It is noticed that “Mixed mangroves” of good crown cover are more commonly found along the water bodies. Categorizing “Mixed mangroves” based on salinity preference is though possible manually, digital discerning of these two categories is difficult. Depending on the crown density, “Mixed mangroves” is classified into three zones - Moderately dense, Sparse and Degraded. Mixed mangroves - degraded are mainly located in saline blanks and in elevated areas

towards landward side and is dominated by mangroves like *Excoecaria agallocha*, mangrove associates like *Acanthus ilicifolius* and salt marshes like *Suaeda maritima*, *Suaeda monoica*, *Salicornia brachiata* etc. In Godavari delta, Mixed mangroves – moderately dense (40-70 % crown density) accounts to 17.98 km², whereas the same community with a low crown cover of 10-40 % is about 16.11 km². Figure 3.1.3 shows a sample map of different mangrove communities in East Godavari (given at the end of the chapter). Plates 3.1.1 to 3.1.8 show Godavari mangrove vegetation. All the plates are provided at the end of the book.

Krishna mangroves

Krishna mangroves are located in the coastal plains of Krishna delta between 15°42'N-15°55'N latitude and 80°42'-81°01'E longitude spread across Krishna and Guntur districts. Krishna Wildlife Sanctuary notified in the year 1989 covers a total area of 194.81 km². It includes reserved forests of Kottapalem, Lankivanidibba, Yelichetladibba, Nachgunta, Sorlagondi, Molagunta and Adavuladivi.

Kottapalem R.F

Dominant mangrove species present are *Avicennia marina*, *Avicennia officinalis*, *Excoecaria agallocha*, *Rhizophora mucronata*, *Lumnitzera racemosa*, *Bruguiera gymnorrhiza* and *Aegiceras corniculatum*. Some areas are also covered with mangrove associates like *Acanthus ilicifolius* and marsh vegetation comprising of *Suaeda*. *Rhizophora mucronata* is dominant along the banks of the creek. Density of the mangrove vegetation varies between sparse (10-40 %) to moderate (40-70 %) and the most dominant species are *Avicennia marina*. Plantations of some mangrove species like *Avicennia marina*, *Avicennia officinalis*, *Excoecaria agallocha* and *Lumnitzera racemosa* are also present in the RF. Invasion by *Prosopis juliflora* in the mangrove area is quite common and it becomes prominent towards the sea coast.

Lankevanidibba RF

Lankevanidibba RF is located in the Guntur district. Dominant species are *Avicennia marina*, *Avicennia officinalis*, *Excoecaria agallocha*, *Bruguiera gymnorrhiza* and *Rhizophora mucronata*. Density of the mangrove vegetation in this RF is moderately dense (40-70 %) and the height of the mangrove goes

upto 6-7 ft. *Rhizophora mucronata* is more prominent along the banks of the creeks. Other vegetation, *Prosopis*, is also very common in Lankevanidibba RF.

Yelichetlidibba RF

Yelichetlidibba reserved forest of Krishna Wildlife Sanctuary comes under Guntur district. Dominant species are *Avicennia marina*, *Excoecaria agallocha*, *Bruguiera cylindrica* and *Lumnitzera racemosa*. Mangrove associate, *Acanthus ilicifolius*, is also present along with the pure mangrove species. *Rhizophora* is prominent along the banks of the creeks with a crown density cover of 10-40 % (sparse) and height varies from 3-6 ft. Most of the area is covered with degraded mangrove patches. Degraded patches are also found along the creeks. Other vegetation, *Prosopis* is very common in this reserved forest and it is more prominent towards the sea coast. Prawn-culture is also practiced in some areas of around 500 ha.

Nachgunta RF

Nachgunta Reserved forest comprises about 6,065 ha and falls in Krishna district. Dominant species are *Avicennia marina*, *Excoecaria agallocha*, *Rhizophora* and *Suaeda*. Invasion of other vegetation, *Prosopis* is very common in this RF. Between 15°47'01.86''N and 80°53'16.31''E to 15°45'42.77''N and 80°53'5.63''E only *Prosopis* sp. is encountered along with some plants of *Excoecaria agallocha* and there is no other mangrove cover. Assemblages of species like *Avicennia marina*, *Excoecaria agallocha*, *Rhizophora* sp., *Bruguiera cylindrica* are also found along the canals. Mangrove cover is mainly sparse (10-40 %) and height of the mangrove species varies between 2-5 ft. Patches of *Rhizophora mucronata* is dominant near the creeks in this RF.

Soralagondi RF

Soralagondi reserved forest comes under Krishna district. Species like *Avicennia marina*, *Avicennia officinalis*, *Excoecaria agallocha*, *Rhizophora*, *Lumnitzera racemosa* are common in this reserved forest. *Rhizophora* and *Excoecaria agallocha* occur along the creeks. Pure patches of *Avicennia marina* are also dominant in certain parts of the reserved forest with a density between 40-70 % (moderately dense), otherwise the density of the mixed

mangroves is sparse (10-40 %). Heights of the mangroves vary between 4-6 ft in some areas and in other areas it is in the range of 2-3 ft. Other vegetation, *Prosopis juliflora* is also common in the uplands and near the mouth of the river, Krishna. Degraded mangrove patches are present at around 80°58'42.87''E longitude and 15°50'24.06''N latitude.

Mangrove communities of the Krishna Wildlife Sanctuary

Four major mangrove communities viz., mixed mangroves - Degraded, Mixed mangroves - Sparse, *Avicennia marina* - Moderately dense, *Rhizophora mucronata* - Sparse (Figure 3.1.4) have been delineated based on the density and occurrence of species. Area-wise contribution of each community to the mangrove cover is given in Table 3.1.4. Plates 3.1.9 to 3.1.13 show the mangrove vegetations of the Krishna delta.

Table 3.1.4: Mangrove communities of Krishna Wildlife Sanctuary

Mangrove Communities	Area in Hectares
Mixed mangroves – Degraded	394.10
Mixed mangroves – Sparse	4171.39
<i>A. marina</i> - Moderately Dense	6301.84
<i>Rhizophora mucronata</i> - Sparse	161.80
Total	11029.13

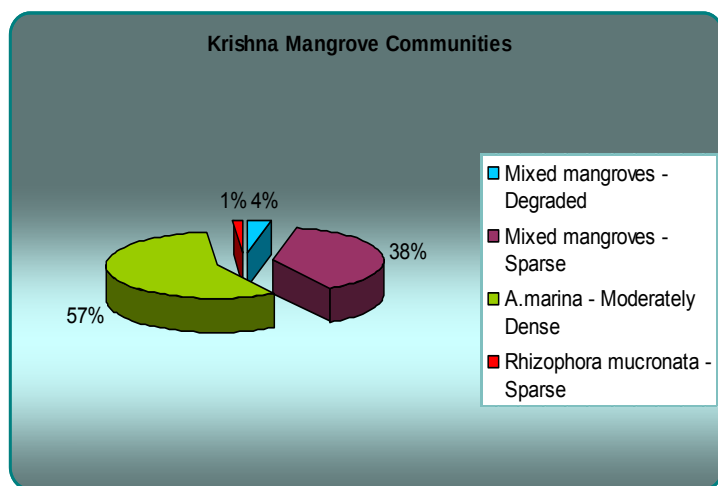


Fig. 3.1.4: Percentage-wise distribution of Krishna mangrove communities

According to the present classification, Andhra Pradesh has a mangrove cover of 351.26 km² (Table 3.1.5) contributed by 9 mangrove communities with varying crown cover densities. *Avicennia marina* - Moderately dense is found to be the most widely distributed mangrove class constituting about 82.60 km². Krishna Sanctuary, south eastern part of Coringa Sanctuary and Nizampatnam of Guntur district harbour vast expanse of pure *Avicennia marina*. Mixed mangroves – sparse ranks second with an area of 80.55 km². It is characterized by an assemblage of mangroves forming a community and is found as patches or as fringe mangroves along rivers, mainly Gaderu and its associated creeks of Coringa Sanctuary, along Krishna and in Bandar fort reserved forest in Machalipatanam, where there is optimum tidal inundation and freshwater influx. As can be inferred from Figure 3.1.5 moderately lush mangrove cover of Andhra Pradesh is mainly contributed by four communities: a. pure patches of *Avicennia* species viz., *A. marina*, *A. officinalis* and *A. alba*, b. enmesh of well grown *Excoecaria agallocha* forming almost closed canopies, c. *Avicennia marina* along with under cover of *Excoecaria agallocha*, d. ‘mixed mangrove’ community comprising of three or more true mangrove species like *Sonneratia apetala*, *Rhizophora* sp., *Avicennia* sp., *Ceriops decandra*, *Bruguiera gymnorrhiza*, *B. cylindrica*, *Lumnitzera racemosa* etc.

Table 3.1.5: Mangrove communities of Andhra Pradesh

Mangrove Communities	Area in Hectares
Mixed mangroves – Degraded	4726.27
Mixed mangroves – Sparse	8055.68
Mixed mangroves - Moderately Dense	1798.11
<i>A. marina</i> - <i>E. agallocha</i> - Moderately Dense	6475.15
<i>A. officinalis</i> - Moderately Dense	3316.72
<i>E. agallocha</i> - Moderately Dense	1067.70
<i>A. marina</i> - Moderately Dense	8260.93
<i>A. alba</i> - Moderately Dense	100.09
<i>A. marina</i> – Sparse	745.80
<i>A. marina</i> - <i>A. officinalis</i> – Sparse	170.54
<i>Acanthus ilicifolius</i> - Sparse	66.15
<i>Rhizophora mucronata</i> - Sparse	165.02

<i>A. marina</i> - Degraded	41.79
<i>A. officinalis</i> - Sparse	93.86
<i>A. marina</i> - <i>E. agallocha</i> - Sparse	42.85
Total	35126.67

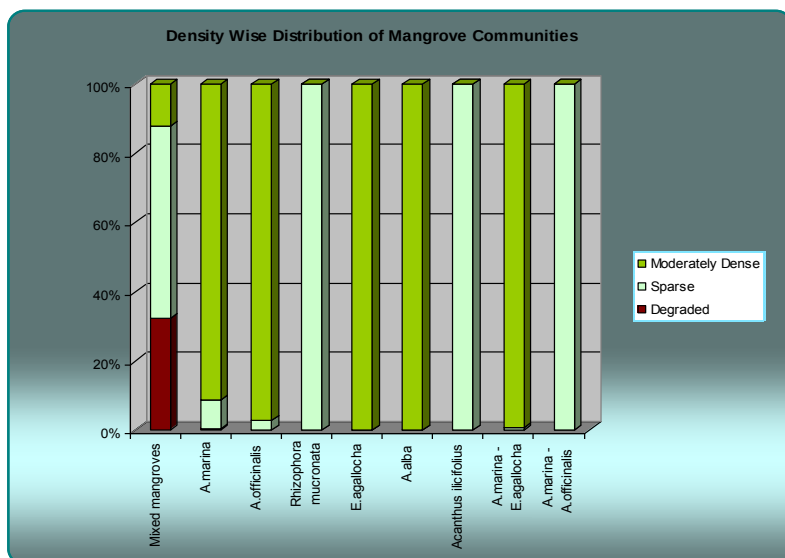


Fig. 3.1.5: Density-wise distribution of mangrove communities of Andhra Pradesh

A total area of 47.67 km² is recorded as 'degraded' based on the canopy cover density of less than 10 %, of which 47.26 km² is 'mixed mangroves' comprising mainly of widely spaced true mangroves like *Excoecaria agallocha*, *Avicennia marina* along with associates like *Acanthus ilicifolius*, *Clerodendrum inerme*, *Ipomoea pes-caprae* or marsh vegetation like *Suaeda* sp., *Salicornia* sp. etc., mangroves in degraded state mainly due to change in environmental gradients giving way to hypersalinity, plantation patches and patches of mangrove species in natural regenerative phase having crown cover less than 10 %. The remaining 0.42 km² is contributed by *Avicennia marina* patches mainly in the early stages of growth. The regeneration of mangrove patches can be considered as a positive trend in perceiving the well being of mangrove vegetation for the years to come.

Orissa

Orissa is located in the eastern part of the country, with a geographic area of 155,707 km², which constitutes 4.74 % area of the country. It lies between latitude 17°47' and 22°34' N and longitude 81°22' and 87°29' E. The forest cover of the state is 48,374 km² which is 31.07% of the geographic area of the state. Physiographically, the state can be divided into four regions, viz., Northern Plateau, Eastern Ghats, Central Tableland, and Coastal Plains. The three major rivers of the state are Mahanadi, Brahmani, and Baitarni.

Orissa has an average climate, except in western districts like Balangir, Sambalpur and Sundergarh. The average annual rainfall ranges between 1200 – 1600 mm. Average annual temperature ranges from 25°C – 27°C.

Mangroves of the Orissa coast is mainly tide dominated. Dominant features are high tidal range with strong bi-directional current, main river channels are funnel shaped with extensive tidal flats dominated by mangroves. The total length of the coast line in Orissa is about 430 km and this coastline is mainly in the depositional stages, with the sediments carried down by the rivers, Mahanadi and other two minor rivers, i.e., the Brahmani and the Baitarani. All these rivers form deltas in the Orissa coast viz., Bhitarkanika located between the latitude 19°N and 22°N and longitude between 85°E and 87°30'E. Most of the mangrove areas are legal forests in Orissa.

Bhitarkanika is the third important mangrove habitat among the Indian mangals with respect to mangrove species diversity. Important mangrove and mangrove associate species of the Mahanadi-Brahmani-Baitarani deltas are *Avicennia alba*, *A. officinalis*, *Aegiceras corniculatum*, *Aegialitis rotundifolia*, *Acrostichum aureum*, *Bruguiera parviflora*, *B. gymnorrhiza*, *B. cylindrica*, *Ceriops decandra*, *Excoecaria agallocha*, *Heritiera kanikensis* (rare & endemic), *Heritiera fomes*, *Kandelia candel*, *Phoenix paludosa*, *Porteresia coarctata*, *Sonneratia apetala*, *Rhizophora mucronata*, *R. apiculata*, and *Salvadora persica*. Bhitarkanika is the important natural breeding place of estuarine crocodiles (*Crocodilus porosus*) and several species of threatened sea turtles, *Lepidochelys olivacea*, batagur baska and the king crab, *Carcinosepius rotundicanda* and *Tachypleus gigas*. The endangered species

of dolphins, viz., *Platinista gangetica*, *Neomeris phocaenoides*, and *Sotalia plumba* are also reported in the Mahanadi estuary (Anonymous, 1992). Haines (1921) categorized the mangrove forests viz., “tree cover forests” and “littoral scrub fringe and open forest”.

Mahanadi Mangrove Wetland

The river Mahanadi is the largest river in Orissa. The Mahanadi Mangrove Wetland is located in the district of Kendrapara, in the mid-region of the Orissa coast, 250 km south of Sunderbans mangroves. The presence of innumerable meandering creeks, channels, islets with regular flushing by tidal waters and discharge of large quantities of freshwater for longer periods of time create suitable niches for the development of luxuriant mangroves in the Mahanadi mouth region. The Mahanadi Mangrove Wetland consists of eight forest blocks, namely, Kantilo, Kendrapatia, Jambu, Bhitar Kharnasi, Bahar Kharnasi, Kansardia, Hatamundia and Hukitola.

Kantilo Forest Block

In this forest block *Ceriops decandra*, *Avicennia marina*, *Kandelia candel* and *Rhizophora apiculata* are present ranging from low to medium density. The dominant species towards the creek is *Avicennia marina* and *Rhizophora apiculata* towards landside.

Kendrapatia Forest Block

In the north block of Kendrapatia forest, *Avicennia alba* is dominant. *Avicennia officinalis*, *Ceriops decandra*, *Aegialitis rotundifolia* and *Aegiceras corniculatum* are also present in large numbers.

Jambu Forest Block

This forest block is highly degraded. *Avicennia officinalis*, *A. marina*, *Sonneratia apetala*, *Excoecaria agallocha* and *Ceriops decandra* are present, but the density varies with places.

Bhitar Karnasi Forest Block

In this forest block *Avicennia officinalis* is the dominant species. *Avicennia marina*, *Ceriops decandra*, *Sonneratia apetala*, *A. alba*, *Heritiera fomes* and *Excoecaria agallocha* are also present in abundance.

Bahar Kharnasi Forest Block

In this forest block *Avicennia marina* is the most dominant species occurring in association with *Avicennia alba*, *A. officinalis*, *Sonneratia apetala* and *Excoecaria agallocha*. Other mangrove species like *Bruguiera cylindrica* and *Kandelia candel* are present but few in numbers.

Kansardia Forest Block

In this forest block *Rhizophora apiculata*, *R. mucronata*, *Avicennia alba*, *A. officinalis*, *Excoecaria agallocha*, *Aegialitis rotundifolia*, *Ceriops decandra*, *Aegiceras corniculatum* and *Lumnitzera racemosa* are present in large numbers. Though this forest block exhibits rich species diversity, it is in a degraded state due to prawn culture and over exploitation.

Hatamundia Forest Block

The abundantly present species in this forest block are *Avicennia marina*, *Rhizophora apiculata*, *R. mucronata*, *Ceriops decandra*, *Avicennia officinalis*, *Avicennia alba* and *Aegialitis rotundifolia*. Other commonly found mangrove species are *Aegiceras corniculatum*, *Bruguiera cylindrica* and *Xylocarpus granatum*. In this block the mangrove forest is facing heavy degradation because of over-exploitation and prawn culture.

Hukitola Forest Block

This forest block exhibits both mangroves and non-littoral vegetation. In the areas under tidal influence, mangroves and their associates dominate. The dominant mangrove species in this forest block are *Avicennia marina*, *Excoecaria agallocha*, *Sonneratia apetala*, *Avicennia officinalis*, *Ceriops decandra* and *Lumnitzera racemosa*. In the point bar, situated southwest of Hukitola, *Sonneratia alba*, *Avicennia marina* and *A. officinalis* exist mostly in stunted form.

Bhitarkanika Wildlife Sanctuary

Bhitarkanika Wildlife Sanctuary is located on the east coast of India between the latitudes 20° 30' - 20° 50' N and the longitudes 86° 45' – 87° 10' E and lies in the northeast of the Mahanadi delta in Kendrapara district. Here the mangrove vegetation is very thick and difficult to penetrate. The Kendrapara district has around 90 % and the Bhadrak district has 10 % of the mangrove vegetation

cover. The entire forest is managed by the Mangrove Forest Division, Rajnagar under the control of Chief Wildlife Warden, State Forest Department, Orissa. Bhitarkanika Wildlife Sanctuary is divided in six reserved forests.

Dhamara RF

This area is present in the south of Bhadrak district, having low density and degraded mangroves. The mangrove and mangrove associate species present here are *Avicennia marina*, *A. officinalis*, *Excoecaria agallocha*, *Phoenix paludosa*, *Acanthus ilicifolius*, *Hibiscus tiliaceus*, *Suaeda maritima*, *Thespesia populnea* and *Tamarix ericoides*.

Kalibhanjdia RF

This 8 km² area island is in the middle of Dhamra river supporting the flourishing dense mangroves. This is the longest island in the Bhitarkanika National Park with the highest mangrove genetic diversity. The mangrove species present in this island are *Avicennia officinalis*, *Avicennia marina*, *Sonneratia apetala*, *Heritiera fomes*, *Ceriops decandra*, *Excoecaria agallocha* and *Rhizophora mucronata*.

Bhitarkanika RF

This area has a large network of creeks provided by the Bhitarkanika ‘nadi’ which is a tributary of Maipura river. Here the large patches of less saline tolerant species like *Excoecaria agallocha*, *Heritiera fomes* and *Ceriops decandra* can be found. Other mangrove species like *Avicennia marina*, *Lumnitzera racemosa*, *Tamarix troupis* and *Acanthus ilicifolius* are also present. *Heritiera fomes* is the dominant species of this area with very high density.

Katikhaal RF

This reserved forest is at the mouth of the opening of Maipura river in the Bay of Bengal. In this area the mangrove species present on the coastal side are less dense and the density increases towards landside. The common mangrove species present in this reserved forest are *Avicennia marina*, *A. alba*, *Xylocarpus granatum*, *Sonneratia alba*, *S. apetala*, *Lumnitzera racemosa* and *Ceriops decandra*.

Sunirupi RF

This area is present in the southeastern part of Bhitarkanika Reserved Forest and has Gahirmatha beach on its eastern side which is one of the world's largest Olive Ridley Turtle rookeries. This forest area consisting of Thakurdia and Kakarnasi blocks has high saline tolerant mangrove species such as *Avicennia marina*, *Aegialitis rotundifolia*, *Aegiceras corniculatum* and *Sonneratia caseolaris*. Other mangrove species like *Tamarix troupii*, *Excoecaria agallocha* etc. are also present. In the southern part of this Forest area *Phoenix paludosa* is the Dominant species.

Kantika RF

This forest has a very small area and mangrove species found here have sparse to moderate density. The common species present in this area are *Avicennia marina*, *A. alba*, *Excoecaria agallocha*, *Sonneratia apetala*, *Phoenix paludosa*, *Xylocarpus granatum* and *Acanthus ilicifolius*.

Devi Mouth Mangrove Wetland

Devi river is a distributary of Mahanadi river separating from it near Cuttack. This mangrove wetland is located at the southernmost part of the Mahanadi delta in the district of Jagatsinghpur. It lies between 20° 05' and 20° 10' N latitude and between 86° 15' and 86° 25' E longitude. The mangrove vegetation is luxuriant near the estuaries of the Devi river and in the protected forest along the creeks of Boruan 'nadi'. The Devi mouth mangrove comes under Kujang range of Rajnagar Division. There are three forest areas that are termed as "Protected Forest". A large mangrove area is found in the Bandar forest belt which is termed as "undermarked mangrove forest" because of a dispute over the ownership of this forested area between the Revenue Department and the Forest Department. The Devi Mouth Mangrove Wetland is divided into three forest blocks.

Salio Forest Block

In this forest block along the Bitikola riverbank, the dominant species is *Phoenix paludosa* in association with *Myriostachya wightiana* and *Acanthus ilicifolius*. Other mangrove species present here are *Avicennia alba*, *Avicennia officinalis*, *Aegiceras corniculatum*, *Derris trifoliata*, *Excoecaria agallocha*

and *Ceriops decandra*. In the mud-flats *Fimbristylis ferruginea* and *Suaeda maritima* are common.

Boruan Forest Block

In this forest block the dominant species are *Phoenix paludosa*, *Avicennia alba* and *Excoecaria agallocha*. Other mangrove species present in this forest block are *Ceriops decandra*, *Avicennia officinalis*, *Aegialitis rotundifolia*, *Bruguiera gymnorrhiza* and *Acanthus ilicifolius*, which are sporadically distributed. In this block the mangrove forests are highly degraded due to biotic interference of high magnitude.

Bandar Forest Block

In this forest block the mangrove forest is mainly in degraded or sparsely dense condition. The common mangrove and associate species of this forest block are *Rhizophora* species, *Avicennia* species, *Sonneratia apetala*, *Aegiceras corniculatum*, *Ceriops decandra*, *Excoecaria agallocha*, *Bruguiera gymnorrhiza*, *Myriostachya wightiana*, *Fimbristylis ferruginea*, *Porteresia coarctata* and *Acanthus ilicifolius*.

Subarnrekha Mangrove Wetland

This mangrove wetland is present in the Baleshwar district of Orissa, lying next to Medinipur district of West Bengal. The opening of Subarnrekha river into Bay of Bengal provides the estuarine habitat necessary for the flourishing mangroves. It lies between 21° 33' to 21° 43' N latitude and between 87° 18' to 87° 28' E longitude. The mangrove forest is luxuriant in Vichitrapur P.R.F. only which is under the supervision of DFO, Baleshwar. In other areas mangrove vegetation is either sparsely dense or is in degraded condition.

Vichitrapur Protected Reserved Forest (P.R.F)

The moderately dense mangrove species are present in the areas of Muralidandi, Subarnpurdandi and Narayanmohantiparia. At these places mixed mangroves consisting of the different mangrove species like *Sonneratia apetala*, *Avicennia officinalis*, *A. marina*, *Aegiceras corniculatum*, *Aegialitis rotundifolia*, *Bruguiera parviflora*, *B. gymnorrhiza*, *Rhizophora apiculata*, *Ceriops decandra* and *Xylocarpus granatum* are present. Other mangrove species like *Excoecaria agallocha* and *Acanthus ilicifolius* also exist, but in

sparsely dense or degraded condition. Degradation of mangrove vegetation because of sand deposition and human interference for wood collection and fodder can be easily seen on the coastal side in Chandrabali.

The whole state of Orissa is divided into 36 mangrove communities (Table 3.1.7). The three species of *Avicennia* viz, *A. officinalis*, *A. marina* and *A. alba* dominate in majority of the mangrove forest areas. Among these three species, *A. marina* is found to be covering the largest area in pure patches (3144.21 ha), followed by *A. alba* and lastly by *A. officinalis*.

Avicennia marina - Moderately Dense

Pure patches of moderately dense *A. marina* (40-70 %) are dominating the scenes all along the coastal side of Baleshwar and Bhadrak district, majority of the areas in Udabali island and in parts of the Bhitarkanika National Park, where the tidal influence is high because of the network of large number of creeks. The presence of this species near to the coast clearly demonstrates its affinity to saline conditions.

Avicennia Alba – Moderately Dense

Moderately dense patches of pure *Avicennia Alba* is dominant on the seaward side facing Bay of Bengal all along the coast of Baleshwar and Bhadrak districts and the coastal areas of Jambu, Kendrapatia and Hetamundia Forest blocks in Kendrapara district. Hypersalinity is a favorable condition for the growth of this species, which is quite evident from its occurrence along the open sea.

Avicennia officinalis - Moderately Dense

Moderately dense pure patches of *Avicennia officinalis* are found only in Vichitrapur P.R.F in Bhadrak district and that too in small areas. These patches are less common along the creek rather they are found more often on the stabilized lands.

Excoecaria agallocha – Moderately Dense

Pure patches of moderately dense *Excoecaria agallocha* are present only at few places like near the embankment in Jambu forest block and in the interior part of Bhitara Kharnasi forest block.

Phoenix paludosa – Moderately Dense

Moderately dense pure patches of *Phoenix paludosa* are found in majority of the areas of Sunirupi RF in Bhitarkanika National Park and Salio and Boruan Forest Blocks in Devi mouth mangrove wetland. These patches are present generally in the upland areas where there is lack of regular inundation, but are flushed thoroughly during one or the other season.

Sonneratia apetala – Moderately Dense

Moderately dense pure patches of *Sonneratia apetala* are common in the Kalibhanj Dian and its constituent islands, and some very small patches are present in Vichitrapur P.R.F in Bhadrak district.

Heritiera fomes – Very Dense and Moderately Dense

Heritiera fomes is a characteristic mangrove species of Bhitarkanika National Park and is present in very dense pure patches (more than 70% crown density) in Dangmal and Bhitarkanika Forest Blocks of the National Park. Moderately dense pure patches of *H. fomes* are present on the peripheral sides of the very dense patches in the same areas and in the interior parts of Kalibhanjdia Forest Block. The presence of *H. fomes* mainly in the inward regions, away from the Bay of Bengal clearly depicts its affinity for less saline conditions.

Avicennia marina - Avicennia alba - Moderately Dense

Moderately dense patches of *Avicennia marina - Avicennia alba* are present in between the pure patches of *A. marina* and *A. alba* along the coast throughout Bhadrak and Baleshwar district and it also covers a large area in the Udabali island.

Avicennia marina - Avicennia officinalis - Moderately Dense

Moderately dense patches of *Avicennia marina - Avicennia officinalis* are present in almost all the Forest Blocks of Mahanadi Mangrove Wetland, but their occurrence is restricted to this wetland only in Orissa.

Avicennia officinalis – Excoecaria agallocha - Moderately Dense

This community is present only in Vichitrapur P.R.F in Bhadrak district and covers substantial areas in the highly stabilized uplands.

Lumnitzera racemosa – Ceriops decandra - Moderately Dense

Moderately dense patches of this community are present in all the Forest Blocks of Bhitarkanika National Park, except Kalibhanjdia Forest Block. Small patches of this community cover significant areas in Bagulidea Forest Block, Dangmal Forest Block, Sunirupi Protected Forest (PF), and Habalikhathi PF.

Tamarix troupii - Excoecaria agallocha – Moderately Dense

Large areas of mangrove forest are covered by moderately dense patches of this community in Sunirupi Protected Forest in Bhitarkanika National Park. Small patches of this community are also present in Satbhaya Forest Block, Dangmal Forest Block, Gupti Forest Block and Bhitarkanika Forest Block. Some small patches are also present in between Talchua point and Maipura river mouth.

Rhizophora apiculata - Avicennia officinalis - Moderately Dense

This community is predominantly present along the creeks and at some places in the inward side in Hatamundia Forest Block, Kansardia Forest Block, Hukitola Forest Block and Kharnasi Forest Block in Mahanadi Mangrove Wetland.

Xylocarpus granatum - Avicennia marina - Moderately Dense

Moderately dense patches of *Xylocarpus granatum* – *Avicennia marina* are present in the middle region of the mangrove forest between Talchua point and Maipura river mouth, at some places in Mahakuladia island and in the Habalikhathi PF.

Avicennia marina - Avicennia officinalis - Sonneratia apetala - Moderately dense

This community is constituted by three species and is named as per their dominance of occurrence in the patch. Thus, it can be clearly made out that *Avicennia marina* covers the maximum area whereas *Sonneratia apetala* is covering the least area in the patch formed by their association. This community is present in majority of the areas of Bhitarkanika National Park and in almost all the Forest Blocks of Mahanadi Mangrove Wetland.

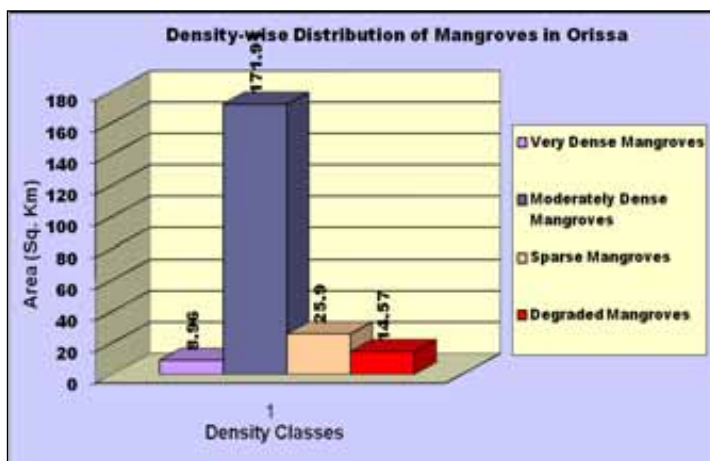


Fig. 3.1.6: Density-wise distribution of mangroves in Orissa

Mixed mangroves

An assemblage of mangrove species comprising mainly of *Avicennia marina*, *Aegiceras corniculatum*, *Aegialitis rotundifolia*, *Sonneratia alba*, *Xylocarpus granatum* and *Excoecaria agallocha* are found along the creeks (which are frequently inundated by saline water from Bay of Bengal) in parts of Kendrapatia, Kansardia and Hatamundia Forest Blocks in Mahanadi Mangrove Wetland. The occurrence of these species along the creeks clearly shows their affinity for saline conditions. “Mixed mangroves” is classified into three zones – Moderately dense, Sparse and Degraded. Mixed mangroves – degraded are mainly located in saline blanks and in elevated areas towards landward side where there is much human interference and is dominated by salt marsh plants like *Suaeda maritima*, *Suaeda nudiflora*, *Salicornia brachiata*, mangroves like *Excoecaria agallocha* and mangrove associates like *Acanthus ilicifolius* in few places.

Area of moderately dense mangroves is highest (Figure 3.1.6). On the basis of Figure 3.1.7 it can be easily depicted that some mangrove communities in Orissa are found only in moderately dense condition, like *A. officinalis*, *L. racemosa*, *S. apetala*, *A. officinalis* – *A. alba*, *A. marina* – *A. officinalis*, *A. officinalis* – *E. agallocha*, *T. troupii* – *E. agallocha*, *X. granatum* – *A. marina*, *A. marina* – *A. officinalis* – *S. apetala* etc. This shows that these communities are present from longer period of time and are not facing much biotic or abiotic interference. On the other hand community like *E. agallocha* – *S. maritima* is

present only in degraded condition. This community is found only in degraded condition because of its occurrence in the upland areas, which is easily accessible to cattle for grazing and also faces much human interference. *A. marina* - *A. alba* and mixed mangrove are the only two communities which are present in three different density classes, viz. moderately dense, sparse and degraded. The degraded patches of *A. marina* - *A. alba* are not actually facing any degradation problem, but these are the patches generally having the constituent species in the early stages of their growth. *Heritiera fomes* is the only species which is present both in moderately dense and very dense conditions in Bhitarkanika National Park.

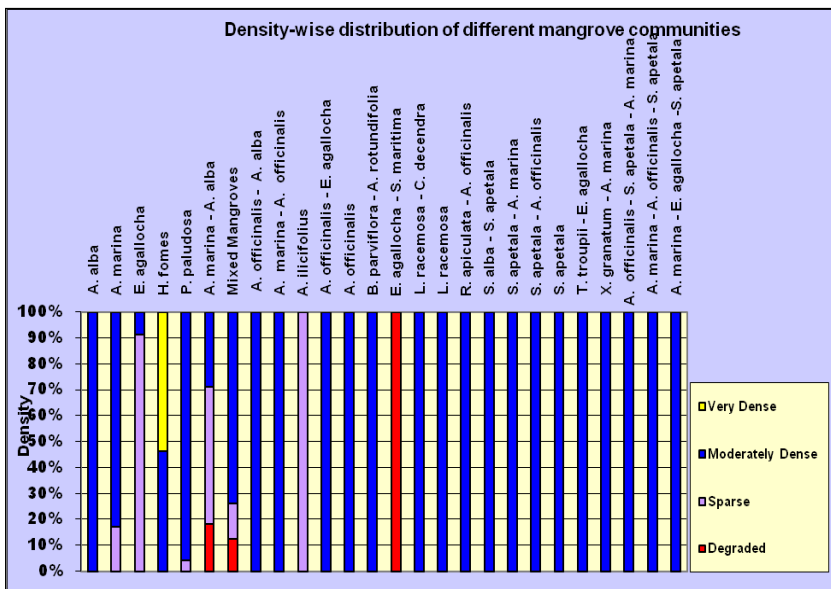


Fig. 3.1.7: Density-wise area statistics of Orissa

According to the present classification, the state of Orissa has a mangrove cover of 221.06 km² contributed by 36 mangrove communities. 'Mixed mangroves – Moderately dense' is found to be the most widely distributed community accounting to about 4288.20 ha. *Avicennia marina* - Moderately Dense ranks second in area statistics (3144.21 ha) as pure patches of this species cover vast areas along the coast in Bhadrak and Baleshwar district, majority of mangrove cover in Udabali island and most of the parts in Mahanadi Mangrove Wetland. A total area of 1458.62 ha is recorded as

‘degraded’ based on the canopy cover density (less than 10%) of which 663.84 ha is contributed by ‘mixed mangroves’ and the rest is accounted by *Excoecaria agallocha* – *Suaeda maritima* (532.32 ha) and *Avicennia marina* – *Avicennia alba* patches (262.46 ha) which are mainly in the early stages of growth (Table 3.1.6). Figures 3.1.8 - 3.1.10 show sample maps of different mangrove communities in the Bhadrak and Kendrapara districts (given at the end of the chapter). Plates 3.1.14 to 3.1.28 (given at the end of the book) show mangrove vegetations of Orissa.

Table 3.1.6: Mangrove communities of Orissa

Mangrove Communities	Area in Hectares
<i>A. officinalis</i> - Moderately dense	1.4688
<i>A. marina</i> - Moderately dense	3144.2112
<i>A. marina</i> - Sparse	635.7744
<i>A. alba</i> - Moderately dense	1045.2096
<i>A. alba</i> - Sparse	7.6608
<i>H. fomes</i> - Moderately dense	548.5248
<i>E. agallocha</i> – Moderately dense	13.4208
<i>E. agallocha</i> - Sparse	78.912
<i>P. paludosa</i> - Moderately dense	1300.8528
<i>P. paludosa</i> - Sparse	54.7056
<i>S. apetala</i> - Moderately dense	104.6016
<i>L. racemosa</i> - Moderately dense	5.0112
<i>A. ilicifolius</i> - Sparse	140.976
<i>A. marina</i> – <i>A. alba</i> - Moderately dense	417.9312
<i>A. marina</i> – <i>A. alba</i> - Sparse	797.6736
<i>A. marina</i> – <i>A. alba</i> - Degraded	262.4688
<i>A. marina</i> – <i>A. officinalis</i> - Moderately dense	472.0896
<i>A. officinalis</i> – <i>A. alba</i> - Moderately dense	85.1328
<i>A. officinalis</i> – <i>E. agallocha</i> - Moderately dense	64.8288
<i>S. apetala</i> – <i>A. marina</i> - Moderately dense	436.3632
<i>S. apetala</i> – <i>A. officinalis</i> - Moderately dense	42.4656
<i>S. alba</i> – <i>S. apetala</i> - Moderately dense	92.1312
<i>L. racemosa</i> – <i>C. decendra</i> - Moderately dense	559.8
<i>T. troupii</i> – <i>E. agallocha</i> - Moderately dense	780.6096
<i>R. apiculata</i> – <i>A. officinalis</i> - Moderately dense	1103.4864
<i>B. parviflora</i> – <i>A. rotundifolia</i> - Moderately dense	99.2448

<i>X. granatum</i> – <i>A. marina</i> - Moderately dense	168.8544
<i>E. agallocha</i> – <i>S. maritima</i> - Degraded	532.3248
<i>A. marina</i> – <i>A. officinalis</i> – <i>S. apetala</i> - Moderately dense	2119.6512
<i>A. officinalis</i> – <i>S. apetala</i> – <i>A. marina</i> - Moderately dense	225.3024
<i>A. marina</i> – <i>E. agallocha</i> – <i>S. apetala</i> - Moderately dense	37.0512
Mixed Mangroves - Moderately dense	4288.2048
Mixed Mangroves - Sparse	879.048
Mixed Mangroves - Degraded	663.84
<i>H. fomes</i> - Very dense	896.904
Total	22106.74

Puducherry

Puducherry is a Union Territory having a geographic area of 480 km². It is scattered over four locations, each having the status of a district: Puducherry (Tamil Nadu), Karaikal (Tamil Nadu), Yanam (Andhra Pradesh) and Mahe (Kerala). The main territory of Puducherry lies on the east coast, about 180 km south of Chennai. Karaikal is about 150 km south of Puducherry on the east coast, Mahe on the Malabar coast on the Western Ghats, and Yanam on the east coast adjoining Godavari district. Physiography is almost plain and climate is tropical. Puducherry and its surrounding enclaves lie on the drainage basin of the Gingee river. Karaikal, located in the fertile Cauvery delta is fed by the waters of the Arasalar, the Natter, the Vanjiar and the Nulur rivers. The Mahe river forms the northern boundary of Mahe town. The Gorinagar river flows through the town of Yanam.

Puducherry is the Capital of this Union Territory. Puducherry lies on the Coromandal coast between 11° 46' and 12° 30' N latitude and between 79° 36' and 79 ° 52' E longitude.

Karaikal lies on the east coast about 150 km south of Puducherry and 300 km south of Chennai located on the Coromandel Coast of the Bay of Bengal. Karaikal Region is situated in more or less a flat land. This region lies in the Cauvery delta and the main soil types in this region are red ferrallitic, black clay and coastal alluvial.

Mahe is situated on the west coast in Kerala, on the Malabar coast of the Arabian Sea. Mahe is bounded on the southwest by the Arabian sea, on the north by river Ponniyar (Moolakadavu) and on the other sides by a stretch of calcareous hills of medium height, which are linked to the Ghats by a series of wooded hillocks. Mahe and Ponniyar are the main rivers of this region. The river Mahe forms the northern boundary of Mahe town separating it from the enclaves of Kallayi and Naluthara on the north. Geographic location is 11° 42' to 11° 43' N latitude and 75° 31' to 75° 33' E longitude.

Yanam situated on the east coast and falls in the state of Andhra Pradesh and is about 162 km south of Chennai located on the Coromandel coast of the Bay of Bengal. It is built on a place where the river Coringa and the Godavari meet and is bounded on the east and the south by these rivers. The Godavari discharges into sea 9 miles south of Yanam town. Total area of the region is 30 km². The soil is alluvial type. The climate is tropical in nature with hot summers and moderate winters. The months of April to June are the summer months with the temperature ranging from a minimum of 27°C to 45°C. The temperature during winter months ranges from 28°C to 17°C. The average humidity ranges from 68 % to 80 % during summer season. The annual rainfall in the region is contributed by the south west monsoons.

District Yanam in Puducherry has patches of mangroves of the open category. The mangrove species found in this area is *Bruguiera cylindrica*, *Rhizophora apiculata*, *Avicennia marina* and *Acanthus ilicifolius*. Associate flora like *Suaeda maritima* and *Sesuvium portulacastrum* are also found. Puducherry and Karaikal districts have mainly patches of *Avicennia marina* from moderately dense to degraded condition, but at some places mangrove species like *Rhizophora apiculata*, *Excoecaria agallocha* and associates like *Thespesia populnea* are also present. In the Mahe river area, only some *Rhizophora mucronata* is present. The plantation of *R. mucronata* and *Aegialitis rotundifolia* along the bank of the river, done by Agricultural department was a failure; therefore in Mahe the area covered by mangroves is insignificant.

Mangrove communities of Puducherry

The mangrove forest of Puducherry is classified into eight communities. *Avicennia marina* and *Avicennia officinalis* species are the prominent

constituents of the different communities in majority of mangrove forests in Puducherry.

Avicennia marina - Moderately Dense

This community is found in some areas in Yanam but dominates the mangrove forests in Puducherry and Karaikal. A small pure patch of moderately dense *Avicennia marina* is present at the extreme northern part of Yanam district in the west of Gaderu channel. On the other hand, a very big patch of the same community is present in the backwater area at Thengaithettu-Puducherry.

Avicennia marina - Sparse

Small patches of sparsely dense pure *Avicennia marina* are present only in the Puducherry and Karaikal districts at the places namely, Huppalam (old port area) in Puducherry district and near Arsalar river at Vikram Sarabhai Road in Karaikal district.

Avicennia officinalis - Moderately Dense

Small patches of pure *Avicennia officinalis* in moderately dense condition are present mainly in Yanam district near to Gaderu channel area. These patches are facing threats of degradation because of the construction of a refinery in the nearby area.

Excoecaria agallocha - Moderately Dense

Pure patch of moderately dense *Excoecaria agallocha* is present only in Karaikal district at a place commonly known as Pilaithirunasal. This patch is a three kilometre long stretch along the Nula river.

Avicennia marina – *Excoecaria agallocha* -Moderately Dense

This community is present only at the eastern most part of Yanam district near to the Gaderu river.

Mixed mangroves

An assemblage of mangrove species comprising mainly of *A. marina*, *Avicennia officinalis*, *Buguiera cylindrica*, *Rhizophora apiculata*, *Excoecaria agallocha* and *Acanthus ilicifolius* are commonly found in Yanam district mostly in degraded and sparse conditions. On the other hand, species like *A.*

marina, *R. apiculata*, *E. agallocha*, *A. ilicifolius* and *T. populnea* constitute the degraded mixed mangroves community in most of the areas in Puducherry and Karaikal districts.

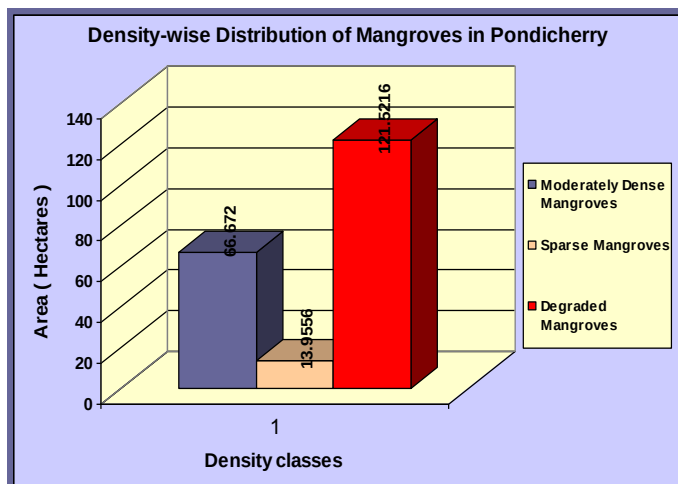


Fig. 3.1.11: Density-wise area statistics of Puducherry

According to the present classification, the Puducherry UT has a mangrove cover of 1.69 km² (Table 3.1.7) contributed by eight mangrove communities. Degraded mangroves represent the highest area (Figure 3.1.11) of Puducherry. Moreover, ‘Mixed mangroves – Degraded’ is found to be the most widely distributed community accounting to about 123.31 ha. *Avicennia marina* - *Excoecaria agallocha* - Moderately dense (17.25 ha) ranks second in area statistics followed by *Avicennia marina* – Moderately dense (12.17 ha). Figure 3.1.12 shows sample map of different mangrove communities in Puducherry (given at the end of the chapter). Plates 3.1.29 to 3.1.32 show mangrove vegetations of Puducherry.

Table 3.1.7: Mangrove communities of Puducherry

Mangrove Communities	Area in Hectares
Mixed mangroves – Degraded	123.31
Mixed mangroves – Sparse	3.80
Mixed mangroves - Moderately Dense	1.28
<i>A. marina</i> – Sparse	1.67
<i>A. marina</i> - Moderately Dense	12.17

<i>A. officinalis</i> - Moderately Dense	9.24
<i>E. agallocha</i> - Moderately Dense	1.07
<i>A. marina</i> - <i>E. agallocha</i> - Moderately Dense	17.25
Total	169.79

Goa

Goa is the smallest state of the country having a geographic area of 0.37 million ha. It lies between latitude 14°53' and 15°40' N and longitude 73°40' and 74°21' E. Mandovi and Zuari are two major rivers which are lifeline of Goa. These two rivers originate from the Western Ghats and flow towards the southern boundary to join the Arabian Sea.

The Goa territory has seven estuaries and on the intertidal zones of all these estuaries are flat lands formed with silty sand and silty clay along with abundant organic matter. Average annual rainfall ranges between 2300 mm – 4800 mm. Mean temperature varies from 25°C to 28°C. Mangroves along the coastal zones of Goa and the estuarine mouths are relatively poor in number and are subjected to severe biotic pressure.

Most of the mangroves in Goa are notified forests but some are outside the recorded forest areas.

The dominant mangrove flora of Goa comprises of *Avicennia officinalis*, *A. alba*, *Rhizophora mucronata*, *Excoecaria agallocha*, *Sonneratia alba*, *S. caseolaris*, *Kandelia candel*, *Bruguiera gymnorrhiza* and *B. cylindrica*. Less dominant mangroves include *Rhizophora apiculata*, *Aegiceras corniculatum*, *Avicennia marina*, *Ceriops tagal* etc. Mangrove associates like *Acanthus ilicifolius* and *Acrostichum aureum* are dominant throughout the estuaries. Mainly twelve species of mangroves find their home in the saline waters of Goa. The estuaries of rivers housing mangroves in Goa are Terekhol, Chapora, Mapusa, Mandvi, Zuari (North bank) in North Goa District and Sal, Talpona, Galgibag and Zuari (South bank) in South Goa District. Besides these, good mangrove cover is also present in Kumbharjua canal, which joins Mandvi and Zuari rivers. In Goa, mangroves have also come up very well in many privately owned areas, which are inundated by backwaters of sea and these areas are

termed as “Khazan Lands” in Goa. ‘Mixed mangrove’ communities consisting of *Avicennia marina*, *A. officinalis*, *Rhizophora apiculata*, *Excoecaria agallocha* and *Sonneratia alba*.

The species found in Goa includes *Rhizophora mucronata*, *R. apiculata*, *Avicennia officinalis*, *A. alba*, *Bruguiera gymnorrhiza*, *B. cylindrica*, *Kandelia candel*, *Ceriops tagal*, *Sonneratia alba*, *S. caseolaris*, *Aegiceras corniculatum*, *Excoecaria agallocha*, *Acanthus ilicifolius*, *Lumnitzera racemosa* and *Xylocarpus* spp. Almost all the species are found in all the river estuaries. *Kandelia candel*, a rare species on west coast, is found in plenty in Mandvi, Mapusa and Zuari rivers. However, *Avicennia* species are dominant in most of the places having high salinity and *Sonneratia* species is dominant in low salinity areas. Chorao island in Mandvi river is one of the best mangroves forests and houses most of the species found in Goa.

Dr Salim Ali Bird sanctuary (Chorao)

A mangrove nursery was established for the first time in Goa at Chorao in 1985. Of this, an area of 1.78 km² was declared as Bird Sanctuary and named after the renowned ornithologist, Late Dr. Salim Ali. Chorao island is 5 km from Panaji and the sanctuary is located on the west end of the island. It is accessible by ferry from Ribandar, which is on the southern bank of the river Mandovi. The sanctuary Chorao is one of the larger islands at the mouth of the river Mandovi. The whole area consists of mangrove vegetation in a criss-cross network of water channels having tidal variations. It is a suitable habitat for estuarine fishes, other marine fauna and birds. The area has naturally regenerated mangrove vegetation which is over 30 to 40 years old. The sanctuary has 14 different species of mangroves. Mangrove scrub exists along the banks of the rivers Mandovi and Mapusa. The different species observed in the sanctuary are *Rhizophora mucronata*, *R. apiculata*, *Avicennia officinalis*, *A. alba*, *A. marina*, *Bruguiera gymnorrhiza*, *B. cylindrica*, *Kandelia candel*, *Ceriops tagal*, *Sonneratia alba*, *S. caseolaris*, *Aegiceras corniculatum*, *Excoecaria agallocha* and *Acanthus ilicifolius*.

Plantation of mangroves

Plantation of different mangrove species is being taken up every year by the Forest Department in most of the river estuaries. Species used for plantation

are mainly *R. mucronata*, all species of *Avicennia*, *Bruguiera cylindrica*, *Ceriops tagal*, *Kandelia candel* and other species to a limited extent.

Mangrove communities of Goa

Mangrove forest is classified into five communities in Goa. *Avicennia*, *Sonneratia* and *Rhizophora* species along the rivers like Mapusa, Zuari and Mandovi cover the majority of area under mangrove cover. Plates 3.1.33 to 3.1.38 show mangrove vegetations of Goa.

Sonneratia alba- Avicennia officinalis – Moderately Dense

Moderately dense patches of this community are present along all the major rivers of the state viz., at Aldona, Gasvado and Kamarkajali along Mapusa river, at Danda, Adpal and Panchvadi along Zuari river and at Chorao Sanctuary along Mandovi river. Occurrence of this community at these places shows its affinity for saline conditions as these areas are regularly inundated by tidal flux from Arabian Sea. This community covers the maximum area (Figure 3.1.13).

Avicennia alba – Rhizophora mucronata – Sparse

Sparsely dense small patches of this community are present more towards the periphery of the islands and along the banks of the rivers like Mandovi, Zuari, Chapora and Terekhol.

Avicennia officinalis – Excoecaria agallocha – Sparse

Avicennia officinalis – *Excoecaria agallocha* community is also present as sparsely dense patches along all the rivers but its occurrence is found more towards the landward side rather than on the banks. This community covers a significant area under mangrove forest in the Chorao Sanctuary.

Mixed mangroves

An assemblage of mangrove species comprising mainly of *Aegiceras corniculatum*, *Ceriops decandra*, *Bruguiera gymnorrhiza*, *B. cylindrica*, *Kandelia candel*, *Derris heterophylla* is found along with the pure patches of mangrove communities mentioned above. Mixed mangroves (sparse and degraded) are mainly located in saline blanks and in elevated areas towards landward side and cover the least area (886.29 ha) (Table 3.1.8) among the five

communities. Figure 3.1.14 shows a sample map of different mangrove communities in North Goa (given at the end of the chapter).

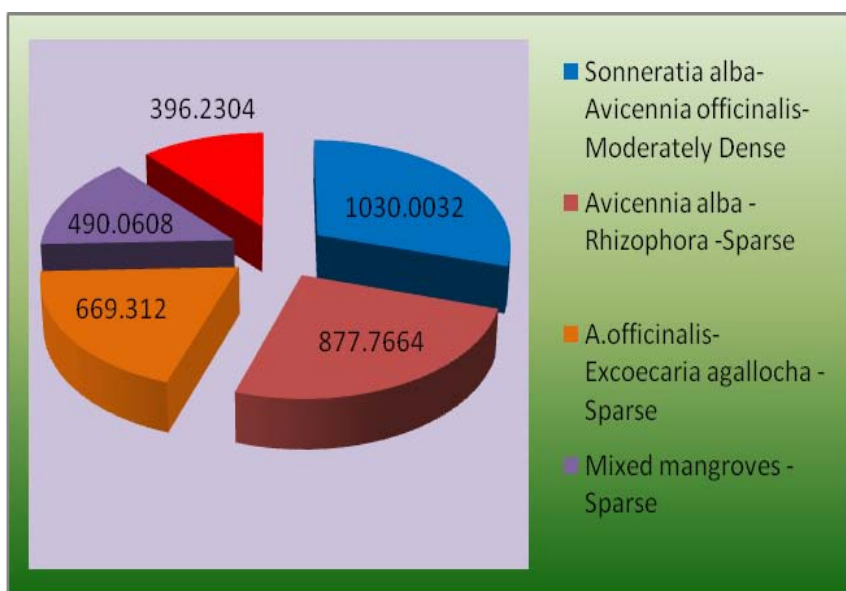


Fig. 3.1.13: Community-wise mangrove area statistics of Goa (area in ha)

Table 3.1.8: Different mangrove communities of Goa

Mangrove Communities	Area in Hectares
<i>A. officinalis</i> - <i>Excoecaria agallocha</i> – Sparse	669.312
<i>A. alba</i> – <i>R. mucronata</i> – Sparse	877.7664
<i>Sonneratia alba</i> - <i>A. officinalis</i> - Moderately Dense	1030.0032
Mixed mangroves – Sparse	490.0608
Mixed mangroves – Degraded	396.2304
Total	3463.37

Kerala

Kerala, the southern most state of the country lies between 8°17' and 12°47'N latitudes and 74°52' and 77°24' E longitude. The geographic area of the state is 38,863 km² with a forest cover of 15,595 km², which is 40.13 % of the state's geographic area. Western Ghats constitute the eastern boundary while the Arabian Sea marks the western boundary of the state. Physiographically,

Kerala is divided into highland, midland and lowland. Rainfall varies from 1016 mm to 7620 mm. Temperature ranges between 23.9°C and 37.7°C in plains and 10.0°C to 32.2°C in the hills. The soil is lateritic and generally loamy in hilly regions while in plains and valleys it is alluvial.

Kerala being a coastal state endows a coastal line of about 576 km² with many wetlands, including estuaries and backwaters. Population pressure and the subsequent infrastructure development have prompted land reclamation on a large scale in coastal areas, a main reason attributed for the dwindling of this natural resource. Agriculture, extensive aquaculture practices and in recent years tourism related activities also have contributed to its decline. Major mangrove harbouring areas in the state are in Valapattanam, Kunhimangalam, Kasargod-Nileswar, Kavvay and Puthuvypin. Mangrove areas in the state are largely under private ownership. Some plantations of mangrove have been raised.

The Kavvay estuary is one of the major estuaries in northern Kerala. The Kunhimangalam river joins the estuary from the north eastern side of the area. Areas surrounding Kavvay estuary as well as Kunhimangalam river support mangrove vegetation. Mangrove species include mainly *Avicennia officinalis*, *A. marina*, *Excoecaria agallocha*, *Bruguiera cylindrical* and *Acanthus ilicifolius*.

Comparatively, the Valapattanam estuary, located in the south western part adjoining Valapattanam river area has an extensive patch of mangroves. Around 12 species of mangroves and mangroves associates have been identified. Common species are *Avicennia officinalis*, *A. marina*, *Rhizophora mucronata*, *R. apiculata*, *Sonneratia caseolaris*, *S. alba*, *Aegiceras corniculatum* and *Excoecaria agallocha*. Among these, *A. corniculatum* shows prominence, followed by *Avicennia* species.

Chetwai is an estuarine backwater complex of Kerala, which is situated in Orumanayur 'Grama Panchayat' of Thrissur district. This estuary is situated in the latitude 10° 32' N and longitude 76° 02' E. Mangroves are present mainly in two islands lying side by side. The mangrove flora includes species like *Avicennia*, *Bruguiera*, *Rhizophora*, *Acanthus ilicifolius* etc. Most of the once

vegetated islands have now been converted into coconut groves and tourist resorts.

From north to south, the mangrove forests of Kerala can be divided district-wise viz., Kannur, Kozhikode, Ernakulam and Allepey.

Kannur

This is the northern most district of Kerala state and exhibits luxuriant mangrove forests which cover almost 80 % of the total mangrove forests of the state. This district can be divided in four forest ranges, namely, Kasargod, Taliparamba, Kottiyur and Kanhangad.

Kasargod range

In this range 13.4 ha mangrove plantation is present in the backwaters near to the forest range office itself. The plantation was done in the year 2003 and the species planted are mainly *Rhizophora apiculata* and *Kandelia candel*. Another moderately dense patch of mangrove forest is present near NH-17, just 15 km before Mangalore. This area exhibits different species like *Avicennia officinalis*, *Avicennia marina*, *Kandelia candel*, *Excoecaria agallocha* and *Rhizophora apiculata* in an area of 56.6 ha.

Taliparamba range

In this range flourishing mangrove forests can be seen all along the Pattuvam and Pariyangadi rivers. In the Pattuvam river area pure patches of *Rhizophora apiculata* along the creek and dominant *Avicennia marina* on the inner side are present. In the same area community of *Sonneratia alba*, *Avicennia officinalis*, *Avicennia marina*, *Rhizophora apiculata*, *Myriostachya wightiana* and *Kandelia candel* are also present with 40 to 70 % density. In the Dahlil and Cherukunu village areas a 6 km long stretch of mixed mangroves (*Avicennia officinalis*, *Avicennia marina*, *Rhizophora apiculata*, *Bruguiera parviflora*, *Acanthus ilicifolius* and *Excoecaria agallocha*) is present along the Pariyangadi river.

Kottiyur range

In this range moderately dense mangrove is present at a place known as Koduvelli. The mangrove species present in this area are *Avicennia officinalis*,

Avicennia marina, *Sonneratia alba* and *Rhizophora apiculata* ranging from 40-70 % density.

Kanhangad range

In this range the mangrove forest is present at few areas, namely, Eadaillakad, Madakkal and Thalankara. The mangrove species present are *Avicennia officinalis*, *Avicennia marina*, *Rhizophora apiculata* and *Acanthus ilicifolius* ranging from 10-70 % density.

The majority of the mangrove forests of Kannur division lie in the Vallapatnam bridge area where the mangroves are present in a vast area in very good condition. The species present in the area are mainly *Avicennia officinalis* and *Rhizophora apiculata* with 40 to 70 % density. In the same area 5000 seedlings were planted by the forest department in 2006.

In the Vellikkel area a mixed patch of *Avicennia officinalis*, *Avicennia marina*, *Excoecaria agallocha*, *Kandelia candel*, *Rhizophora apiculata*, *Sonneratia alba* and *Acrostichum aureum* is present with 40 to 70 % density.

Kozhikode

In this district mangroves are present at Kadalundi area, where *Avicennia officinalis* is the dominant species. Other mangrove species present in the area are *Avicennia marina*, *Acrostichum aureum* and *Kandelia candel* with 40-70 % density.

Ernakulam

In this district mangroves are present mainly at three sites viz., Pithuvypin, Mangalvanam Bird Sanctuary and Kundannur area.

Puthuvypin area

In this area on one side high density mangrove patches and on the other side completely degraded mangroves can be seen clearly. The cause of the degradation is the construction work going on in the area by the BPCL and LNG Petronet Project (Central Govt. Project). The construction work has cutoff the salt water supply to the mangroves, thereby, causing complete deterioration. *Avicennia marina* and *Avicennia officinalis* are the dominant

species in the high density mangrove patches. *Rhizophora apiculata* is also present, but is less common.

Mangalvanam Bird Sanctuary

In the Mangalvanam Bird Sanctuary near the Kerala High Court, 2.74 ha area is occupied by mangrove flora with good height, but the patches are sparsely dense. The species present in this area are *Avicennia officinalis*, *Rhizophora mucronata*, *Acrostichum aureum*, *Acanthus ilicifolius* and *Bruguiera parviflora*.

Kundannur area

In the Kundannur area a very small mixed patch of *Avicennia officinalis*, *Bruguiera sexangula* and *Acanthus ilicifolius* is present with 10 to 40 % density.

Allepey

In this district mangroves are present at only one place i.e, Kumarakom. The species present in the area are mainly *Avicennia marina* with some trees of *A. officinalis* in degraded form. The density of the mangrove patch is around 0 to 10 %.

Quilon

In this district mangroves are present at three places, namely, Adventure Park Ashramam (Ashtamudi lake area), Mandroruth islands and Kumbalam area.

Adventure Park Ashramam

At this place big trees of mangrove species are present, but very few in numbers and mixed with other vegetation. The place had dense mangrove patches in the past but because of human intervention it got degraded. The mangrove species present in the area are *Sonneratia caeseolaris*, *Bruguiera parviflora* and *Thespesia populnea*.

Munroturuttu area (commonly known as Munro islands)

Only two mangrove and mangrove associate species namely, *Excoecaria agallocha* and *Acrostichum aureum* are present and that too with sparse density.

Kumbalam area

In this area mangrove is present at privately owned land. At this place *Excoecaria agallocha* and *Rhizophora apiculata* are present in regenerating stage along with *Acanthus ilicifolius*.

Mangrove communities of Kerala

Kerala state is classified into five mangrove communities. *Avicennia* and *Rhizophora* species are the prominent constituents of the different communities in almost all the mangrove forests in Kerala.

***Rhizophora apiculata* - Moderately Dense**

This community is found in almost all the areas along the river banks like in Kasargod, Kottiyur and Vallapatnam areas and Pariyangadi river.

***Kandelia candel* - *Rhizophora apiculata* - Moderately Dense**

This community is present only at the Kasargod Range office area where plantation was done by the forest department in an area of 13.4 ha.

***Excoecaria agallocha* – *Acrostichum aureum* - Sparse**

This community is present in sparsely dense patches covering small areas only at a place named Munroturuttu in Munro islands along the Ashtamudi Lake.

Mixed mangroves

Assemblage of mangrove species comprising mainly of *Avicennia officinalis*, *A. marina*, *Rhizophora mucronata*, *R. apiculata*, *Sonneratia caseolaris*, *S. alba*, *Aegiceras corniculatum* and *Excoecaria agallocha* are commonly found along the river banks in areas like Pariyangadi, Kunjhimangalam, Vallapatnam, Mangalvanam Sanctuary, Puthuvypin area etc. in moderately dense and sparse conditions.

According to the present classification, Kerala has a mangrove cover of 6.63 km² contributed by five mangrove communities. Density-wise, moderately dense mangroves cover the maximum area (Figure 3.1.15). ‘Mixed mangroves – Moderately dense’ is found to be the most widely distributed community accounting to about 259.26 ha (Table 3.9). Mixed mangroves – Sparse ranks second in area statistics (187.89 ha), followed by *Rhizophora apiculata* -

Moderately dense (97.92 ha). A small area of 26.90 ha is recorded as ‘degraded’ based on the canopy cover density (less than 10 %) which is solely contributed by mixed mangroves community. Figure 3.1.16 shows a sample map of different mangrove communities in Cannanore district (given at the end of the chapter). Plates 3.1.39 to 3.1.48 show mangrove vegetations of Kerala.

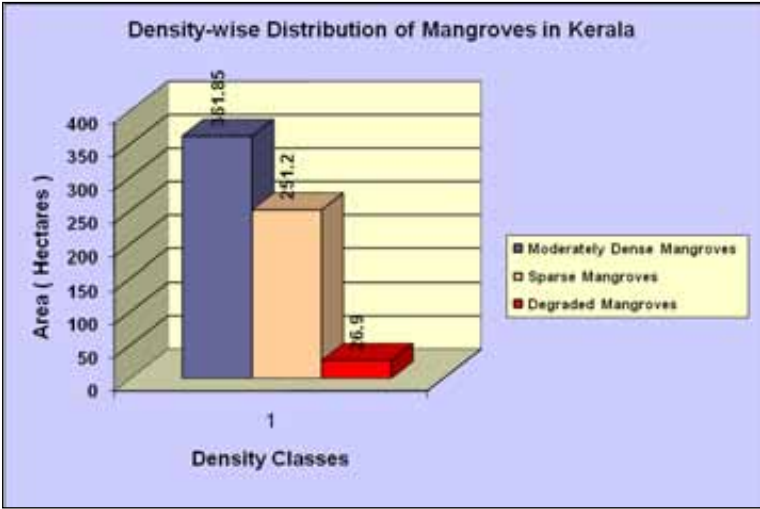


Fig. 3.15: Density-wise area statistics of Kerala

Table 3.1.9: Mangrove communities of Kerala

Mangrove Communities	Area in Hectares
<i>R. apiculata</i> - Moderately dense	97.92
<i>K. candel</i> – <i>R. apiculata</i> – Moderately dense	4.67
<i>R. apiculata</i> – Sparse	43.03
<i>E. agallocha</i> – <i>A. aureum</i> – Sparse	20.28
Mixed mangroves - Moderately dense	259.26
Mixed mangroves - Sparse	187.89
Mixed mangroves - Degraded	26.90
Total	663.09

Karnataka

Karnataka is bordered by the Arabian Sea in the west, Goa in the northwest, Maharashtra in the north, Andhra Pradesh in the east, Tamil Nadu in the

southeast and Kerala in the southwest. The state covers an area of 191,976 km² or 5.83 % of the total geographical area of India. As per 2001 Census, the state's population was 527 lakhs. Karnataka occupies ninth place with regard to population and the density of population as per 2001 Census was 275 persons per km², which was lower than the all-India density of 324. It lies between 11°40'49"N-76°40'57"E and 18°45'37"N-78°27'9"E. It is situated on a tableland where the Western and Eastern Ghats converge into the Nilgiri hill complex, in the Western part of the Deccan peninsular region of India. Karnataka extends to about 750 km from north to south and about 400 km from east to west.

The state has been divided into three sub-divisions namely, (a) Coastal Karnataka (Dakshina Kannada and Uttara Kannada districts), (b) North Interior Karnataka (Belgaum Bidar, Bijapur, Dharwad, Gulbarga and Raichur districts) and (c) South Interior Karnataka (the remaining districts of Bangalore Rural, Bangalore, Bellary, Chikmagalur, Chitradurga, Kodagu, Hassan, Kolar, Mysore, Mandya, Shimoga and Tumkur districts).

The annual rainfall in the state varies roughly from 50 to 350 cm. The rainfall increases significantly in the Western part of the state and reaches its maximum over the coastal belt. The south-west monsoon is the principal rainy season during which the state receives 80 % of its rainfall.

About 38724 km² (or 20 % of Karnataka's geographic area) area is covered by forests. The forests are classified as reserved (28,611 km²), protected (3,932 km²), unclosed (5,748 km²), village (124 km²) and private (309 km²) forests.

About 320 km long coastline of Karnataka is interrupted all along by the mouths of rivers, rivulets, creeks, sandy ridges and bays, most of which can support some mangrove formations. The widespread discontinuity among the fringe mangroves is due to large-scale wood-cutting or reclamation for agricultural and aquacultural purposes. A semblance of zonation exists in the estuarine islands. Socio-economic pressures have affected the zonation even here. Zonation to some degree is visible in muddy depressions along estuarine shores and shallow lagoon banks having gentler gradient. Pure *Rhizophora mucronata* formation is observed as a pioneer species to the exclusion of

others in many places of tidal influences. The main reason for suppression of others is the dense shade created by *Rhizophora* canopy. Formation of *Avicennia* predominates when the area is poorly drained and water-logged and not much affected by tides (Rao and Suresh, 2001). Coastal districts viz., Karwar, Honnavar, Kundapur, Mangalore houses luxuriant growth of mangroves.

Karwar

Mangrove vegetations are mainly present in the Kali river, Shinkeri bridge area, Gopshitta range, Devbagh area, Kantibada and Mudgah.

Kali river houses the major mangrove growth in Karwar. Major species found are *Acanthus ilicifolius*, *Aegiceras corniculatum*, *Avicennia alba*, *A. marina*, *A. officinalis*, *Bruguiera cylindrica*, *Bruguiera gymnorrhiza*, *Ceriops decandra*, *Derris trifoliata*, *Excoecaria agallocha*, *Kandelia candel*, *Rhizophora apiculata*, *R. mucronata*, *Sonneratia alba* and *S. apetala*.

Near the Shinkeri bridge large *Sonneratia alba* patch are present with density 70 %. In Kali river sand mining activities is effecting the mangrove growth. Some mangrove nurseries have been made by Karwar sub-division. Degradation of mangrove can be seen along the river because of sand mining, cattle grazing, illicit cutting, sea algae, commercial cultivation of shrimp and prawns. At Gopshitta range mangrove plantation is being carried out. Big patches of mud-flats are also seen in this area.

Devbagh area of Karwar harbours mangrove and mangrove associates like *Lumnitzera racemosa*, *Rhizophora mucronata*, *Avicennia alba*, *Rhizophora mucronata*, *Bruguiera gymnorrhiza*, *Excoecaria agallocha*, *Acanthus ilicifolius*, *Sonneratia alba*. Along the Devbagh beach, large *Casuarina* plantations are present. Mangroves are dense at the mouth of the river. Density of mangrove species of this area is < 40 %.

In Kantibada and Mudgah, the planted species are *Avicennia alba*, *Sonneratia alba*, *Rhizophora mucronata* and *Acanthus ilicifolius*.

Honnavar

Major mangrove areas of Honnavar are Gangavali, Aghanashini, Sharavathi-Badgani, and Venkatapur river. These places are housed with species like *Acanthus ilicifolius*, *Acrostichum aureum*, *Aegiceras corniculatum*, *Avicennia marina*, *A. officinalis*, *Excoecaria agallocha*, *Kandelia candel*, *Porteresia coarctata* and *Rhizophora mucronata*. *Bruguiera gymnorrhiza* was found only in Venkatapur river whereas *R. apiculata* shows its presence in all the areas, except Sharavathi-Badgani.

As a result of year-round controlled release of water, the natural tidal effect in Sharavati river estuary has been totally affected. Most of the year, there is influx of freshwater into the estuary. This has very perceivable consequences on the mangrove community of the river. Most noticeable feature is the decline of high salinity tolerant mangrove species such as *Rhizophora mucronata*, *Sonneretia alba*, *Avicennia marina* and *Kandelia candel*. On the other hand, the freshwater tolerant *S. caseolaris* occurs in much larger numbers throughout the estuary.

Kundapur

Kundapur division has the presence of species like *Avicennia officinalis*, *Rhizophora apiculata*, *R. conjugata*, *R. mucronata* and *Sonneratia acida*. Near Hangadi the dominating species are *Avicennia* sp. and *Rhizophora mucronata*. The species found in Kodi, Kedekar, Vittalbadi and Koteshwara are *Avicennia* sp, *Rhizophora* sp, and *Acanthus ilicifolius*. Kedekar is dominated mainly by *Rhizophora* (plantations) and *Avicennia* (natural) sp. Very stunted growth of mangrove species is observed in Kedekar. Planted *Rhizophora* sp. was seen in Koteshwara too.

Mangalore

Mangalore division comprises of *Acanthus ilicifolius*, *Avicennia officinalis*, *Kandelia candel*, *Rhizophora apiculata* and *R. mucronata*. Mangrove forests of Mangalore forest division are spread over in three major estuaries of rivers namely, Netravati, Gurupur and Mulki-Pavanje. Major mangrove genera found are *Rhizophora mucronata*, *Avicennia alba*, *Kandelia candel*, *Bruguiera gymnorrhiza* and *Sonneratia* species. For the last five years Mangalore forest division has raised more than 200 ha of mangrove plantations of *Rhizophora*

mucronata, *Kandelia candel*, *Avicennia* and *Bruguiera gymnorrhiza* at Ullal, Bengara, Sasihitlu, Thannirubavi and Jeppinamagaru localities of Mangalore Taluk. Someshwara is dominated with *Rhizophora* (70 %) and *Avicennia* (30 %). *Casuarina* plantations are also found here. Sashihithelu village is dominated with *Avicennia alba*. The village also has some *Rhizophora* nurseries. In Tannirbavi Club and Kullor, very stunted growth of mangrove species viz., *Avicennia alba* (60 %), *Rhizophora* and *Acanthus ilicifolius* are found.

Overall, the estuarine banks are of limited width and therefore, any well-differentiated zonation among mangroves is not clear. This is probably the main reason for the formation of fringe mangroves along the borders of coastal water bodies, dominated by 1-3 tree species.

Karnataka state is classified into five mangrove communities. ‘Mixed mangrove’ is the most common mangrove community here. Other communities are: *Sonneratia alba* – Degraded, *Sonneratia alba* – *Avicennia marina* – Sparse, Mixed mangrove – Moderately Dense, Mixed mangrove – Sparse and Mixed mangrove – Degraded.

According to the present classification, Karnataka has a mangrove cover of 6.04 km² contributed by five mangrove communities. ‘Mixed mangrove – Sparse’ is found to be the most widely distributed community, accounting to about 283.68 ha (Table 3.1.10). The lowest cover is observed in the community *Sonneratia alba* - *Avicennia marina* – Sparse. Figure 3.1.17 shows sample map of different mangrove communities in Dakshin Kannad (given at the end of the chapter). Plates 3.1.49 shows mangrove vegetations of Karnataka.

Table 3.1.10: Mangrove communities of Karnataka

Mangrove Communities	Area in Hectares
<i>S. alba</i> – Degraded	50.0747
<i>S. alba</i> – <i>A. marina</i> – Sparse	27.4118
Mixed Mangrove – Degraded	61.347
Mixed Mangrove – Sparse	283.6834

Mixed Mangrove - Moderately Dense	182.3172
Total	604.8341

Maharashtra

Maharashtra is surrounded by the Arabian Sea in the west and by Gujarat and Madhya Pradesh in the north. It is also encircled by Madhya Pradesh in the east and by Karnataka and Andhra Pradesh in the south.

Maharashtra with an area of 30.77 million ha, is the third largest state of the country, constituting 9.36 % of the total geographic area. It lies between latitude 15°35' and 22°02' N and longitude 72°36' and 80°54' E. Physiographically, the state can be divided into five regions, viz., Deccan Plateau, Central Highland, Eastern Chotanagpur Plateau, Eastern Ghat and Coastal plain. The average annual rainfall of the state ranges between 1,600 to 2,000 mm and average annual temperature from 25°C to 27.5°C.

The Maharashtra coast is characterized by pocket beaches flanked by rocky cliffs of Deccan basalt on one side and estuaries with patches of mangroves on the other. Maharashtra state has about 720 km long indented coastline, which is marked by the presence of major estuaries and narrow creeks. It comprises of the coastal districts of Thane, Raigarh, Greater Bombay, Ratnagiri and Sindhudurg. The shoreline is generally straight.

There are six forest types in the state, viz., tropical semi-evergreen, tropical moist deciduous, tropical dry deciduous, tropical thorn, sub-tropical broad leaved hill and littoral and swamp forests.

About 44 % of the mangrove regions along the west coast have been reclaimed during the last three decades, resulting in discontinuous distribution of a few species like *Kandelia candal*, *Bruguiera gymnorhiza*, *Ceriops tagal*, *Aegiceras corniculatum*, *Lumnitzera* sp. and *Sonneratia apetala*. Species of *Xylocarpus* reported earlier (Blatter, 1905), have totally disappeared from the west coast. Similarly, paleobotanical evidences which indicated the existence of *Nypa fruticans* from Maharashtra, has also vanished.

Thane and Mumbai suburban region

The exclusive mangrove flora comprises of species like *Acanthus ilicifolius*, *Avicennia marina*, *A. alba*, *A. officinalis*, *Rhizophora mucronata*, *Sonneratia alba* and *S. apetala*. The northernmost coast of Maharashtra (Mumbai) though showing large mangrove regions (26.97 km²), is mostly degraded and mainly represented by stunted *Avicennia marina* and *Acanthus ilicifolius*. However, upstream regions of Thane and Uihis creek are observed to have luxuriant growth of *Sonneratia apetala*, *A. marina*, *A. alba*, *R. mucronata* and *A. officinalis*. Similarly, along the Manori and Malad creeks in Mumbai, *A. marina* is quite dense. Near Vashi Bridge pure homogenous patch of *A. marina* is found with moderately dense cover. Near Godrej colony, the area exhibits large patch of grasses mixed with scattered patches of *A. marina*. In Chembur, the dominated mangrove species identified in the area are *A. marina*. Its density goes on increasing towards Mahul creek. Near Panvel creek, *A. marina* and *A. ilicifolius* mixed with seasonal grasses were observed to have good growth.

Raigarh

Raigarh houses luxuriant growth of mangroves in Alibagh and Roha division. In Alibagh near Dharatar creek, density of *A. marina*, *Acanthus ilicifolius* and *Ceriops tagal* is high near the confluence of the creek and Arabian Sea, but it gradually decreases thereafter. At some places natural regeneration of *Avicennia marina* is seen.

In Roha forest division, mainly Kundalika river, Rajapuria creek, Mhasla creek, Srivardhan, Savitri river houses luxuriant growth of mangroves. In Kundalika river, species found are *A. marina*, *Ipomoea* sp., *Acanthus ilicifolius*, *Sonneratia apetala* *Pongamia pinata* etc. In Rajapuria creek more than 50 % of the area is covered with *R. mucronata*. Other species are *Avicennia officinalis*, *Avicennia marina*, *Acanthus ilicifolius*, *Excoecaria agallocha* and *Ipomoea* sp. Species found in the Mandad river area are *Rhizophora* sp., *Ceriops tagal*, *Avicennia* sp., *Sonneratia apetala*, *Excoecaria agallocha*, *Aegiceras corniculatum* (Bokadshingi), *Ipomoea* sp., Nigda etc. *Acacia* is also also seen in this area. In Mhasla creek mangrove species are scattered and show poor growth. Here, species encountered are *Sonneratia alba* and *Avicennia* sp.

Srivardhan area is dominated mostly by *Sonneratia alba*. Height of these plants varies from 20-25 ft. Other dominating species are *Rhizophora mucronata*, *Rhizophora apiculata*, *Ceriops tagal*, *Avicennia alba* and *Bruguiera gymnorrhiza*. Root suckers are observed around the roots of *Sonneratia alba*.

Along the banks of Savitri river very narrow strips of mangroves are seen. Density of these mangroves is between 40-70 %. Species found are *Sonneratia apetala*, which dominates about 70 % of the area, followed by *Avicennia marina* and *Rhizophora* sp. Height of the *Sonneratia apetala* trees is about 20-30 ft. Density of mangroves in this area is high due to inaccessibility to the place.

Ratnagiri

In Chiplun, the dominating species are *Sonneratia apetala*, *Avicennia officinalis*, *Dalbergia spinosa* and *Ipomoea* sp. Near the creek, density of the mangrove is about 10-40 %, whereas it gradually decreases thereafter. Near Vashishti river, dominant species are *Sonneratia apetala*, *Ceriops tagal*, *Rhizophora apiculata*, *Avicennia* sp.

In Ratnagiri, species are distributed in Bhatya and Pavas creeks, and Machkandi river. Near the mouth of the Bhatya creek, the density of mangroves is about 40-70 %. As we move along the creek towards the Kaili river the density decreases. Near Takle, the dominant species are *Ceriops tagal*, *Avicennia marina*, *Pongamia glabra*, *Rhizophora mucronata* etc. Near the Manglad, *A. marina* is the dominating the species with stunted growth. At Ranpur, near Pavas creek area, heterogeneous patch of mangroves is observed. Inside the creek *Avicennia marina* is mixed with *Acanthus ilicifolius*. Other species are *Ceriops tagal*, *Pongamia glabra* and *Sonneratia alba*. At Guravwadi, big heterogeneous patch of mangrove is found near the junction of Machkandi and Dhoka rivers. Species dominating this area are *Ceriops tagal*, *Avicennia marina*, *Pongamia glabra*, *Rhizophora mucronata*, *Acanthus ilicifolius* and *Sonneratia alba*. Density of the mangroves here is about 40-70 %.

Sindhudurg

The distribution of mangrove in Sindhudurg spreads in Vijaydurg creek, Achara creek, Terekhol river, Vengurla etc. Except in Vijaydurg and Achara creeks, the other places exhibit very poor growth of mangroves. Near Vengurla, *Avicennia* sp, *Acanthus ilicifolius* and *Ceriops decandra* are found mixed together. Near Mochemad, *Acanthus ilicifolius*, *Sonneratia alba*, *Avicennia* sp and *Ceriops decandra* are seen. At Sukharbhat area *Excoecaria agallocha* occur together with *A marina* and *Acanthus ilicifolius*. Terekhol river forms boundary between Maharashtra and Goa. This is the only estuary where *Ceriops tagal* is registered. At the adjoining places *Avicennia officinalis*, *Sonneratia alba*, *Acanthus ilicifolius*, *Derris heterophylla* and *Rhizophora mucronata* are found. At Hadi, around 20 ha of land are dominated with mangroves (heterogenous type) with moderately dense cover. Mangroves growing here are *Avicennia officinalis*, *Sonneratia alba*, *Rhizophora mucronata*, *Acanthus ilicifolius* and *Ceriops tagal*. At Achara creek, the species found are *Sonneratia alba* (60 % of the area) and *Rhizophora mucronata*. *A. marina* is in a much degraded condition. In Vijaydurg creek, very narrow patches of mixed mangroves grow along the river. Near Girya, *Rhizophora mucronata* is found abundant with other species like *Sonneratia alba* and *Acanthus ilicifolius*. Density of the mangrove species is about 10-40 %. Near Tirlot, the density of mangrove species is about 40-70 % and is mostly dominated with *Rhizophora mucronata*, *Avicennia* sp., *Sonneratia alba*, and *Acanthus ilicifolius*. Wadatar bridge, which joins Vijaydurg to Devgarh, witnesses pure patches of *Sonneratia alba*. Near Eliye bridge, pure patch of *Avicennia* sp was found all along the creek. Density varies from 40-70 %. Away from the creek, the species found are *Rhizophora mucronata*, *Acanthus ilicifolius* and *Sonneratia alba* with density about less than 10 %. The areas near Mithmumbri village and Duribadi are dominated with *Avicennia* sp. in degraded form.

Maharashtra state is classified into eleven mangrove communities: *Sonneratia apetala* – Moderately Dense, *Sonneratia alba* – Sparse, *Sonneratia apetala* – *Avicennia marina* – Moderately Dense, *Avicennia marina* – *Rhizophora mucronata* – Moderately Dense, *Avicennia marina* – *Rhizophora mucronata* – Sparse, *Avicennia marina* – Moderately Dense, *Avicennia marina* – Sparse,

Avicennia marina – Degraded, Mixed mangroves – Moderately Dense and
Mixed mangroves – SparseMixed mangroves – Degraded.

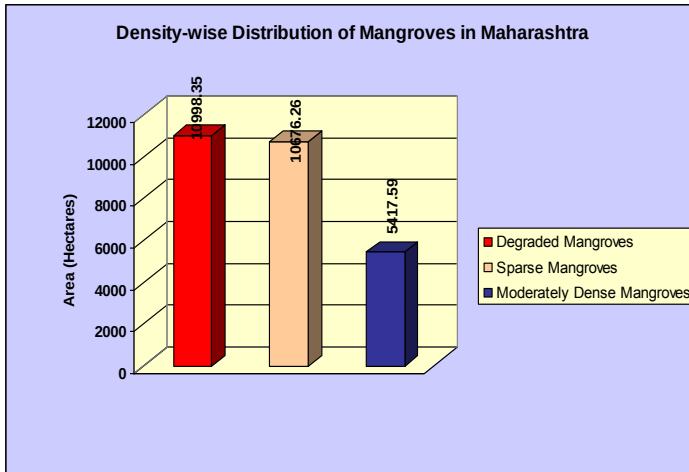


Fig. 3.1.18: Density-wise area statistics of mangroves in Maharashtra

‘Mixed mangrove’ is the most common mangrove community here. Figure 3.1.18 shows density-wise area statistics of Maharashtra mangroves. Figures 3.1.19 to 3.1.21 show sample maps of different mangrove communities in Thane, Kolaba and Ratnariri (given at the end of the chapter). Plates 3.1.50 to 3.1.56 show mangroves of Maharashtra.

Table 3.1.11: Mangrove communities of Maharashtra

Mangrove Communities	Area in Hectares
<i>A. marina</i> – Degraded	10667.24
<i>A. marina</i> – Sparse	7164.04
<i>A. marina</i> - Moderately Dense	3205.63
<i>S. apetala</i> - <i>A. marina</i> - Moderately Dense	176.62
<i>A. marina</i> – <i>R. mucronata</i> – Sparse	628.65
<i>A. marina</i> – <i>R. mucronata</i> - Moderately Dense	540.17
<i>S. alba</i> – Sparse	119.06
<i>S. apetala</i> - Moderately Dense	394.83
Mixed mangroves – Degraded	331.11
Mixed mangroves – Sparse	2764.51
Mixed mangroves - Moderately Dense	1100.34
Total	27092.20

Tamil Nadu

Tamil Nadu has a coastal length of about 1076 km lying south east part of Indian peninsular coast. Ecologically sensitive areas such as Pulicat bird sanctuary, Kaliveli backwaters, Pichavaram mangroves, Vedaranyam Wildlife sanctuary, Muthupet mangroves, Ramanathapuram mangroves and Gulf of Mannar biosphere reserve are the important protected areas of Tamil Nadu coast. Mangroves are the predominant and ecologically important one among these ecosystems which stretches along the Tamil Nadu coast.

A total number of 13 exclusive mangroves species are present in the mangrove wetlands of Tamil Nadu. Natural hybrid of *Rhizophora* species is found in Pichavaram mangrove forests of Tamil Nadu. Maximum of 12 species are present in Pichavaram whereas Muthupet mangroves harbours 8 species. Mangrove species *Pemphis acidula* is endemic to the islands of Gulf of Mannar. Community structure studies show that *Avicennia marina* is mono specifically dominant in all the mangrove wetlands of Tamil Nadu. Other species are represented by limited number of individuals.

Regarding distribution pattern of the flora, two distinct zones namely, *Rhizophora* zone and *Avicennia* zone are identified in the case of Pichavaram mangrove wetlands. The *Rhizophora* zone, which is about 5 to 20 m in breadth, is found along the fringes of the tidal creeks and channels. Distribution of 11 species of the Pichavaram is restricted to this narrow zone. Pure stands of *A. marina* are found beyond the *Rhizophora* zone. In some hypersaline areas, pure halophyte *Suaeda* dominates and this zone is called as *Suaeda* zone.

Unlike the other mangrove wetlands of the east coast, both the Pichavaram and Muthupet mangroves receive freshwater mostly during the northeast monsoon season that extends from October to November. Most of the freshwater required by the mangroves of Pichavaram is supplied by the discharge from Coleroon barrage of Coleroon river. The mangroves of Muthupet receive freshwater from the Kallanai dam at Thiruchirapally and from the catchment of the tail end distributors of river Cauvery such as Asuviniyar, Padminiya, Kattar and Marakkakoraiyar. These distributors join the Palk Bay through

Muthupet mangroves. Muthupet is situated 400 km south of Chennai and lies close to Point Calimere on the southeast coast of Peninsular India (100° 25' N; 79° 39' E). It is at the southern end of the Cauveri delta covering an area of approximately 6800 ha. Of which only 4 % is occupied by well-grown mangroves. Various tributaries of the river Cauveri flow through Muthupet and adjacent villages. At the tail end, they form a lagoon before meeting the Palk Strait. The northern and western borders of the lagoon are occupied by a sand spit which is devoid of mangrove vegetation. This mangrove forest was declared as reserve forest in February 1937 by the Government of Tamil Nadu (Shanmugasundaram, 1985). The Muthupet mangrove ecosystem embraces a heterogeneous mixture of mangrove elements of plants and animals. Among the six principal mangrove species, *Avicennia marina*, is the most common species and abundant followed by *Excoecaria agallocha*, *Aegiceros corniculatum*, *Acanthus ilicifolius*, *Suaeda maritima* and *S. monoica* in that order.

In the Gulf of Mannar, there are only a few studies on the distribution of mangroves in certain islands. Iyengar (1927) reported luxuriant growth of mangroves from the Krusudai Island. The mangrove vegetation includes *Avicennia officinalis*, *Excoecaria agallocha*, *Bruguiera cylindrica*, *Ceriops tagal*, *Lumnitzera racemosa*, *Suaeda maritima*, *S. monoica* and *Sesuvium portulacastrum*. Blasco (1975) and Krishnamurthy *et al.* (1987) reported on the distribution of mangrove species in the Gulf of Mannar islands. Perichiappan *et al.* (1995) have reported 13 species of mangroves from the Mandapam group of islands. Daniel (1998) has provided with a comprehensive account on the flora of Gulf of Mannar islands. Kathiresan and Rajendran (1998) have evaluated the status of mangroves of Gulf of Mannar based on IUCN criteria. ICMAMPD (2001) has reported 9 species of mangroves and 7 mangrove associated species from the Gulf of Mannar region. Apart from this there is no solid work on the mangroves of the Gulf of Mannar; especially, quantification of mangrove change in this group of islands is totally lacking till today. Namalwar and Muniyandi (2000) have rightly pointed out that there is no substantial study on the mangroves of the Gulf of Mannar. Though there are attempts on mapping the coral reefs, seaweeds and seagrass in the Gulf of Mannar, there are not much of studies on mapping the aerial extent of the mangroves of the Gulf of Mannar (SAC, 2003; Krishnamurthy, 2006;

ICMAMPD, 2001; Thanickachalam and Ramchandran, 2003; Thangaradjou *et al.*, 2008).

Krishnamoorthy *et al.* (1997) mapped the mangroves of Pitchavaram and Muthupettai. Ramachandran *et al.* (1998) have described the application of remote sensing and GIS to study the coastal wetland ecology of Tamil Nadu. Krishnamoorthy *et al.* (1997) and Ajithkumar *et al.* (1998) used the ground truth radiometer with IRS and TM PANS to study the spectral properties of mangroves, mangrove waters and sediments of Muthupettai. Perichiappan (1998) has used satellite data to delineate different land cover classes in Muthupettai mangrove area. Madan Kumar and Usha Natesan (2006) stated that in 1930 mangroves in Muthupettai were about 17.51 km² and in 2000, the mangrove area has been estimated as 21.04 km and in 2006, it is about 29.87 km². Ajithkumar *et al.* (2007) mapped the mangroves of this location using old remote sensing data and found the loss of mangroves between 1985 and 1997 as 2470 ha.

The major mangrove species found in the entire coast of Tamil Nadu is *Avicennia marina*. Other major species found are *Rhizophora*, *Excoecaria* and *Acanthus ilicifolius*. Apart from these two major mangrove distributions, most of estuaries and backwater system along the coast have patches of mangroves.

Chennai

Small patches of mangroves comprising *Avicennia marina* and *Suaeda* are found along the intertidal margins of the Adyar estuary as well as Ennore backwaters of Chennai coast. *Avicennia marina* is the dominant species. In the Adyar estuarine region, *Avicennia marina* is present in tree forms whereas in Ennore backwaters they are stunted in growth.

Vilupuram

Mangroves are found along the Kaliveli lake between saltpans. *Avicennia marina* is the dominant species in this area. In this area *Avicennia marina* is very short and dense. *Suaeda* is found along the saltpans. Recently Forest department has been planted the *Rhizophora* plants along Kaliveli creek.

Cuddalore

Pichavaram is the second mangrove wetland of Tamil Nadu covering an area of about 858 ha with mangrove species such as *Avicennia marina*, *Rhizophora apiculata* and *R. mucronata* dominating the wetland spread in the Vellar-Coleroon estuarine complex. *Rhizophora* species found along the backwaters, tidal creeks and canals and whereas interior wetland is covered extensively by *A. marina*. Associated mangrove species such as *Suaeda maritima* and *S. monoica* are also found.

Nagapattinam

In the north Nagapattinam, large patches mangroves of about 120 ha are found along the Buckingham Canal, both north and south of Coleroon estuary. In the south Nagapattinam, patches of mangroves are found along the coast of Vedaranyam canal and Vellar River (near Velankanni). The mud flat areas of Talainayar, which is a Reserve Forest, mangrove is present only in a few hectares (179ha). *Bruguiera cylindrica* and *Acanthus ilicifolius* are also found in few areas. Associated mangroves such as *Suaeda* and *Salicornia* are also found. Total area of mangrove in Nagapattinam District is about 374 ha.

Thanjavur

In Thanjavur, the dense trees of *Avicennia marina* is distributed along the Ambullar river, and small patches of mangroves are found along the Tedakkir, Kattar and Agniar river mouth. Nearly 131 ha of mangroves are found in the district apart from the Muthupet mangroves (2130 ha spreads between Thanjavur and Thiruvarur districts).

Muthupet (Muthupettai)

Previous studies on the mangroves of Muthupettai were carried out in the Muthupet lagoon area only. So, the results obtained from these studies showed less mangrove cover. But, in the present study, we covered the areas of Palanjur Reserve Forests, Tamarankadu Reserve Forests, Maravakadu Reserve Forests, Vadakadu Reserve Forest, Thuraikadu Reserve Forest, Mthupet lagoon and Thondiakadu area. Results of the present study indicate that the total mangrove cover in the Muthupettai mangrove area is about 3582 ha (Table 3.1.12) with the dense cover of *Avicennia marina* (1282.2 ha), *A. marina* sparse (957.4 ha), space cover of *Avicennia-Suaeda* (1151.9 ha) and mudflats

with sparse mangroves (190.5 ha). Muthupet is a combination of *Avicennia marina* forest, creeks, lagoon, mudflats, and man made fishing canals. *A.marina* is the dominant species, constituting nearly 95% of the vegetation cover. Other mangrove species include *Aegiceras corniculatum*, *Excoecaria agallocha*, *Lumnitzera racemosa* and *Acanthus ilicifolius*. Halophytes and mangrove associates are present all over the mangrove areas. The halophytes include *Suaeda monoica*, *S. maritima*, *Salicornia brachiata* and *Sesuvium portulacastrum*. Table 3.1.13 represents the phytosociological data of Muttupetai mangroves.

Table 3.1.12: Mangrove distribution in the Muthupettai region

Toposheet	<i>Avicennia-Suaeda</i> (sparse)	<i>A.marina</i> (dense)	<i>A.marina</i> (sparse)	MF with Sparse mangrove	Total (ha)
58N11SE	138.5	63.01	87.6		289.1
58N11SW	513.8	582.5	320.9		1417.2
58N7SE	469.3	607.2	548.9	190.5	1815.9
58N7SW	30.3	29.5			59.8
Total	1151.9	1282.2	957.4	190.5	3582

Table 3.1.13: Phytosociological data of Muthupettai mangroves

Station	Latitudes	Longitudes	Vegetation characterization
THAMARAI KOTTAI			
Point - 1	10° 18' 51.9" N	79° 30' 50.8" E	<i>Avicennia marina</i> , <i>Rhizophora apiculata</i>
Point - 2	10° 18' 51.3" N	79° 30' 44.3" E	<i>Avicennia marina</i> , <i>Suaeda maritima</i>
Point - 3	10° 21' 11." N	79° 31' 5.1" E	<i>Avicennia marina</i>
Point - 4	10° 21' 2.9" N	79° 31' 55" E	<i>Avicennia marina</i>
Point - 5	10° 20' 8.1" N	79° 30' 10." E	<i>Avicennia officinalis</i> , <i>Avicennia marina</i>
Point - 6	10° 18' 35" N	79° 30' 39" E	<i>S.monica</i> , <i>S. maritime</i>
Point - 7	10° 19' 8.1" N	79° 29' 10." E	<i>S.maritima</i>
MARAVAKADU			
Point - 1	10° 19' 03.8" N	79° 31' 09.4" E	<i>Avicennia marina</i> (Plantation)

VADAKADU			
Point - 1	10° 19' 21.6" N	79° 31' 49.1" E	<i>Avicennia marina</i> , <i>Rhizophora apiculata</i> , <i>Suaeda martima</i> (Plantation)
THURAIKADU			
Point - 1	10° 19' 30.0" N	79° 32' 21.1" E	<i>Avicennia marina</i> , <i>Suaeda martima</i> (Plantation)
Point - 2	10° 19' 36.8" N	79° 32' 21.2" E	<i>Avicennia marina</i> , <i>Suaeda martima</i>
Point - 3	10° 19' 41.7" N	79° 32' 18.6" E	<i>Avicennia marina</i>
Point - 4	10° 19' 50.0" N	79° 32' 18.4" E	<i>Avicennia marina</i> , <i>Rhizophora apiculata</i> (Plantation)
Point - 5	10° 19' 22.2" N	79° 32' 24.1" E	<i>Avicennia marina</i> , <i>Rhizophora apiculata</i> (Plantation)
Point - 6	10° 19' 57.6" N	79° 32' 09.8" E	<i>Avicennia marina</i> , <i>Rhizophora apiculata</i> (Plantation)
Point - 7	10° 19' 54.7" N	79° 32' 11.6" E	<i>Avicennia marina</i> , <i>Rhizophora apiculata</i> (Plantation)
SETHUKUDA			
Point - 1	10° 21' 18.2" N	79° 31' 14.8" E	<i>Avicennia marina</i> , <i>Rhizophora apiculata</i> , <i>Suaeda martima</i> (Plantation)
Point - 2	10° 21' 10.8" N	79° 31' 28.4" E	<i>Avicennia marina</i> , <i>Rhizophora apiculata</i> (Plantation)
Point - 3	10° 21' 08.5" N	79° 31' 27.6" E	<i>Avicennia marina</i> , <i>Rhizophora apiculata</i> , <i>Suaeda martima</i> (Plantation)
Point - 4	10° 21' 03.7" N	79° 31' 26.4" E	<i>Avicennia marina</i> , <i>Rhizophora apiculata</i> , <i>Suaeda martima</i> (Plantation)
Point - 5	10° 21' 00.4" N	79° 31' 25.4" E	<i>Avicennia marina</i> , <i>Suaeda martima</i> (Plantation)
Point - 6	10° 21' 05.2" N	79° 31' 27.0" E	<i>Avicennia marina</i> , <i>Rhizophora apiculata</i> , <i>Suaeda martima</i> (Plantation)

Pudukottai

Dense *Avicennia marina* and associated mangrove of *Suaeda* are distributed the mud flat areas of Kattumavadi and along the Vellar river mouth. Total areas of mangroves in this district are 121ha.

Ramanathapuram (Devipattinam)

Avicennia marina is dominantly distributed along the rivers of Kottakarai and Uppar, Dense mangroves with *Avicennia marina* as the dominant species is found in the mud flats near Devipattinam (38 ha). Mangroves are also found

along the small creeks along the coast. Total area of mangroves in Ramnathapuram district is 379 ha.

Gulf of Mannar

In the present study, mangroves of 17 islands in the Mandapam, Keezhakarai and Vembar groups were mapped using IRS P6 LISS satellite (2004) data. Out of 17 islands, distribution of mappable mangroves was found only in 8 islands and in some stretches along the Tuticorine coast. The mangrove cover in the Gulf of Mannar is given in Table 3.1.14. Mangrove cover in the region is dominated by the mixed mangroves (34.9 ha), followed by short dense *Avicennia* (22.6 ha), largely in the coastal stretches of Tuticorine, medium dense *Avicennia marina* (3.8 ha), dense *S. marina* (1.4 ha) and mudflats with vegetation (0.8 ha) in Uputhanni island only.

Table 3.1.14: Mangrove cover recorded in the Gulf of Mannar islands

Toposheet	A.marina dense	MF with vegetation	Avicennia short dense	Mixed mangrove	Avicennia MD	Total (ha)
58K08SE	1.4	0.8				2.2
58K16NE			0.5			0.5
58L1SE			22.1			22.1
58O04NE				11.9	2.4	14.3
58O04NW				23	1.4	24.4
Total	1.4	0.8	22.6	34.9	3.8	63.5

Pemphis acidula one of the coastal vegetation species is dominated in most of the islands. As a as the mangrove diversity is concerned in the 8 islands, Krusadai and Pullivasal recorded more mangrove diversity (11 each) followed by Manoli (10 species), Poomarichan and Hare island (9), Manoliputti (8) and Shingle (7). In general, mangrove diversity is good in the Mandapam groups of islands when compared to Keezhakarai and Vembar groups. Phytosociological data for different islands of the Gulf of Mannar are given in Table 3.1.15 and 3.1.16.

Table 3.1.15: Diversity of mangrove species recorded from the islands of the Gulf of Mannar

Species	Mandapam Group							Keelakarai Group							Vembar Group		
	Shingle	Krusudai	Pullivasal	Poomarichan	Manoliputti	Manoli	Hare	Mulli	Valai	Talairi	Appa	Poovarasampatti	Valimunai	Anaipar	Nallathanni	Pulivinchalli	Upputhanni
Mangroves																	
<i>Avicennia marina</i>	+	+	+	+	+	+	+	+	--	+	+	--	--	+	+	-	+
<i>Rhizophora mucronata</i>	--	+	+	+		+	+	--	--	--	--	--	--	--	--	--	--
<i>Ceriops tagal</i>	--	+	+	+	+	+	+	--	--	--	--	--	--	--	--	--	--
<i>Bruguiera cylindrical</i>	--	+	+	+	+	+	--	--	--	--	--	--	--	--	--	--	--
<i>Lumnitzera racemosa</i>	+	+	+			+	+	--	--	--	--	--	--	--	--	--	--
<i>Pemphis acidula</i>	+	+	+	+	+	+	+	+	+	+	+	--	+	+	--	--	--
<i>Exoecaria agallocha</i>	+	+	+	+	+	+	+	--	--	--	+	--	--	--	--	--	--
<i>Aegiceras corniculatum</i>	--	+	+	--	--	--	--	--	--	--	--	--	--	--	--	--	--
<i>Rhizophora apiculata</i>	--	--	+	+	--	+	--	--	--	--	--	--	--	--	--	--	--
Salt marsh plants																	
<i>Pandanus sp.</i>	+	+	--	--	+	+	+	--	--	--	--	--	--	--	--	--	--
<i>Sesuvium sp.</i>	+	+	+	+	+	+	+	+	+	+	--	--	+	+	+	+	+
<i>Suaeda maritima</i>	+	+	+	+	--	--	--	+	+	+	--	--	--	--	--	--	--
<i>Salicornia brachiata</i>	--	--	--	--	+	--	+	--	--	+	--	--	--	--	+	--	--
Total no of species	7	11	11	9	8	10	9	4	3	5	3	--	2	3	3	1	2

Table 3.1.16: Phytosociological data of the island of Gulf of Mannar

Station	Latitudes	Longitudes	Characters
Shingle Island			
Point - 1	9°14'26.3N	79°14'0.1E	Dead corals <i>Ipomea</i> sp is dominant
Point - 2	9°4'32.2N	79°14'0.1E	Live corals
Point - 3	9°14'29.2N	79°14'12.8E	<i>Avicennia marina</i> , <i>A.effinialis</i> , <i>Lumnitzerra</i> sp are present
Point - 4	9°14'27.3N	79°14'14.1E	<i>R.mucronata</i> , <i>A.officinalis</i> , <i>Suaeda monoica</i> , <i>S.maritima</i>
Krusudai Island			
Point - 1	9°14'56.9N	79°13'16.4E	<i>Acropora</i> sp (coral) is dominant
Point - 2	9°15'0.2N	79°12'51.3E	<i>Avicennia marina</i>
Pullivasal Island			
Point - 1	9°14'58N	79°12'52E	<i>Lumnitzera</i> sp and <i>Avicennia marina</i>
Point - 2	9°14'52N	79°12'47E	<i>Avicennia officinalis</i>
Point - 3	9°14'29.1N	79°11'0.60E	<i>Rhizophora apicularta</i> , <i>R.mucronata</i> , <i>Bruguiera</i> sp and <i>A. marina</i>
Point - 4	9°14'29.6N	79°11'07.9E	<i>Bruguiera</i> sp, <i>Rhizophora mucronata</i> and <i>Avicennia marina</i>
Point - 5	9°14'27.3N	79°11'04E	<i>Rhizophora mucronata</i>
Poomarichan Island			
Point - 1	9°14'29.1N	79°11'02.6E	<i>Bruguiera</i> sp, <i>Rhizophora mucronata</i> and <i>Avicennia marina</i>
Point - 2	9°14'53.6N	79°11'01.3E	<i>Suaeda monoica</i> , <i>S.maritima</i> , <i>Avicennia officinalis</i> , <i>Rhizophora apicularta</i> , <i>R.mucronata</i> and <i>Excoecaria agallocha</i>
Point - 3	9°14'53.6N	79°10'57.9E	<i>Avicennia officinalis</i>
Hare Island			
Point - 1	9°12'24.9N	79°04'0.69E	<i>Lumnitzera</i> sp
Point - 2	9°12'26.1N	79°04'04.9E	<i>Lumnitzera</i> sp and <i>Thespesia</i> sp
Point - 3	9°12'11.8N	79°03'47.7E	<i>Avicennia marina</i> , <i>Lumnitzera</i> sp and <i>Thespesia</i> sp
Point - 4	9°12'07.4N	79°03'48.8E	<i>Avicennia officinalis</i> , <i>A. marina</i> and <i>Lumnitzera</i> sp
Manoli Island			
Point - 1	9°13'16.1N	79°06'49.9E	<i>Suaeda monoica</i> , <i>S.maritima</i> , <i>Avicennia marina</i> , <i>Bruguiera</i> sp. <i>Rhizophora</i> sp.
Point - 2	9°12'59.9N	79°07'30.1E	<i>Suaeda monoica</i> , <i>S.maritima</i> , <i>Avicennia marina</i> , <i>Bruguiera</i> sp. <i>Rhizophora</i> sp.
Point - 3	9°32'57.4N	79°07'32.5E	<i>Suaeda monoica</i> , <i>S.maritima</i> , <i>Avicennia marina</i> , <i>Bruguiera</i> sp. <i>Rhizophora</i> sp.

Tuticorin

The mangroves in Punnakayal are predominantly occupied by stunted *Avicennia marina*. *Suaeda* and *Salicornia* are other associated mangroves commonly found in Punnakayal. The Punnakayal mangrove covers about 272 ha of poorly grown mangroves.

Kanniyakumari

The river Pazhayar confluence with the Arabian Sea near Manakkudi village forming the Manakkudi estuary with small islands. One of islands has artificially regenerated mangroves. *Rhizophora* is the dominant species in this area. It covers less than 1 ha in area.

Mangrove communities

Tamil Nadu state is classified into nine mangrove communities (Table 3.1.17). Plates 3.1.57 to 3.1.63 show mangroves of Tamil Nadu.

Acanthus ilicifolius – Sparse

This community is observed in district Nagapattinam.

Avicennia – Dense

This community is observed in eight districts, namely, Thiruvallur, Cuddalore, Nagapattinam, Thanjavur, Pudukottai, Ramanathapuram, Tuticorin and Muthupettai. This community is also witnessed in the islands of Gulf of Mannar.

Avicennia – Short Dense

This community is seen in all the above districts except, Kanniyakumari. It is also observed in the islands of Gulf of Mannar.

Avicennia – Sparse

All the districts, excepting Kanniyakumari and Chennai exhibit this mangrove community.

Excoecaria agallocha – Moderately Dense

Moderate dense *Excoecaria agallocha* trees are observed only in Cuddalore.

Rhizophora – Dense

Dense *Rhizophora* are found in Cuddalore, Nagapattinam and Kanniyakumari.

Avicennia – Suaeda – Sparse

This community is observed in Muthupettai region.

Avicennia – Moderately Dense

Moderately dense *Avicennia* communities are found in Gulf of Mannar islands.

Mixed mangroves

This community is found in the islands of Gulf of Mannar.

Table 3.1.17: Mangrove communities of Tamil Nadu

Mangrove Communities	Area in Hectares
<i>Acanthus ilicifolius</i> – Sparse	7.89
<i>Avicennia</i> - Dense	1785.03
<i>Avicennia</i> – Moderately Dense	3.8
<i>Avicennia</i> – Short Dense	568.91
<i>Avicennia</i> – Sparse	2017.53
<i>Excoecaria agallocha</i> – Moderately Dense	1.84
<i>Rhizophora</i> – Dense	94.01
<i>Avicennia</i> – <i>Suaeda</i> – Sparse	1151.9
Mixed mangroves	34.9
Total	5665.81

West Bengal

Sundarbans is considered to be one of the world's largest blocks of mangrove vegetation and lies in the delta of two rivers, the Ganges and the Brahmaputra of the Indian subcontinent (FAO forestry paper, 2007). It spreads over the southern part of three districts, South 24 Parganas (India), Khulna and Backharganj (Bangladesh). The rivers Raimangal and Hoogly on the east and west, respectively, demarcate the boundary of the Sundarbans within India. It occupies a latitudinal range of 21°31' N to 22°30' N and the longitudinal range of 88°10' E to 89°51' E. The vegetation is dense and evergreen. The term 'Sundarbans' came into existence either from the vernacular name 'Sundri' of the once prevalent mangrove species *Heritiera fomes* Buch. Ham. or from the

words ‘Sundar’ (meaning beautiful) and ‘ban’ (meaning forest) i.e. beautiful forest (Naskar and Guha Bakshi, 1987).

The Sundarbans mangroves are phytogeographical components of the warm humid climate of the sub-tropical belt, and face a moderate fluctuation in temperature. During winter, the temperature hardly goes down to 10 °C and in summer, owing to prevalence of vast amount of water surface never exceeds 38 °C. From the month of February the temperature begins to rise and reaches its peak in April- May. During this period the atmosphere remains relatively dry. In May and October-November, incidence of thunderstorm is a very common phenomenon due to depression in the Bay of Bengal. The average rainfall during monsoon is 173 cm; the highest rainfall occurs during July-August and humidity rises up to 96 % (Chanda and Datta, 1986).

In the present study 37 true mangrove and 32 mangrove associate species have been recorded. The category of fringe mangroves in the Sundarban is largely covered by *Avicennia* community especially *A. alba*, about 60 % of the total class and rest 40 % of this category is occupied by *Phoenix*, *Ceriops* specially where erosion is pronounced. In few places *Sonneratia*, *Rhizophora* and *Bruguiera* species have also been observed at the field, but it is hardly possible to map these species as separate entity in this scale.

West Bengal Sundarban is classified into eleven classes of mangrove communities (Table 3.1.18). Plates 3.1.64 - 3.1.69 show mangroves of Indian Sundarbans.

Table 3.1.18: Mangrove communities of West Bengal

Mangrove Communities	Area in Hectares
<i>Aegialitis</i> - <i>Excoecaria</i> – Dense	15.16
<i>Avicennia</i> – Dense	101.46
<i>Avicennia</i> – Sparse	138.33
<i>Excoecaria agallocha</i> – Dense	8.17
Fringe mangrove	197.61
Mixed mangroves – Dense	11.07
<i>Phoenix</i> – Dense	14.54
Mangrove – Sparse	651.59

Mixed mangroves (<i>Avicennia</i> – <i>Excoecaria</i> - <i>Ceriops</i>) – Dense	930.90
Mixed mangroves (<i>Ceriops</i> – <i>Excoecaria</i> - <i>Phoenix</i>) – Dense	211.38
<i>Avicennia</i> - Moderately Dense	249.06
Total	2529.27

Andaman and Nicobar Islands

Andaman and Nicobar islands are the largest archipelago which comprises of more than 572 scattered islands, islets and rocky outcrops. Total area of Andaman group of islands is 6408 km² while that of Nicobar is 1841 km². These island groups are separated from each other by ten degree channel, an international navigation passage. Almost all regions in both groups of islands are hilly with broken terrain except Car Nicobar (Dam et al., 2009). The total coastline of the islands is 1962 km, which accounts for 25 % of the country's coastline and encompasses 28 % of the total Exclusive Economic Zone. These islands harbour 34 true mangrove species belonging to 15 genera, 10 orders and 12 families (Dam et al., 2009).

Andaman

The mangroves in Andaman are probably the best in our country. Anchored in transition zones throughout the coasts, the mangrove forests deliver a wide range of pecuniary benefits. The mangroves along the coastline defend the coastal communities from tidal surges and similar ecological threats. The major true mangrove species encountered here are *Scyphiphora hydrophyllacea*, *Cynometra iripa*, *Avicennia marina*, *A. officinalis*, *Excoecaria agallocha*, *Bruguiera cylindrica*, *B. gymnorrhiza*, *B. parviflora*, *B. sexangula*, *Ceriops tagal*, *Rhizophora apiculata*, *R. mucronata*, *R. stylosa*, *Heritiera littoralis*, *Lumnitzera littorea*, *L. racemosa*, *Sonneratia alba*, *S. caseolaris*, *S. ovata*, *Aegiceras corniculatum*, *Xylocarpus granatum*, *Nypa fruticans* and *Phoenix paludosa*. This community of transition mangroves comprises of *Cerbera odalum*, *Scyphiphora*, *Cynometra*, *Intsia bijuga*, *Flageleria indica*, *Fimbxylis*, *Excoecaria ebractata*, etc.

Andaman is classified into 31 classes of mangrove communities (Table 3.1.22). North Andaman comprises of 13 classes (Table 3.1.19), Middle

Andaman 22 classes (Table 3.1.20) and South Andaman (Table 3.21) only 9 classes of mangrove communities. Plates 3.1.70 - 3.1.78 show mangroves of Andaman.

North Andaman

Table 3.1.19: Mangrove communities of North Andaman

Mangrove Communities	Area in Hectares
<i>Avicennia</i> – Sparse	783.15
<i>Bruguiera</i> - <i>Rhizophora</i> – Dense	1609.18
Fringe mangroves	3132.53
Mangrove – Sparse	2085.36
Mixed mangroves (<i>Rhizophora</i> - <i>Bruguiera</i> - <i>Ceriops</i>) - Dense	11.22
Mixed mangroves (<i>Xylocarpus</i> - <i>Phoenix</i> - <i>Heritiera</i>) - Dense	87.96
<i>Phoenix</i> – <i>Avicennia</i>	187.56
<i>Phoenix</i> – <i>Xylocarpus</i> – Dense	594.26
<i>Rhizophora</i> - <i>Bruguiera</i> – Dense	1050.59
<i>Rhizophora</i> - <i>Ceriops</i> – Dense	267.67
<i>Rhizophora</i> – Dense	3390.83
<i>Rhizophora</i> – Sparse	3519.21
<i>Xylocarpus</i> – Dense	255.96
Total	16975.48

Middle Andaman

Table 3.1.20: Mangrove communities of Middle Andaman

Mangrove Communities	Area in Hectares
<i>Avicennia</i> – <i>Excoecaria</i> – Dense	169.93
<i>Bruguiera</i> – Dense	218.38
<i>Ceriops</i> – <i>Excoecaria</i> – Sparse	283.58
Fringe mangroves	2626.76
Mangroves – Degraded	449.59
Mangroves – Sparse	3044.24
Mixed mangroves - Moderately Dense	959.04
Mixed mangroves (<i>Avicennia</i> – <i>Bruguiera</i> - <i>Ceriops</i> - <i>Lumnitzera</i>) - Dense	105.95
Mixed mangroves (<i>Ceriops</i> – <i>Avicennia</i> - <i>Excoecaria</i>) - Dense	699.95

Mixed mangroves (<i>Phoenix</i> – <i>Avicennia</i> - <i>Excoecaria</i>) - Dense	215.94
Mixed mangroves (<i>Rhizophora</i> - <i>Bruguiera</i> - <i>Ceriops</i>) - Dense	640.63
Mud-flat with sparse mangroves	102.27
<i>Nypa</i> – Dense	189.99
<i>Phoenix</i> – <i>Acrostichum</i> – Sparse	1009.03
<i>Phoenix</i> – <i>Avicennia</i> – Dense	1754.88
<i>Rhizophora</i> - <i>Avicennia</i> – Dense	927.29
<i>Rhizophora</i> - <i>Bruguiera</i> – Dense	4499.47
<i>Rhizophora</i> – Dense	5860.86
<i>Rhizophora</i> - Moderately Dense	1060.44
<i>Rhizophora</i> – Sparse	6389.89
<i>Xylocarpus</i> – Dense	667.09
<i>Xylocarpus</i> – <i>Heritiera</i> – Dense	116.72
Total	31980.69

South Andaman

Table 3.1.21: Mangrove communities of South Andaman

Mangrove Communities	Area in Hectares
Fringe mangroves	498.54
Mangrove- Degraded	1453.69
<i>Rhizophora</i> - <i>Bruguiera</i> – Degraded	82.93
<i>Rhizophora</i> – Dense	521.53
<i>Rhizophora</i> - Moderately Dense	1476.55
<i>Rhizophora</i> – Sparse	2409.88
<i>Rhizophora</i> - <i>Xylocarpus</i> – Sparse	564.54
Transition mangroves	93.82
<i>Xylocarpus</i> – Dense	600.56
Total	7702.04

Table 3.1.22: Mangrove communities of Andaman

Mangrove Communities	Area in Hectares
<i>Avicennia</i> - <i>Excoecaria</i> – Dense	169.93
<i>Avicennia</i> – Sparse	783.15
<i>Bruguiera</i> – Dense	218.38

<i>Bruguiera</i> - <i>Rhizophora</i> – Dense	1609.18
<i>Ceriops</i> - <i>Excoecaria</i> – Sparse	283.58
Fringe mangroves	6257.83
Mangroves – Degraded	1903.28
Mangroves – Sparse	2080.98
Mangroves – Sparse	3048.62
Mixed mangroves - Moderately Dense	959.04
Mixed mangroves (<i>Avicennia</i> – <i>Bruguiera</i> - <i>Ceriops</i> - <i>Lumnitzera</i>) - Dense	105.95
Mixed mangroves (<i>Ceriops</i> - <i>Avicennia</i> - <i>Excoecaria</i>) - Dense	699.95
Mixed mangroves (<i>Phoenix</i> - <i>Avicennia</i> - <i>Excoecaria</i>) - Dense	215.94
Mixed mangroves (<i>Rhizophora</i> - <i>Bruguiera</i> - <i>Ceriops</i>) - Dense	640.63
Mixed mangroves (<i>Xylocarpus</i> - <i>Phoenix</i> - <i>Heritiera</i>) - Dense	87.96
Mud-flat with sparse mangroves	102.27
<i>Nypa</i> – Dense	189.99
<i>Phoenix</i> - <i>Xylocarpus</i> – Dense	594.26
<i>Phoenix</i> - <i>Acrostichum</i> – Sparse	1009.03
<i>Phoenix</i> - <i>Avicennia</i> – Dense	1942.44
<i>Rhizophora</i> - <i>Avicennia</i> – Dense	927.29
<i>Rhizophora</i> - <i>Bruguiera</i> – Degraded	82.93
<i>Rhizophora</i> - <i>Bruguiera</i> - Dense	5550.06
<i>Rhizophora</i> - <i>Ceriops</i> – Dense	267.67
<i>Rhizophora</i> – Dense	9773.22
<i>Rhizophora</i> - Moderately Dense	2536.99
<i>Rhizophora</i> – Sparse	12318.98
<i>Rhizophora</i> - <i>Xylocarpus</i> – Sparse	564.54
Transition Mangroves	93.82
<i>Xylocarpus</i> – Dense	1523.61
<i>Xylocarpus</i> - <i>Heritiera</i> – Dense	116.72
Total	56658.22

Nicobar Islands

In general, mangroves of the Nicobar group of islands have been destructed by the tsunami waves and in almost all the islands, degraded mangroves dominate in the area contribution, followed by dense *Rhizophora-Bruguiera*, *Avicennia-Excoecaria*, mixed dense, *Nypa* (dense) and fringe mangroves. A total of 1813.6 ha of mangroves were recorded including 360.4 ha of *Rhizophora-Bruguiera* (dense), 78.9 ha of *Nypa* (dense) and 190.7 ha of mixed mangroves.

Whereas FSI (2005) has reported a total of 12 km² of mangroves including 10 km² moderately dense mangrove and 2 km² of open mangroves and a total loss of 15 km² mangroves between 2003-2005 assessments.

Mangrove mapping was undertaken for Great Nicobar, Little Nicobar, Camorta, Katchal, Nancowry, Trinket, Tarasa, Tillanchong and Car Nicobar islands using IRS P6 LISS III data. Field data were collected from these islands except Little Nicobar, Tarasa and Tillanchong as these islands were inaccessible during, 2007 due to impacts of tsunami and lack of logistic supports. Phytophysiological data recorded on the mangroves of the Nicobar groups of islands are given in Table 3.23.

Table 3.1.23: Phytosociological data of mangroves of Nicobar Islands

Station	Latitude	Longitude	Observation
GREAT NICOBAR ISLAND			
Station -1. Old Town area	7 ⁰⁰ 22.3"N	93 ⁵⁵ 59.1"E	Only two mangrove trees are alive with a few branches Species: <i>Rhizophora</i> sp., <i>Sonneratia</i> sp
Station -2. Donginallah (Jawahar nallah)	7 ²⁸ 99.54"N	93 ⁵⁴ 36.2"E	No mangrove trees. Hydrogen sulfide rich environment.
Station - 3. Magar Nallah (Point I)	6 ⁵⁹ 36.00"N	93 ⁵⁴ 59.9"E	Mangrove regenerating area, More than 10 saplings of 1-2 feet height. Species: <i>Rhizophora</i> sp Remarks: Severe insect attack and cattle grazing.
Point II	6 ⁵⁹ 30.9"N	93 ⁵⁴ 47.6"E	Mangrove degraded area, Completely washed due to tsunami. Dead mangrove trees alone are remaining only there.
Station – 4. Gandhi nagar 30km	6 ⁵⁰ 22.9"N	93 ⁵³ 44.1"E	Mangrove degraded area.
Point I (32km)	6 ⁴⁹ 38.5"N	93 ⁵³ 32.5"E	Two trees of <i>Rhizophora</i> are alive near the road.
Point II (33 km)	6 ⁴⁹ 10.6"N	6 ⁴⁹ 10.6"N	Single <i>Rhizophora</i> tree with white bark near road.
Point III (29km)	6 ⁵⁰ 57.9"N	93 ⁵³ 31.2"E	No mangrove plants are alive.
Point IV (27 km)	6 ⁵¹ 43.5"N	93 ⁵³ 31.0"E	No mangrove plants are alive.
Point V (26 km)	6 ⁵² 09.7"N	93 ⁵³ 38.1"E	No mangrove plants are alive.
Station -5. Sashtri nagar (35km)	6 ⁴⁸ 18.7"N	93 ⁵⁸ 29.1"E	Isolated patches of <i>Nypha fruticans</i> and <i>Ipomea</i> sp. Spread along the coast.

Station – 6. Lakshmi Nagar	7 ⁰ 1'20.4"N	93 ⁰ 54'45.1"E	Forest department nursery and plantation. <i>Cerriops</i> sp. plantation. only 10 plants are grown up to height of 1 foot.
KAMORTA ISLAND			
Station – 1. Lantha Kadi	8 ⁰ 2'38.9"N	93 ⁰ 33'49.8"E	Washed, dead mangrove trees are remaining. Sea invaded more than 200 m. No beach, water intruded upto mountain slope.
Station - 2 Degi Busthi	8 ⁰ 2'46.5"N	93 ⁰ 32'29.9"E	Water reservoir fully flooded with freshwater, inaccessible
Station – 3. Dengi Busthi	8 ⁰ 2'50.4"N	93 ⁰ 32'32.7"E	Estuarine area, only dead mangroves. At bank mangroves are regenerated, <i>Nypha fruticans</i> and <i>Rhizophora</i> sp. are sparsely distributed.
Station – 4. Expedition Harbour	8 ⁰ 4'42.0"N	93 ⁰ 31'08.3"E	Degraded mangrove area.
Point I	8 ⁰ 4'40.0"N	93 ⁰ 31'17.5"E	Dried mangroves
Point II	8 ⁰ 3'56.00"N	93 ⁰ 31'26.2"E	Dead mangrove and coastal plants.
Point III	8 ⁰ 3'48.4"N	93 ⁰ 30'24.0"E	Inaccessible due to mangrove debris. Dead and degraded mangroves
Station – 5. Port bay	8 ⁰ 0'97.5"N	93 ⁰ 30'32.5"E	Dried mangrove.
Point I	8 ⁰ 0'50.3"N	93 ⁰ 30'25.00"E	Only dead mangroves are distributed, inaccessible to shore.
Station – 6. Vikas nagar (16km)	8 ⁰ 7'28.8"N	93 ⁰ 31'13.6"E	Dead mangroves remains and sea invaded for more than 100 meters towards landward side.
NONCOWRY ISLAND			
Station -1 Wasp bay	8 ⁰ 1'13.6"N	93 ⁰ 31'43.1"E	Degraded mangrove area.
Point I	8 ⁰ 0'28.5"N	93 ⁰ 31'50.4"E	Dried mangroves
Point II	8 ⁰ 0'15.00"N	93 ⁰ 31'37.6"E	Dried mangrove and coastal plants
Point III	07 ⁰ 59'48.1"N	93 ⁰ 31'15.6"E	Only dead mangroves, Sea water intruded up to mountain slope No mud flats
Station 2. Spiteful Bay	8 ⁰ 1'07.7"N	93 ⁰ 32'17.7"E	Dead mangrove area.
Point I	8 ⁰ 0'46.5"N	93 ⁰ 32'31.0"E	No mangroves and coastal plants
Point II	7 ⁰ 59'55.4"N	93 ⁰ 32'53.9"E	Degraded mangrove area
Point III	07 ⁰ 59'34.7"N	93 ⁰ 33'01.1"E	Only dead mangroves, Sea water intruded upto mountain slope No mud flats

Station 3. Edged Rock	8 ⁰ 01'23.3"N	93 ⁰ 33'35.4"E	<i>Rhizophora</i> sp. and <i>Ceriops</i> sp. are naturally regenerated Around 50 saplings of 2-3 feet high.
TRINKET ISLANDS - Station- 1 Kuikemeta			
Point I	8 ⁰ 06'54.5"N	93 ⁰ 33'56.6"E	Dried mangrove area.
Point II	8 ⁰ 06'30.4"N	93 ⁰ 33'42.8"E	Dead and degraded mangrove region.
Point III	8 ⁰ 06'22.3"N	93 ⁰ 34'25.7"E	Dead mangroves, mangroves are completely washed out.
Station 2 Ola ona creek Point I	8 ⁰ 04'52.7"N	93 ⁰ 35'00.2"E	Coastal plants are alone seen
Point II	8 ⁰ 04'44.3"N	93 ⁰ 35'00.8"E	Degraded mangroves
Point III	8 ⁰ 04'34.2"N	93 ⁰ 35'07.3"E	Dead mangroves
Point IV	8 ⁰ 04'06.3"N	93 ⁰ 34'23.6"E	Dead mangrove trees and coastal plants
Point V	8 ⁰ 04'10.5"N	93 ⁰ 35'17.8"E	Mangrove regeneration noticed Plants are about 2 feet (<i>Ceriops</i> sp. and <i>Rhizophora</i> sp.) Insufficient water flow.
KATCHALL ISLAND			
West bay - Point I	8 ⁰ 00'32.4"N	93 ⁰ 20'07.4"E	Degraded mangroves
Point II	8 ⁰ 00'21.9"N	93 ⁰ 19'55.4"E	Some coastal plants and dead mangroves
Point II	8 ⁰ 00'17.00"N	93 ⁰ 19'49.9"E	Only Ipomea is available, Sea intruded more than 100 meter.
CARNICOBAR ISLAND			
Kimios Bay- Point I	9 ⁰ 07'60.00"N	92 ⁰ 46'42.57"E	Totally degraded mangrove area only remnants of dead trees are seen along with a few seedlings of <i>Rhizophora</i> sp.
Point II	9 ⁰ 08'02.83"N	92 ⁰ 46'09.30"E	<i>Ceriops</i> .is noticed
Jahul Nala Point I	9 ⁰ 12'46.32"N	92 ⁰ 46'01.59"E	A few trees of <i>Nypa</i> alone surviving
Sawai Nala	9 ⁰ 12'51.60"N	92 ⁰ 45'22.31"E	A few patches of <i>Nypa</i> are alone surviving

Great Nicobar

Mapping of mangroves of this island indicate wide spread loss of mangroves in almost all the mangrove pockets of this island. Specifically speaking the larger mangrove pockets viz. Galatlea Bay and Alexandra mangrove pockets were devastated. In the Galathea region mangroves of shoreward region were totally damaged and some patches of *Nypa* and *Rhizophora-Bruguiera* were remain in the upper reaches of the Galathea estuarine system. In the case of Alexandra mangrove pocket almost all the mangroves were degraded to its maximum

extent. This condition is prevails in almost all the mangrove pockets of this island especially along the western coast Permayya Bay and Magapod island. However northern mangrove pockets have few patches of *Rhizophora-Bruguiera* dense, this could be possible because of their protected geographical locations. Satellite pictures also clearly indicate the total loss of vegetation in the Megapod island including the mangroves. Almost all the mangroves have been destroyed due to tsunami and only two trees of *Ceriops decandra* are alive with few branches in the Campbel Bay site; a few plants of *Nypa fruticans* are alive in Sasthri Nagar site. A few seedlings of *Rhizophora* and *Avicennia* of 1-2 feet height are found in the Magarnallah region and in all the other places, there are no mangroves at all. However, satellite data analysis showed presence of mangroves in the upper reaches of Galathea and Alexandria rivers and these parts were inaccessible mainly because of wood logs dumped in the water ways, blocking the boats.

Little Nicobar

Remote sensing analysis indicates the presence of few patches of degraded mangroves in the Northern parts of this island, especially along the narrow creek regions and regions protected by natural land boundaries. There is no other pockets of mangroves along the east coast while along the south western parts of this island few mangrove patches dominated by degraded and *Bruguiera-Rhizophora* were found distributed. The island has not yet recovered from the tsunami impact and due to lack of logistics; field work was not carried out.

Katchal

Major portion of mangrove area of this region is permanently flooded with seawater and the entire mangrove was destroyed. Now the degraded mangrove pockets were found distributed along the landward boundary of the West Bay. Field studies found that there are no mangroves in this island and the entire mangroves of the West Bay have been destructed. Only degraded mangroves exist.

Trinket

Large scale loss of mangroves was noticed in the Kuikemeta and olamona creak regions of this island. More interestingly loss of mangroves and

complete submerged of these mangrove area into water made this island looking like three parts. Satellite imageries indicate the presence of degraded mangrove and *Nypa* patches in the Olanona creek region especially along the landward margins. Same in the case of Kuikeneta region also and this creek is now dominated only by the degraded mangroves. Few patches of *Avicennia-Excoecaria* were also noticed along the landward side of creek. The entire mangroves of Kuikeneta and Olanona creek have been completely washed out. Only a few plants of *Ceriops* and *Rhizophora* are regenerating naturally. However, mangroves are present in the interior parts of the water ways but inaccessible for field work.

Camorta

Satellite picture indicates the existence of mangroves in the Kaulisk Bay and harbour regions especially along the interior parts of the mangroves creeks which are not exposed to the open coast. The protected creeks might have saved the mangroves of this region. The mangroves of the Expedition harbour and Grand harbour regions were totally devastated. This is because of submerged of low lying mangroves areas by seawater. These made the mangroves to die and are degraded when we visited the islands in 2007. However there are few patches of mangroves along the east coast of this island especially along the southern parts this is because of the protection provided by the Trinket island. Almost all the mangroves of this island were lost due to tsunami. Only a few linear patches of *Nypa fruticans* are found alive in the Degibusthi region. In the entire field work, it is in this site four live *Rhizophora* trees were found. In all the other parts of the island, only dead mangroves were seen.

Nancowary

Larger mangrove pockets were existed along the warp Bay and there are few mangrove patches especially *Nypa fruticans* found distributed along the interior parts of the spiteful Bay region and towards the seaward region most of the mangroves were degraded. There is no mangroves found distributed along the other parts of this island. Almost all the mangroves of this island have been washed out. In the Edged rocks region, *Rhizophora* and *Ceriops* species are naturally regenerating (approximately 5 plants/ 10 m²).

Car Nicobar

In the case of Kimios Bay it is not only mangroves are destroyed but also the entire mangrove area was deposited with coral sand and debris which made this area unsustainable for mangrove regeneration in the Bay in future. Though satellite pictures indicates the existence of larger patches of *Nypa*, *Avicennia-Excoecaria* and *Rhizophora-Bruguiera* dense mangroves it is not persist during our field studies in this island during 2007. This might be due to the reduction in water flow due to the geomorphological variations happened after the earthquake. Few linear patches of *Nypa fruticans* are found in Jahaul Nala and Teetop region. Luxuriant of mangroves existed in Kimios Bay has entirely been degraded due to tsunami. Few seedlings of *Rhizophora* and *Avicennia* are found in the site. More importantly, the entire mangrove site has been dumped with 1-2 feet high coral sands, and thereby making the entire area unsuitable for natural recovery of the mangroves.

Though considerable quantities of mangroves of different classes were classified using remote sensing data but their distribution in the field was not found to be that much. This difference between the mangrove distribution in remote sensing and field studies is largely due to the selection of satellite data. Most of the satellite data which are used for this study are early 2005 i.e. immediately after the tsunami. So, only those mangroves which escaped the fury of the tsunami waves (struggling for survival) were mapped. However, two years after when field studies were made, most of the mangrove plants were dried. The following might have contributed significantly for the death of the mangroves. Whatever mangroves escaped the fury of the giant waves could have dried later due to the physical damage and physiological stress caused by the wave force, and also by the geomorphological changes occurred in the islands. These changes include elevation of land, and dumping of coral sand in the mangrove habitat which changed the nature of these ecosystems by blocking the mangrove water ways. In addition, deposition of sediments and wood logs and permanent submergence of bottom half of the mangrove trees without any tidal exposures have led to the mangrove loss subsequently. Changes in soil chemistry including increased pH level and soil salinity levels and increased sulphur and calcium levels in the soil have made the mangrove soils toxic and anoxic, thereby unsuitable for the survival of major biota of the region.

Based on the field studies it is understood that the natural regeneration of mangroves in these islands could be difficult because of several reasons:

- Non-availability of natural seed resources, as most of the matured plants have died. So, the seed resources are very much restricted.
- Available of limited seed resources in the interior parts may not get dispersed effectively to the destroyed areas as the water ways have been very much altered and in several places, they have been blocked by dead wood logs and deposition of sand.
- Changes in mangrove soil characteristics due to dumping of coral debris and beach sands have made the mangrove habitats not suitable for mangrove growth.
- Change of soil chemistry especially increased calcium and sulphur contents in the tsunamigenic soil would not favour the mangrove seedlings to establish and grow.
- Loss of several hectares of mangrove areas due to the submergence of land permanently into sea has made these sites unsuitable for mangrove regeneration and restoration.

Mangrove communities

Nicobar is classified into six mangrove communities. Degraded mangroves exhibit the maximum area (Table 3.1.24). Plates 3.1.79 to 3.1.89 show mangroves of Nicobar islands.

Table 3.1.24: Mangrove communities of Nicobar

Mangrove Communities	Area in Hectares
Degraded mangroves	1233.12
<i>Rhizophora</i> – <i>Bruguiera</i> - Dense	512.31
<i>Nypa</i> – Dense	176.89
<i>Avicennia</i> – <i>Excoecaria</i>	174.91
Fringe mangroves	27.1
Mixed mangroves	49.75
Total	2174.08

Gujarat

Mangrove vegetation is observed in the districts – Valsad, Navsari, Surat, Anand, Bharuch, and Ahmedabad, in four districts of Saurashtra - Bhavnagar, Amreli, Junagadh and Porbandar, in Jamnagar, Rajkot, Kachchh and Kori creek area. Table 3.1.25 shows the district-wise distribution of mangrove and mangrove associate species. Plates 3.1.90 to 3.1.95 show mangroves of Gujarat.

Table 3.1.25: District-wise distribution of mangrove and mangrove associate species

District	Mangrove	Mangrove associate
Valsad	<i>Avicennia marina</i>	<i>Porteresia coarctata</i>
	<i>Acanthus ilicifolius</i>	<i>Aeluropus lagopoides</i>
	<i>Sonneratia apetala</i>	<i>Suaeda nudiflora</i>
	<i>Aegiceras corniculatum</i>	<i>Sesuvium portulacastrum</i>
	<i>Avicennia officinalis</i>	<i>Salvadora persica</i>
	<i>Bruguiera cylindrica</i>	<i>Thespesia populnea</i>
	<i>Ceriops tagal</i>	<i>Phoenix sylvestris</i>
	<i>Lumnitzera racemosa</i>	<i>Casuarina equisetifolia</i>
	<i>Excoecaria agallocha</i>	
	<i>Rhizophora mucronata</i>	
Navsari	<i>Avicennia marina</i>	<i>Porteresia coarctata</i>
	<i>Acanthus ilicifolius</i>	<i>Aeluropus lagopoides</i>
	<i>Sonneratia apetala</i>	<i>Suaeda nudiflora</i>
	<i>Bruguiera cylindrica</i>	<i>Sesuvium portulacastrum</i>
	<i>Ceriops tagal</i>	<i>Salvadora persica</i>
	<i>Rhizophora mucronata</i>	<i>Thespesia populnea</i>
		<i>Derris trifoliata</i>
Surat		<i>Clerodendrum inerme</i>
	<i>Avicennia marina</i>	<i>Porteresia coarctata</i>
	<i>Acanthus ilicifolius</i>	<i>Aeluropus lagopoides</i>
	<i>Sonneratia apetala</i>	<i>Suaeda nudiflora</i>
		<i>Sesuvium portulacastrum</i>
		<i>Salvadora persica</i>
Bharuch		<i>Caesalpinia cricta</i>
	<i>Avicennia marina</i>	<i>Porteresia coarctata</i>
		<i>Aeluropus lagopoides</i>
		<i>Suaeda nudiflora</i>
		<i>Sesuvium portulacastrum</i>
Anand		<i>Salvadora persica</i>
	<i>Avicennia marina</i>	<i>Porteresia coarctata</i>
		<i>Aeluropus lagopoides</i>

		<i>Suaeda nudiflora</i>
		<i>Sesuvium portulacastrum</i>
		<i>Salvadora persica</i>
Ahmedabad	<i>Avicennia marina</i>	<i>Porteresia coarctata</i>
		<i>Aeluropus lagopoides</i>
		<i>Suaeda nudiflora</i>
		<i>Sesuvium portulacastrum</i>
		<i>Salvadora persica</i>
Bhavnagar	<i>Avicennia marina</i>	<i>Porteresia coarctata</i>
		<i>Aeluropus lagopoides</i>
		<i>Suaeda nudiflora</i>
		<i>Sesuvium portulacastrum</i>
		<i>Salvadora persica</i>
		<i>Salicornia brachiata</i>
Amreli	<i>Avicennia marina</i>	<i>Suaeda nudiflora</i>
		<i>Sesuvium portulacastrum</i>
		<i>Salvadora persica</i>
		<i>Salicornia brachiata</i>
Junagadh	<i>Avicennia marina</i>	<i>Suaeda nudiflora</i>
		<i>Sesuvium portulacastrum</i>
		<i>Salvadora persica</i>
		<i>Salicornia brachiata</i>
Porbandar	<i>Avicennia marina</i>	<i>Suaeda nudiflora</i>
		<i>Sesuvium portulacastrum</i>
		<i>Salvadora persica</i>
		<i>Salicornia brachiata</i>
Jamnagar	<i>Avicennia marina</i>	<i>Suaeda nudiflora</i>
	<i>Ceriops tagal</i>	<i>Sesuvium portulacastrum</i>
	<i>Rhizophora mucronata</i>	<i>Salvadora persica</i>
	<i>Aegiceras corniculatum</i>	<i>Salicornia brachiata</i>
		<i>Ipomoeae pes-caprae</i>
		<i>Arthocnemum indicum</i>
Rajkot	<i>Avicennia marina</i>	<i>Suaeda nudiflora</i>
	<i>Ceriops tagal</i>	<i>Sesuvium portulacastrum</i>
	<i>Rhizophora mucronata</i>	<i>Salvadora persica</i>
	<i>Aegiceras corniculatum</i>	<i>Salicornia brachiata</i>
		<i>Ipomoeae pes-caprae</i>
		<i>Arthocnemum indicum</i>
	<i>Ceriops tagal</i>	<i>Sesuvium portulacastrum</i>
	<i>Rhizophora mucronata</i>	<i>Salvadora persica</i>
		<i>Salicornia brachiata</i>
		<i>Ipomoeae pes-caprae</i>
		<i>Arthocnemum indicum</i>

South Gujarat

The total mangrove cover in south Gujarat is 81.09 km². Comparatively more area of Bharuch is under mangrove vegetation (62.18 km²) than Valsad (18.90 km²).

Ahmedabad

The area under mangrove vegetation in Ahmedabad district is 36.32 km².

Saurashtra

Among the four districts of Saurashtra, Porbandar covers maximum mangrove vegetation (92.05 km²), followed by Amreli (63.83 km²). Mangrove vegetation accounts for 24.22 km² and 10.80 km² in Junagadh and Bhavnagar respectively.

Jamnagar

This district occupies 149.62 km² area of mangrove cover.

Kori creek area

This area occupies the maximum mangrove cover in Gujarat (407.77 km²).

Kachchh

The mangrove vegetation in Kachchh is about 197.55 km² - second largest mangrove area after Kori creek area in Gujarat.

Table 3.1.26: District-wise area statistics of mangrove communities

	Very Dense <i>Avicennia marina</i>	Moderately Dense <i>Avicennia marina</i>	Degraded <i>Avicennia marina</i>	Sparse <i>Avicennia marina</i>	<i>Avicennia</i> - <i>Ceriops</i> - <i>Rhizophora</i> Mixed Dense	<i>Ceriops</i> <i>Rhizophora</i> Mixed Dense	<i>Acanthus ilicifolius</i> Sparse	<i>Sonneratia apetala</i> <i>A.marina</i> Moderately Dense	Total
Valsad	1108.94	3581.88	785.73	6116.48	0.00	0.00	0.00	0.00	11593.03
Bharuch, Surat, Navsari	661.58	2210.82	279.00	3067.02	0.00	0.00	0.00	0.00	6218.42
Ahmedabad, Anand	423.16	1036.07	60.76	2111.69	0.00	0.00	0.00	0.00	3631.68
Bhavnagar	24.19	284.25	184.89	587.08	0.00	0.00	0.00	0.00	1080.43
Amreli	0.00	50.74	261.08	326.47	0.00	0.00	0.00	0.00	638.28
Junagadh	0.00	0.00	0.00	24.22	0.00	0.00	0.00	0.00	24.22

Porbandar	0.00	1.93	0.00	90.13	0.00	0.00	0.00	0.00	92.05
Jamnagar, Rajkot	259.46	1825.53	4998.98	7571.78	232.57	73.80	0.00	0.00	14962.13
Kachchh	0.00	849.43	12505.36	6399.95	0.00	0.00	0.00	0.00	19754.73
Kori Creek	0.00	2856.97	19559.31	18360.87	0.00	0.00	0.00	0.00	40777.15

Table 3.1.27: Mangrove communities of Gujarat

Mangrove Communities	Area in Hectares
<i>Avicennia marina</i> – Very Dense	1489.87
<i>Avicennia marina</i> – Moderately Dense	9739.92
<i>Avicennia marina</i> – Degraded	37921.25
<i>Avicennia marina</i> – Sparse	39083.43
Mixed mangroves (<i>Avicennia</i> – <i>Ceriops</i> – <i>Rhizophora</i>) - Dense	232.57
Mixed mangroves (<i>Ceriops</i> – <i>Rhizophora</i>) – Dense	73.80
<i>Acanthus ilicifolius</i> – Sparse	409.18
<i>Sonneratia apetala</i> – <i>A. marina</i> - Moderately Dense	119.36
Total	89069.34

The state of Gujarat is classified into eight mangrove communities: *Avicennia marina* – Very Dense, *Avicennia marina* – Moderately Dense, *Avicennia marina* – Degraded, *Avicennia marina* – Sparse, Mixed mangroves (*Avicennia* – *Ceriops* – *Rhizophora*) – Dense, Mixed mangroves (*Ceriops* – *Rhizophora*) – Dense, *Acanthus ilicifolius* – Sparse and *Sonneratia apetala* – *A. marina* - Moderately Dense. District-wise area statistics and mangrove communities of Gujarat are given in Table 3.1.26 and Table 3.1.27 respectively.

Change detection

On one hand there has been decrease in mangrove cover (Figure 3.1.22) over the years in the Kori creek region due to increase in sedimentation, while on the other hand certain districts of south Gujarat exhibit increase in mangrove vegetations, mainly due to extensive plantations (Figure 3.1.23).

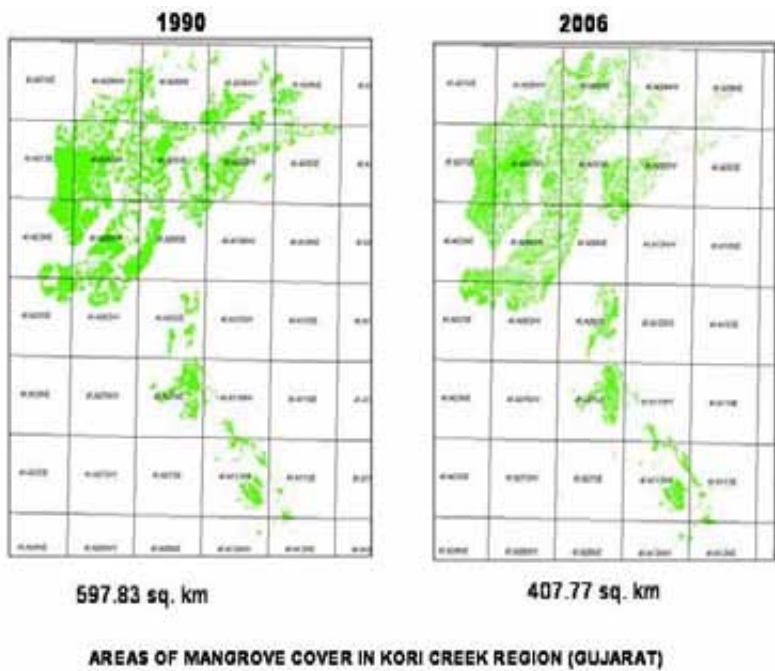


Fig. 3.1.22: Areas of mangrove cover in Kori creek region

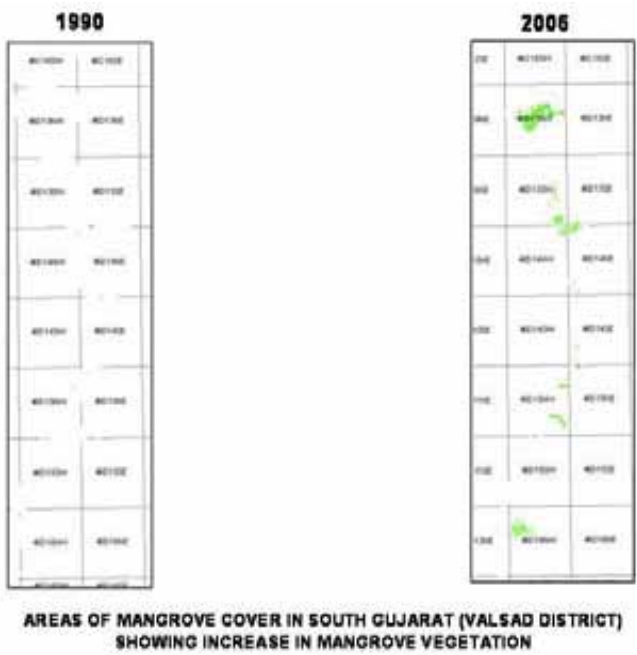


Fig. 3.1.23: Areas of mangrove cover in south Gujarat (Valsad district)

National Scenario of Mangroves

State-wise areas under mangroves based on IRS data of 2005-07 are given in Table 3.1.28. Dominant communities are also given in the table. For comparison, the mangrove area from the mapping based on 1990-93 satellite data, carried out earlier by space Applications Centre, is also given in the table. There is an overall increase in the mangrove area of the country by 515.1 sq km during the above mentioned period (1990-93 to 2005- 2007).There has been considerable decrease in mangrove vegetations in the states of Gujarat, Karnataka, Kerala, Adhra Pradesh and Andaman and Nicobar islands (from 1990-93). Significant increase in the mangrove area has been noticed for the states of Maharashtra, Goa, Tamil Nadu, Orissa and West Bengal.

Table 3.1.28: State wise area statistics of mangroves in India during 1990-93 & 2005-07

State/Union territory	1990-93	2005-07	Dominant communities
	Area in sq km		
Gujarat	1014.6	890.69	<i>Avicennia</i> (+4)
Maharashtra	222.6	270.92	<i>Avicennia</i> (+2)
Goa	6.7	34.63	<i>Avicennia</i> (+3)
Karnataka	8.7	6.05	Mixed (+2)
Kerala	10	6.63	Mixed (+4)
Tamil Nadu (TN) including Puducherry(P)	23.6	57.35 (56.66 TN, 1.70 P)	<i>Avicennia</i> (+4)
Andhra Pradesh	380	351.27	<i>Avicennia</i> (+3)
Orissa	187	221.07	<i>Avicennia</i> (+10)
West Bengal	1838	2529.27	<i>Avicennia</i> (+5)
Andaman	679	566.58	<i>Rhizophora</i> (+17)
Nicobar	70.9	21.74	<i>Rhizophora-Bruguiera</i> (+2)
Total	4441.1	4956.20	



Fig. 3.1.3: Mangrove communities zonation map of East Godavari, Andhra Pradesh

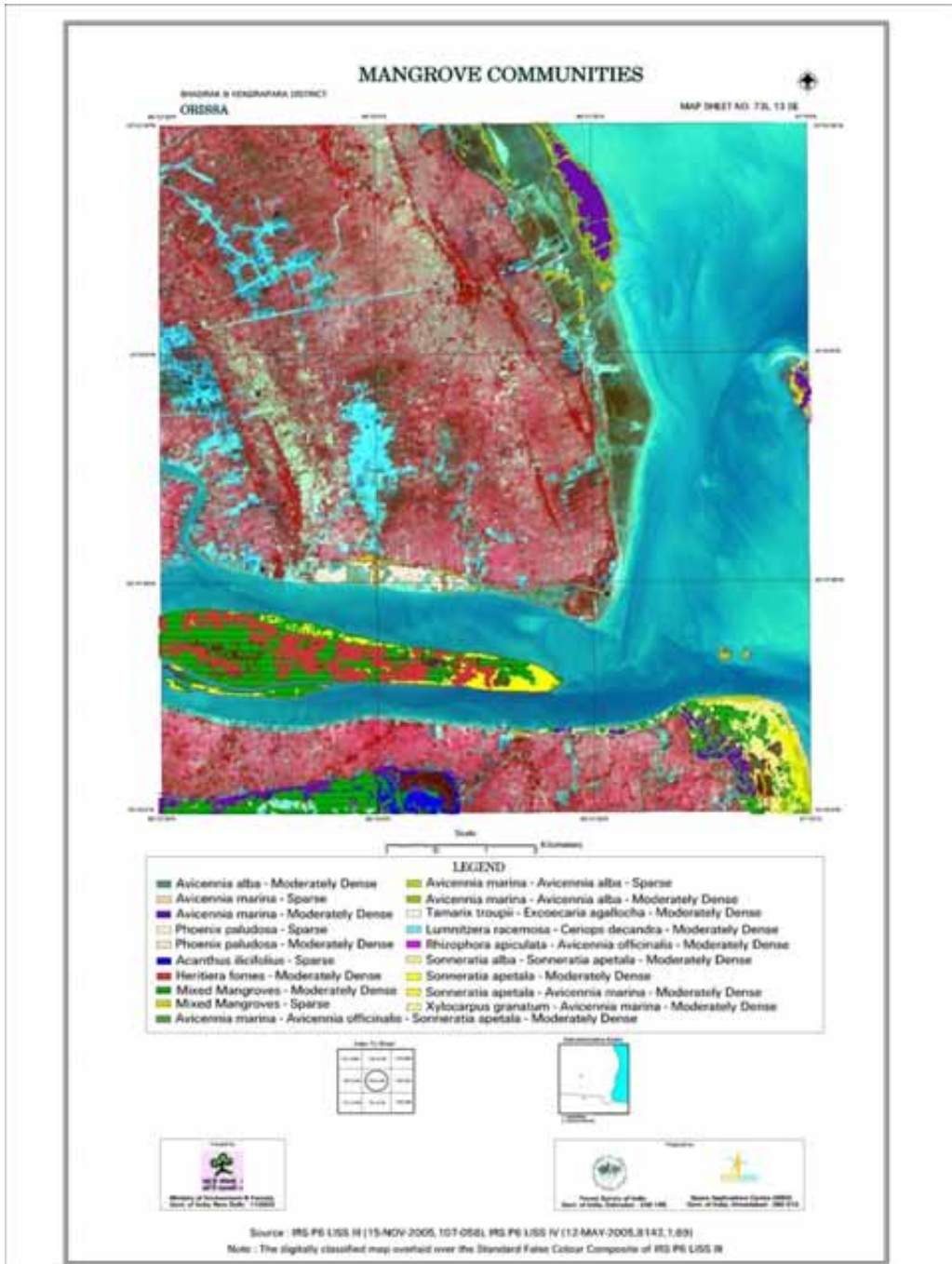


Fig. 3.1.8: Mangrove communities zonation map of Bhadrak and Kendrapara districts, Orissa

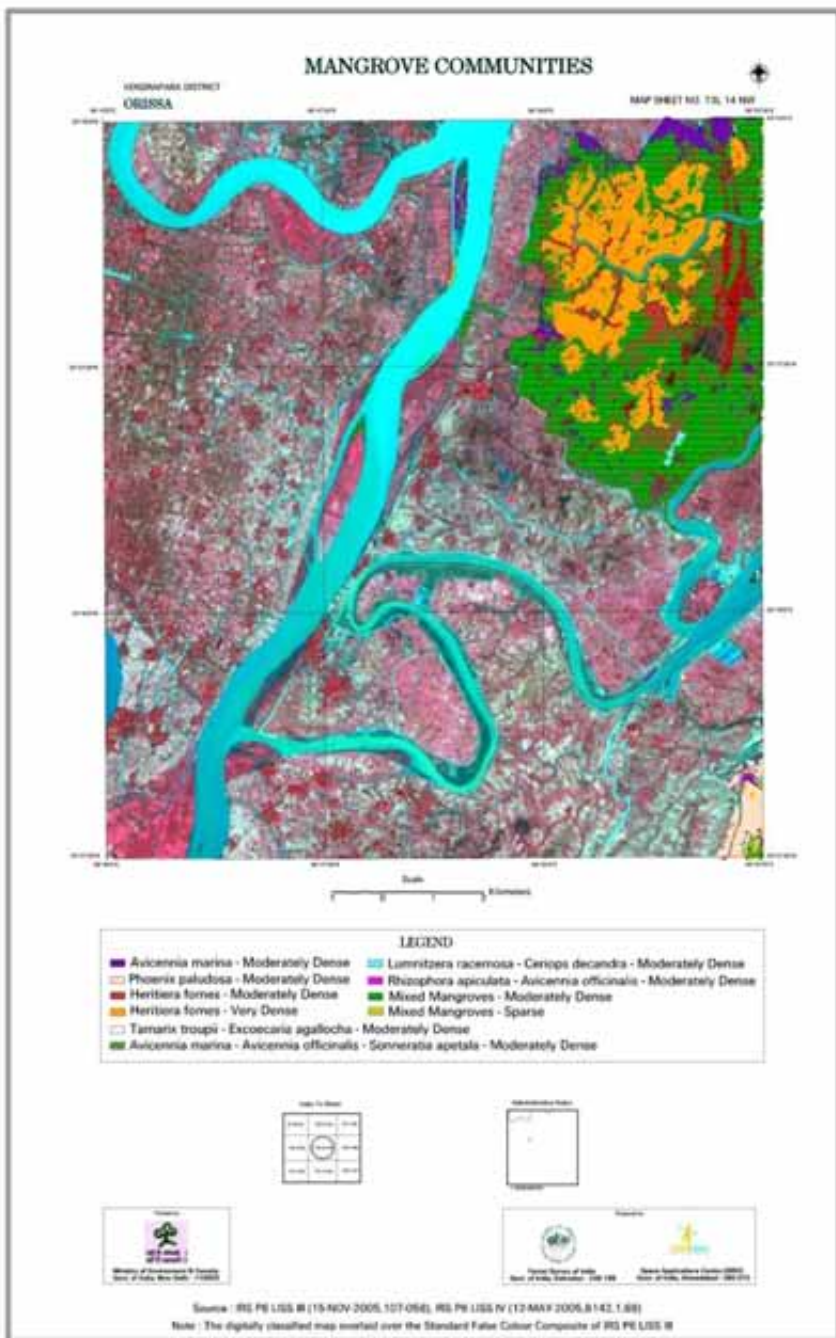


Fig. 3.1.9: Mangrove communities zonation map of Kendrapara district, Orissa

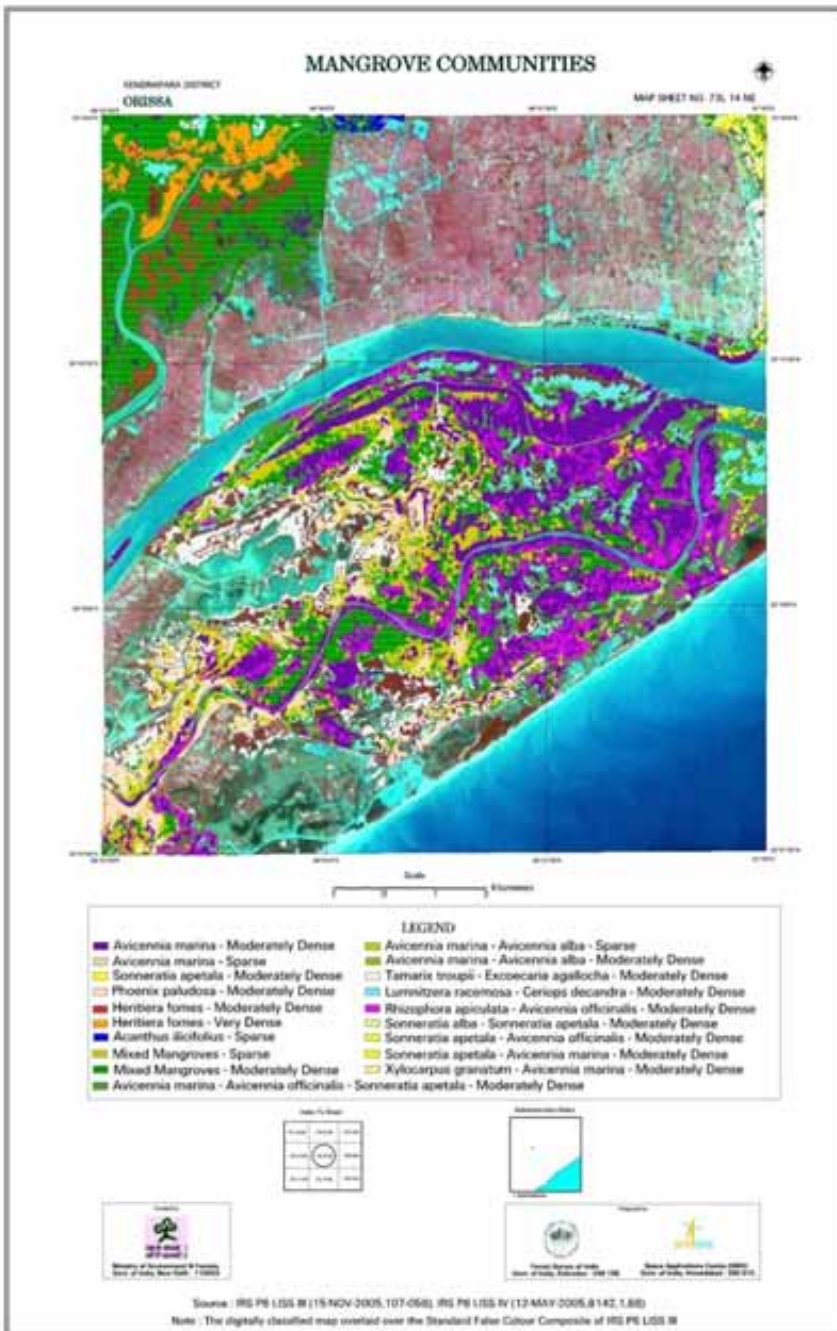


Fig. 3.1.10: Mangrove communities zonation map of Kendrapara district, Orissa

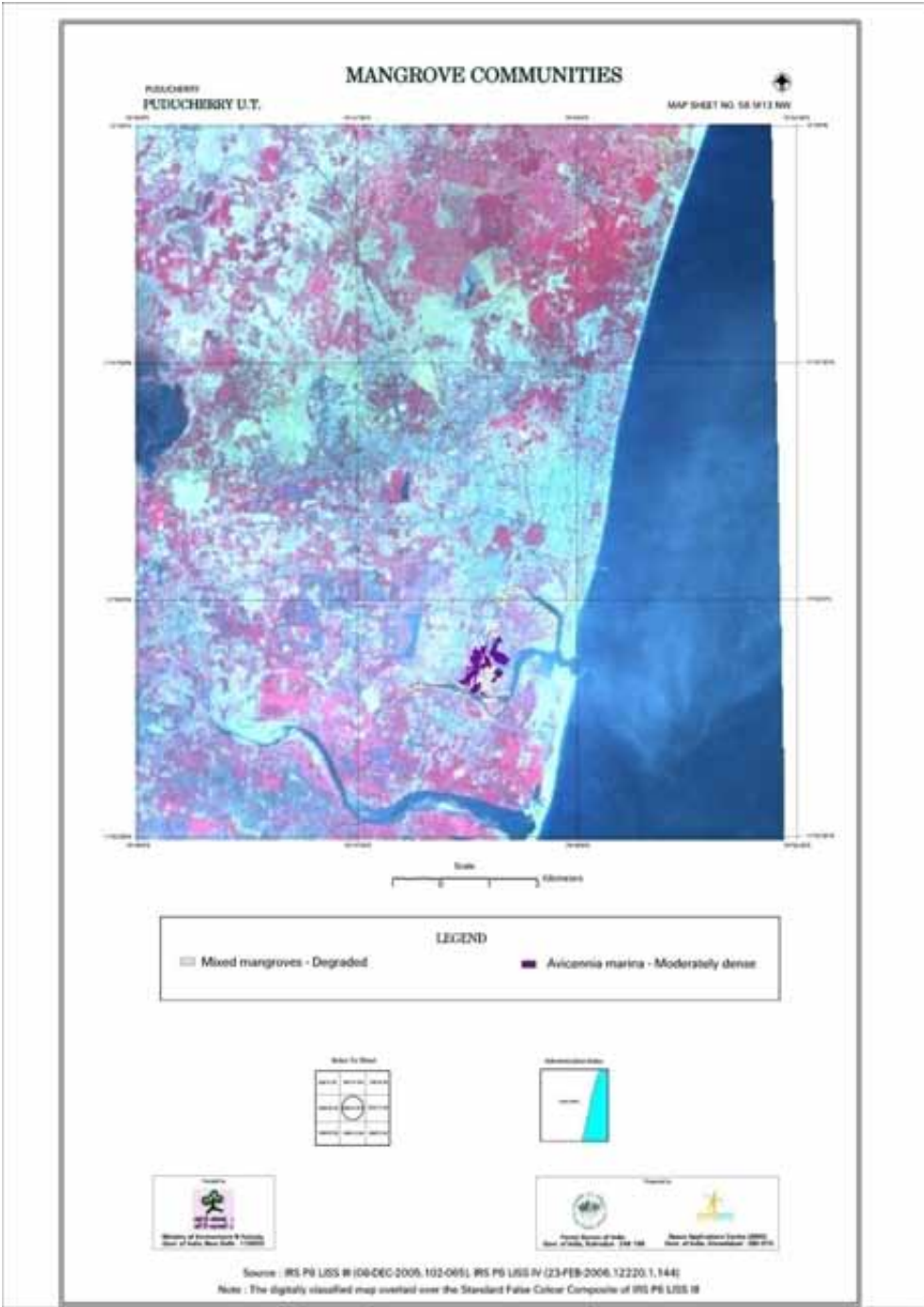


Fig. 3.1.12: Mangrove communities zonation map of Puducherry

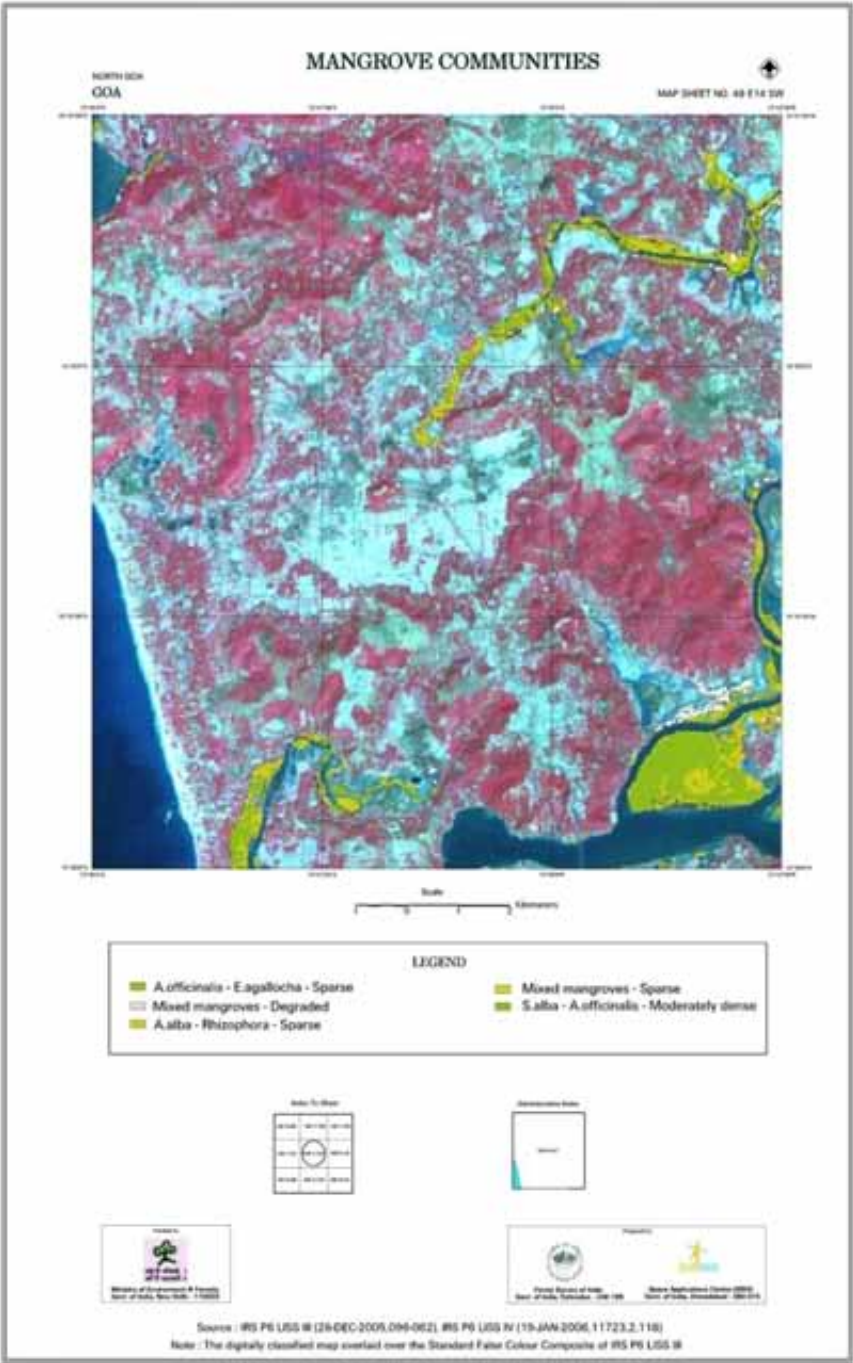


Fig. 3.1.14: Mangrove communities zonation map of North Goa

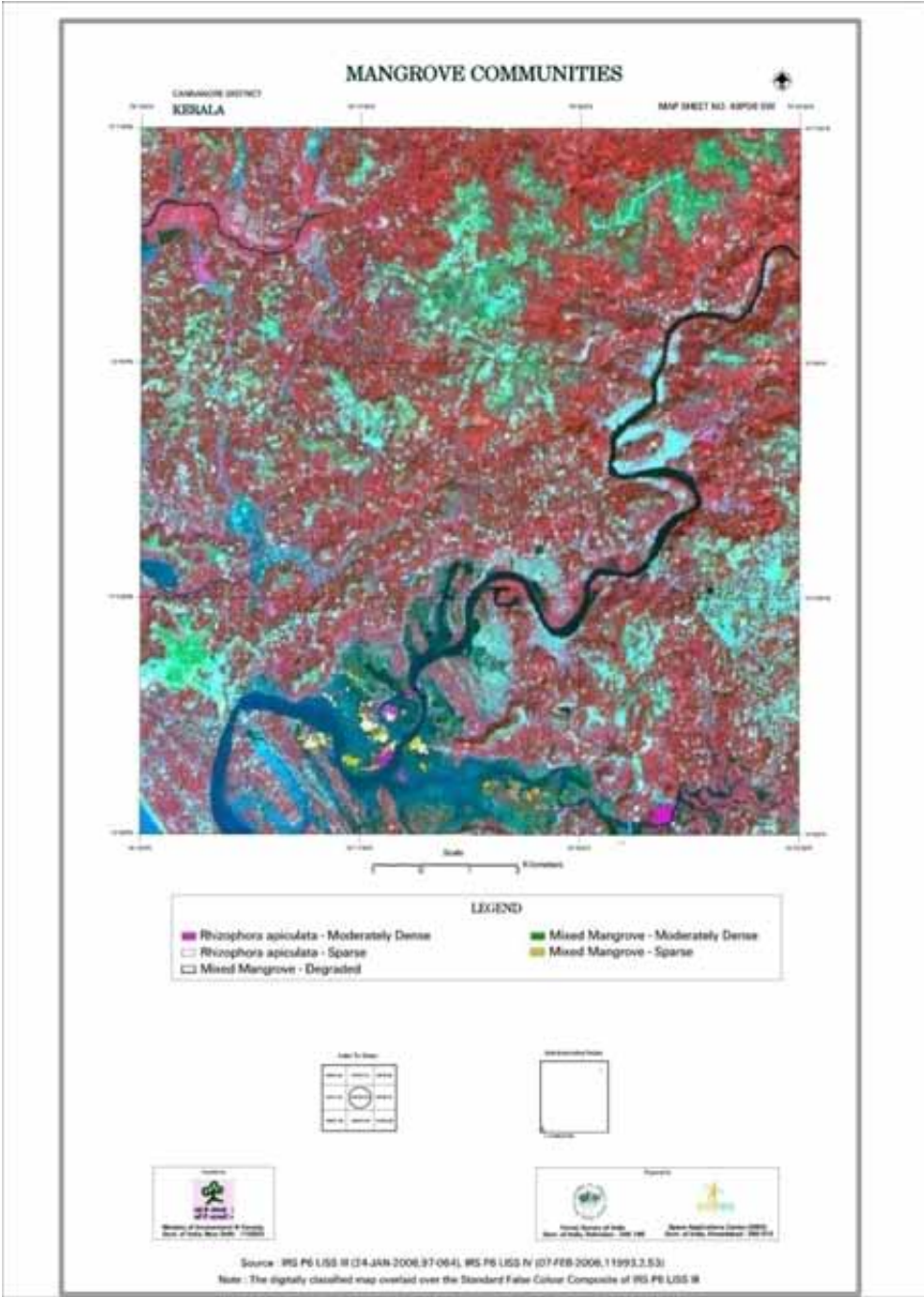


Fig. 3.1.16: Mangrove communities zonation map of Cannanore district, Kerala

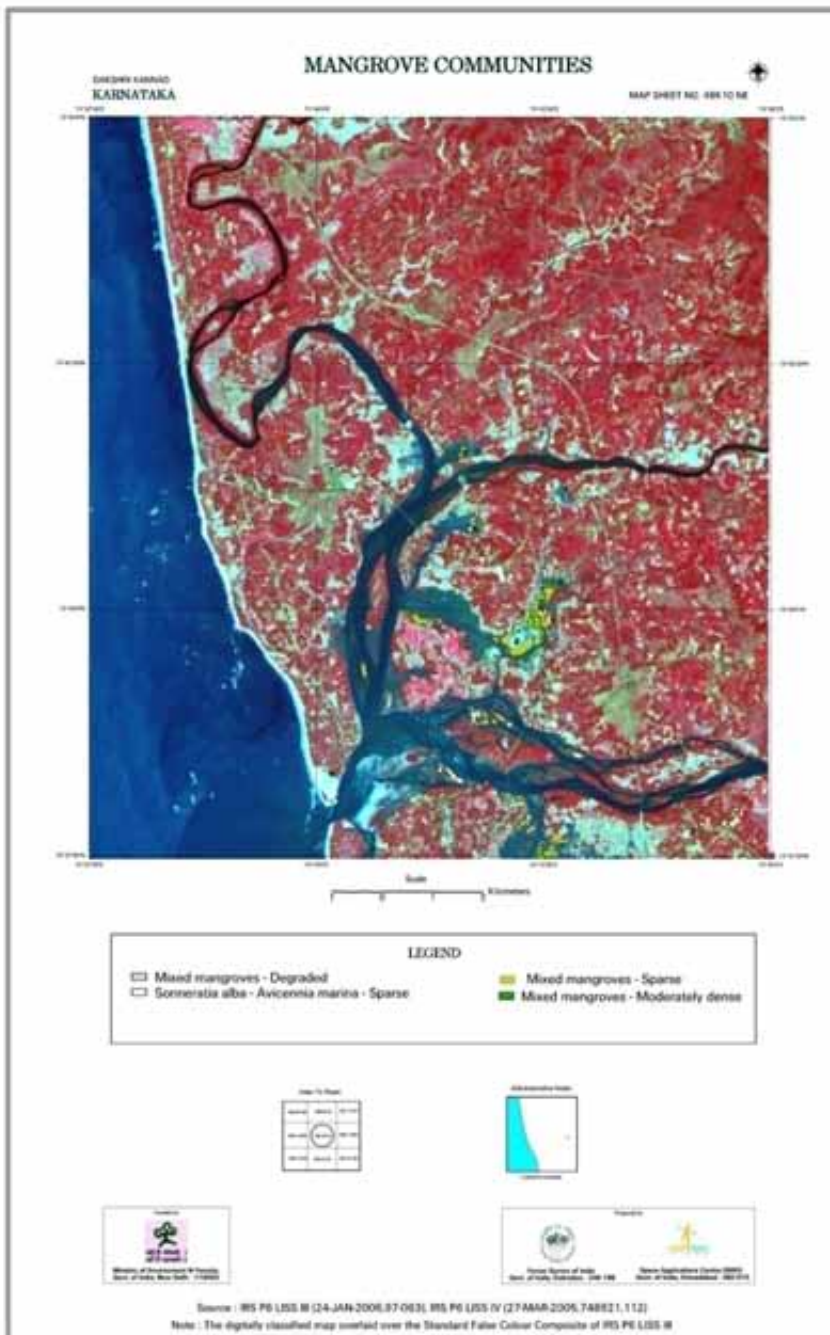


Fig. 3.1.17: Mangrove communities zonation map of Dakshin Kannad, Karnataka

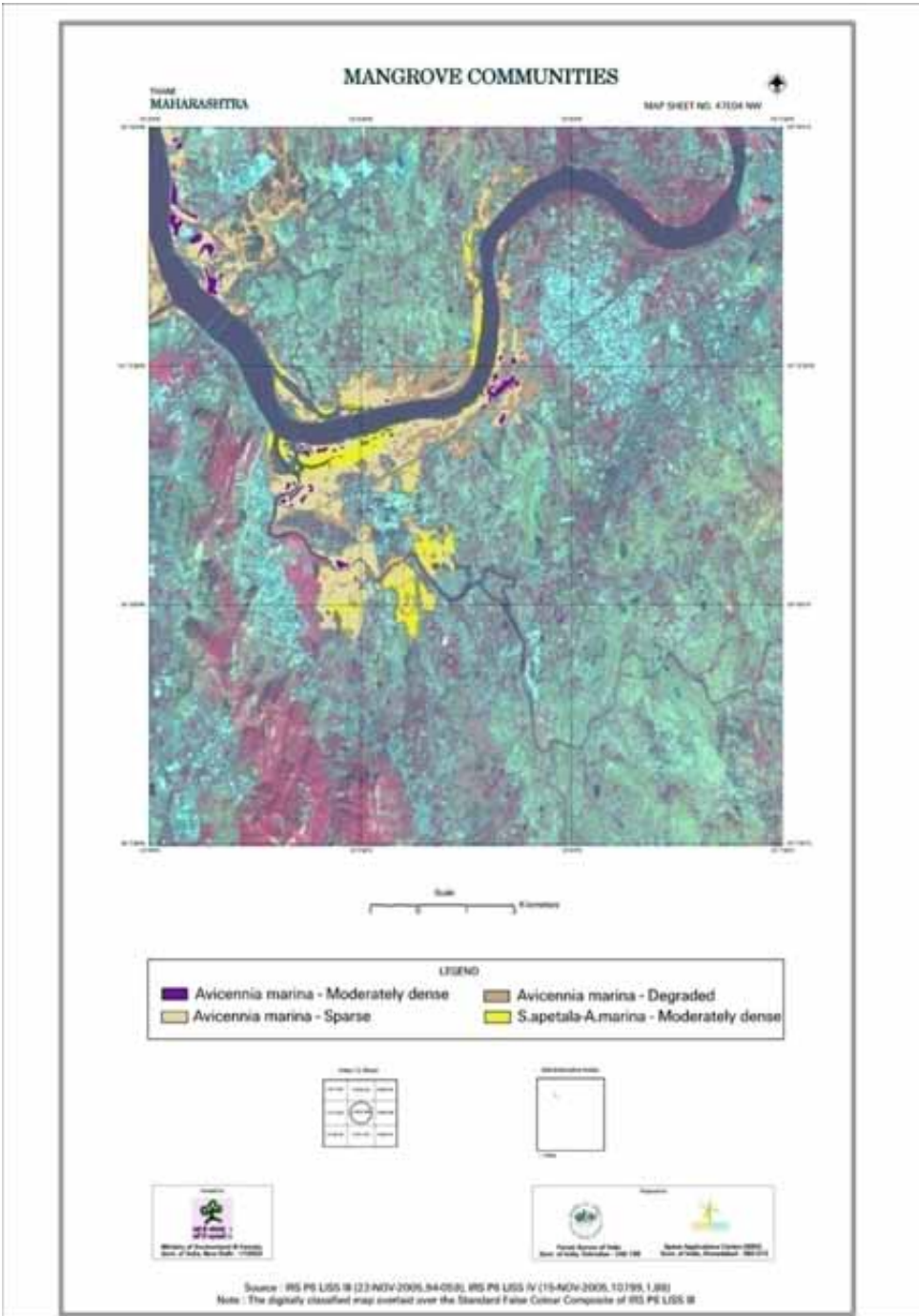


Fig. 3.1.19: Mangrove communities zonation map of Thane, Maharashtra

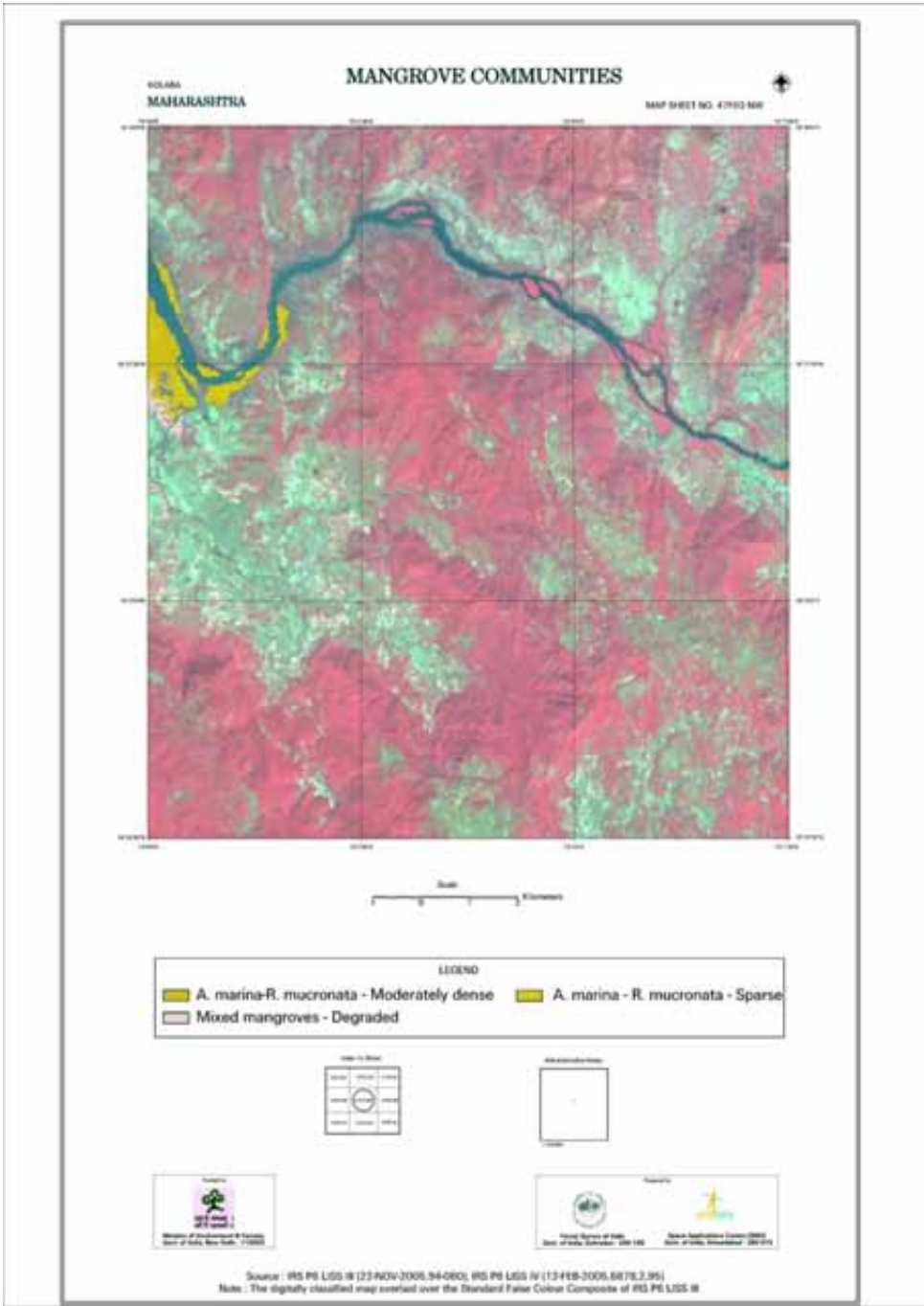


Fig. 3.1.20: Mangrove communities zonation map of Kolaba, Maharashtra

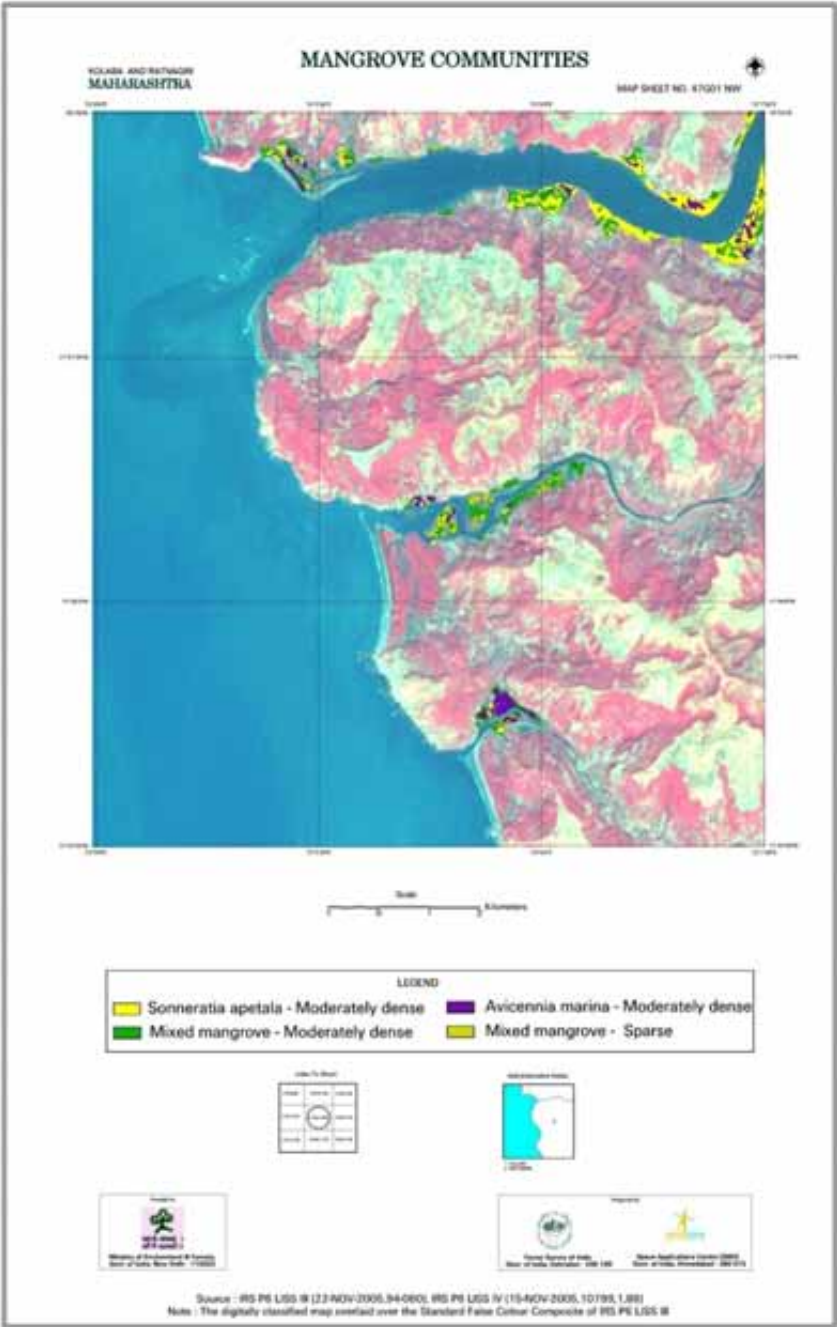


Fig. 3.1.21: Mangrove communities zonation map of Kolaba and Ratnagiri, Maharashtra

3.2 Health Monitoring

All complex systems are by definition made up of a number of interacting parts. In general these components vary in their type, structure and function within the whole system, thus simply adding the behavior of its individual parts cannot summarize a system's behavior. Ecosystem health is a normative concept: a bottom line. It represents a desired endpoint of environmental management, but the concept has been difficult to use because of the complex, hierarchical nature of ecosystems. But to understand and manage complex systems, we need some way of assessing the system's overall performance (its relative health). Amongst the most popular working definition of ecosystem health (Costanza *et. al.*, 1992) is 'An ecological system is healthy and free from distress syndrome if it is stable and sustainable that is if it is active and maintains its organization and autonomy over time and is resilient.' Without an adequate operational definition of the desired endpoint, effective management is unlikely. Several different definitions of ecosystem health have been proposed. This diversity of definitions arises from the fact that different workers have given importance to different factors that impact an ecosystem. These definitions can be grouped into the following major classes.

Health as homeostasis

Health as the absence of disease

Health as diversity or complexity

Health as stability or resilience

Health as vigor or scope of growth

Health as balance between system components

The same problems arise when we try to arrive at a definition of mangrove health. All the different aspects have to be considered to arrive at a definition that meets the end user requirement. For this a meeting of experts on the mangrove ecosystem from all over India was called during September 2007 at MSSRF, Chennai to work out a definition of mangrove health. They deliberated on various aspects related to the health of the mangrove ecosystems and what could be the exact definition of a healthy mangrove. The conservation and monitoring of the Indian mangrove ecosystem for its

management was the main purpose of defining the health of mangroves. This turned out to be tricky on account of the high diversity of mangrove habitats in the country arriving at this definition was difficult. The mangroves of the Andaman and Nicobar Islands and Bhitarkanika on one side were amongst the most diverse while the Mangroves of Gujarat on the other side had a low diversity but were thriving in very difficult environmental conditions. The following lines provide the definition of a Healthy Mangrove habitat that was the agreed upon by the group of experts.

A healthy mangrove habitat is "A natural mangrove wetland with at least 40% tree canopy cover, with a minimum of two mangrove dominant plant community zones excluding associates and with no habitat loss since the 1991 CRZ Notification." In order to facilitate the assessment of health of selected mangrove sites across the country, a methodology was also devised.

The objective is to identify environmental indicators of the mangrove habitat health and to generate a model to assess the health and mangroves-at-Risk index using remote sensing and Geographic Information System (GIS) techniques. The following area has been selected for the model development:

Pichhavaram
Gulf of Kachchh (Core MNP)
Bhitarkanika RF
Andaman (Porlob Jig and Shoal Bay)
Sunderbans (Dhanchi-Lothian and Ajamalmari)

The model Framework:

The multi-parameter mangrove health model developed, is given in Fig. 3.2.1 The model (Fig. 3.2.1) followed the cell-based grid analysis for assessing mangrove health and had the following basic framework.

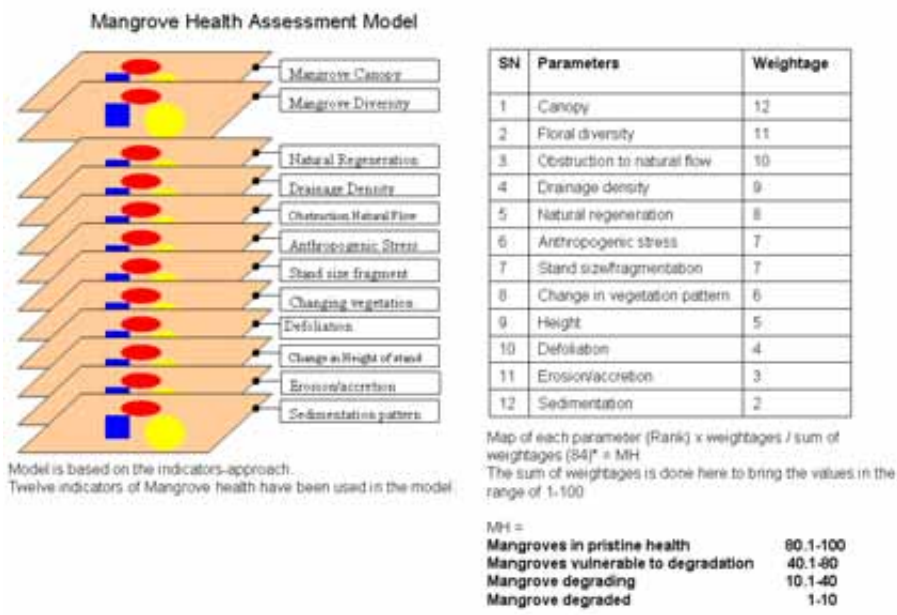


Fig. 3.2.1 Schematic diagram showing Mangrove Health Model

- The entire study area was divided into grids of 1 ha (100m x 100m) size. This forms the master grid.
- The raster maps were converted into vector coverages before any further procession was done. All the different maps, which are generated, will be intersected with the master grid and the information in them will be transferred into a column in the master grid.
- Each theme has been given a value out of 100 based on its importance in determining mangrove health.
- The values in each column (representing each theme) are then used to generate the final Mangrove Health Assessment using the table given below.

The value for each grid is multiplied by the weightage and then divided by the sum of weightages (i.e. 84).

Sr. No.	Parameters	Weightage
1.	Canopy	12
2.	Floral diversity	11
3.	Obstruction to natural flow	10
4.	Drainage density	9
5.	Natural regeneration	8
6.	Anthropogenic stress	7
7.	Stand size/fragmentation	7
8.	Change in vegetation pattern	6
9.	Height	5
10.	Defoliation	4
11.	Erosion/accretion	3
12.	Sedimentation	2

The values for each theme are calculated based on the above calculation and they are added up to give final value. The health of each grid in the study area is the obtained using the following classification.

Sr. No.	Mangrove Health Category	Value
1.	Mangroves in pristine health	80.1 - 100
2.	Mangroves vulnerable to degradation	40.1 - 80
3.	Mangrove degrading	10.1 - 40
4.	Mangrove degraded	01 - 10

Theme 1: Canopy Cover

This theme is generated from the mangrove density map. The map was intersected with the grid and the following classes the corresponding values were transferred to the grid under a new field (column). For all the other categories the value of the grid for this theme was zero.

Sr. No	Category	Value
1.	Very Dense Mangroves	100
2.	Dense mangrove	75
3.	Sparse Mangrove	40
4.	Degraded mangrove	10
5.	All other categories	0

Theme 2: Floral Diversity

The mangrove community zonation map serves to be an input for this theme. Only one time data is required. At times it is not possible to identify all species in satellite data, so field information collected using the PCQ method is also used. Grids are identified using GPS locations. The values for the theme are based on the following criteria.

Sr. No	Category	Value
1.	More than two mangrove species	100
2.	Two mangrove species	80
3.	Less than two mangrove species	60
4.	Less than two other species (associated species)	40
5.	Two other species (associated species)	20
6.	More than two other species (associated species)	10

Theme 3: Tree Height

The average height of major mangroves of Godavari (4.5m), Krishna (4.5m), Bhitarkanika (6m), Mahanadi (6 m), Andaman and Nicobar (7.7 m), Muthupet and Pichavaram (5-6 m), and Gujarat (2-3m) are considered as the height of healthy mangroves. For Gujarat the following table indicates the health of the mangroves trees related to their height. They have been assigned the respective values. For this theme, the mangrove density map and field data have been used as an input. Extrapolation of field data is done on a grid to generate this theme. The values below have been finalized as follows:

Sr. No.	Category	Tree Height	Value
1.	Healthy	2 – 3 m	100
2.	Moderately Healthy	1.5 – 2 m	75
3.	Moderately unhealthy	1 – 1.5 m	50
4.	Unhealthy	<= 1 m	25

Theme 4: Defoliation

Leaf shedding other than *E. agallocha* and *Xylocarpus* sp. in summer (or leaf shedding season) is to be considered unhealthy. As the above two species are

not found in the study area, any kind of defoliation is to be considered unhealthy.

Sr. No.	% Unseasonal defoliation	Category	Value
1.	0	Healthy	100
2.	1-10	Moderately unhealthy	60
3.	> 10	Unhealthy	10

As no case of defoliation was found in any of the field visits all the grids were considered healthy and the theme value was calculated to be 100.

Theme 5: Obstruction to natural flow of tidal and freshwater

The mangrove density map serves as an input for this theme. Formation of sandbars across river mouths or estuaries / formation of sandbars or deposition across rivers or creeks and canals as well as abrupt change in water color from black or dark blue to light blue (barrages) are all considered unhealthy. Based on the area of mangroves that they influence and the time duration for which they are found the following values have been calculated.

Sr. No.	Criteria	Value
1.	Obstruction in 1 ha area or more for more than or equal to 6 months	20
2.	Obstruction in 1 ha area or more for less than 6 months	40
3.	Obstruction in less than 1 ha area for more than or equal to 6 months	60
4.	Obstruction in less than 1 ha area for less than 6 months	80
5.	No obstruction	100

None of the three study sites in Gujarat have this indicator. (This theme is calculated by assigning the above values to each polygon of the canopy map by visually observing the obstruction and the extent of influence of such obstruction on the vegetation).

Theme 6: Drainage density

The creek network map serves as an input for this theme. This map has been prepared from LISS IV data. The width that these creeks have is put as a value

in the arc vector file. A buffer is then created using these values. Based on the percentage area that they have the following values are assigned.

Sr. No.	% Creek area	Value
1.	More than 20%	100
2.	10-20%	80
3.	5-9.9%	60
4.	1-5%	40
5.	Less than 1%	20

Theme 7: Sedimentation pattern in waterways

Very high turbidity has been considered to be unhealthy for the mangroves. Create a vector file of water bodies with classification of the below turbidity values. This will then be used to generate the proximity map and then conversion of proximity grid to vector file. This proximity will be used to assign the values of sedimentation in 1 ha grid shape file by “Select by theme option” of Arc View.

Sr. No.	Criteria	Value
1.	Highly turbid	20
2.	Moderately turbid	70
3.	Less turbid	100

Theme 8: Natural regeneration – Post monsoon field observation (binary value)

Presence of 1 seedling per square metre (10000 seedlings per ha) immediately after the monsoon season can be considered as 100% success in natural regeneration. This is calculated based on various publications which indicate presence of 11,000 to 17,000 seedlings of various species per ha in healthy mangrove ecosystem. The values for these themes are extrapolated from the field observations. These values have been indicated in the following table. A single value [whether Natural regeneration is there (100) or not (10)] is input as a field in the 1 ha grid shape file.

Sr. No.	Criteria	Health	Value
1.	Areas with Natural regeneration	Healthy	100
2.	Areas with no natural regeneration	Unhealthy	10

Theme 9: Anthropogenic stress (RS multi-temporal data)

This is the most important theme with regard to mangrove vegetation in Gujarat. They have been calculated according to the criteria provided below

	<u>Stressors:</u>	<u>Weightage</u>
a.	Pollution – discharge / oil spill -	5
b.	Dredging	4
c.	Embankment	10
d.	Grazing in the mangrove patch	8
e.	Grazing near the mangrove patch	6
f.	Direct cutting of mangroves	10
g.	Reclamation of mangrove forest (aquaculture/salt pans/residential/any other developmental activities)	10

Classification criteria:

- 1) Distance from the stress (More the distance from the mangrove stand less is the stress.
- 2) Distance from the habitation

100 m or less	10
101-500 m	20
501m-1km	40
1km – 2.5 km	60
2.5-5km	80
>5km	100
- 3) Population

<100	100
101-500	80

501-1000	60
1001-5000	40
5001-10000	20
>10000	10

Average of [Map of individual anthropogenic parameter (based on the distance from the stress) + Map of Distance from the habitation + Map of Population density] x weightage of each anthropogenic parameter

a) Pollution

No pollution	100
500m or more is the distance of the source from the mangrove stand	60
100-500 m or more is the distance from the mangrove stands	30
Less than 100m or more is the distance from the mangrove stands	10

b) Reclamation of mangrove forest (aquaculture/salt pans/residential/any other developmental activities)

Thematic layer with either point or line or polygon features of sources of pollution

c) Embankment - Presence of embankment in a creek which is the only source of freshwater for a patch will be unhealthy - 10

Presence/Absence. Presence is High stress (10). Absence is no stress (100)

d) Grazing in the mangrove patch

Presence/Absence. Presence is High stress (10). Absence is no stress (100)

e) Grazing near the mangrove patch

Presence/Absence. Presence is High stress (10). Absence is no stress (100)

f) Direct cutting of mangroves

Presence/Absence. Presence is High stress (10). Absence is no stress (100)

Single value based on above (can be entered as a field in the 1 ha grid shape file)

g) Dredging

Dredging is similar to embankment. Presence of dredging in a creek will be unhealthy - 10

Theme10: Stand size/ fragmentation of the stand

It includes the following two components. They have to be separately calculated and the put as an input into the total theme value.

- a. Change in the size of the stand [multi-temporal]
- b. Percentage of area occupied by saline blanks [one-time]

Stand size

Shape file containing change detection of old RS data (may be 1987) and latest data (2005 to 2007)

Change in the size of the stand [multi-temporal]

No change	100
1-5%	80
5.1-20%	60
20-40%	40
More than 40%	20

Saline blank

One time shape file with polygons showing saline blanks

Percentage of area occupied by saline blanks

No saline blanks	100
1-5%	80
5.1-20%	60
20-40%	40
More than 40%	20

Theme 11: Changing vegetation pattern

The input remains similar to the stand size and the following are the values for the same.

h. Mangrove to non-mangrove – UH	10
i. Mangrove to halophyte – MUH	40
j. Halophyte to mangrove – MH	60
k. Non-mangrove to mangrove – H	100
l. No change in mangroves H	100

Theme 12: Erosion / accretion (Multi temporal RS data)

Erosion – erosion of mangrove stands along shore/ river banks

Accretion – accretion of mangrove stands along shore/ river banks

- Erosion of mangroves (tide dominated mangroves) over a period is unhealthy and accretion of mangroves along the shore is healthy
- Accretion of sand inside mangrove stand is unhealthy.

Erosion	10
Accretion inside mangrove stands	20
Accretion along shore	80
No erosion	100

All these themes were then used to generate the Mangrove Health Maps

Pichhavaram

Pichavaram mangrove is one of the two major mangrove wetlands and the richest in mangrove diversity of Tamil Nadu. True mangrove species such as *Rhizophora apiculata*, *Rhizophora mucronata*, *Avicennia marina*, *Avicennia officinalis*, *Excoecaria agallocha* and Associate mangrove species like *Sueada maritima*, *Salicornia* and *Sueada monoica* are largely found Pichavaram wetlands. The wetlands act as the nursing ground for the variety of fishes and marine organisms such as mollusks, crabs, prawn, bivalves etc. The wetland

lies in the centre of the Coleroon-Vellar estuary and hence fed by sufficient amount of fresh water in monsoon season. In summer, tidal influence will be more than the freshwater flow. Many natural creeks and canals that have tidal diurnal flow inundating the mangrove vegetation also feed the wetland. There are about 12 hamlets surrounding the wetlands where people depend on mangroves for their livelihood such as fishing, firewood, grazing and fencing. In 1990s the restoration of degraded mangroves of Pichavaram carried out by MSSRF and State Forest Department lead to the increase in mangrove area from about 280 ha in 1987 to 820 ha in 2006. The devastating tsunami which hit on Tamil Nadu coast in 26 December 2004, made the local community to realize the importance of mangroves in protecting them from natural hazards. After that, the dependence on green mangroves for grazing and firewood collection is reduced owing to the participation of community in restoration of mangroves.

Temporal data of IRS satellite are used in assessing the health of mangroves. The oldest satellite data available is 1990. During the project phase, post monsoon and pre monsoon data of 2005, 2006, 2007 and 2008 are used to assess the health during all period. Primary data such as vegetation survey in mangrove forests using sample survey and track survey, presence of anthropogenic pressure (pollution, dredging, grazing, reclamation) using reconnaissance survey and the location of user villages of the mangroves are collected.

Model Development and Implimentation

The idea of developing the model to assess the health of mangroves using RS data is to quickly assess health either annually or biannually with minimum field survey. As a first step, a meeting was conducted to gather the knowledge of the mangrove experts on the indicators, which affect the health of mangroves. The outcome of the meeting is briefed below.

Mangrove health is defined as follows:

A natural mangrove wetland is said to be healthy if that contains 40% tree canopy cover with a minimum of 2 mangrove plant community zones

excluding associates with no habitat loss since 1991 (that from the year of CRZ notification)

The indicators that affect the health of mangroves are listed and a brief methodology to map the indicators using multi-temporal remote sensing data and field data collection was also documented.

- i. Canopy cover –mapped using standard methods of analyzing remote sensing data of pre and post-monsoon
- ii. Floral diversity – Mangrove community zonation using remote sensing data is done and is to be supported by species count by quadrant or PCQ method in single observation
- iii. Tree height – The average vegetation stand height is measured in single observation using site-specific standard methods.
- iv. Defoliation – Pre and Post-monsoon remote sensing data are used to map the defoliation including unseasonal shedding of *Excoecaria agallocha* and *Xylocarpus* species
- v. Obstruction to natural flow of tidal and freshwater is mapped using pre and post monsoon remote sensing data for the presence of any obstruction across waterways
- vi. Running water spread – Percentage area of running water near mangroves is calculated using the area covered by either tidal water or creeks and canals network.
- vii. Sedimentation pattern in waterways – Pre and post monsoon data to be used to map the sedimentation along the rivers, lagoons, creeks and channels and other open water bodies.
- viii. Natural regeneration – Field observations in the post monsoon season will be used to map the natural regeneration in the wetland
- ix. Anthropogenic pressure such as pollution, dredging, grazing and reclamation
- x. Stand size/ fragmentation in vegetation stand – Change in stand size/ fragmentation will be mapped using temporal remote sensing data
- xi. Change in vegetation pattern – changes such as mangrove to mangrove, mangrove to halophyte, mangrove to non-mangroves will be mapped using temporal RS data

- xii. Erosion and/or accretion – Temporal RS data will be used to map erosion/ accretion

The following section describes the criteria set for each of the above indicators in the process of quantifying the health of mangrove vegetation, data collection and preparation of thematic maps for the finalised indicators. Mangrove health model is developed by assigning weightages to each of the indicators as given in Table 3.2.1.

Following steps were carried out to finalise the mangrove health model.

1. Preliminary health assessment and review of the model output with experts in CAS Marine Biology, Annamalai University and MSSRF (February 2008) was done
2. Review and fine tuning of the ranking and weightages of the indicators in a expert consultation meet at SAC (March 2008)
3. Modification of the model according to the feed back from above two steps and also from the valuable inputs from other mangrove experts.
4. Review of the model by expert team at SAC (July 2008)
5. Discussion with other implementing institutes (Forest Survey of India - Dehradun, M. S. University, Baroda, CAS Marine Biology – Annamalainagar, ORSAC – Bhubaneswar) of the project for their feedback (July 2008). Based on the feed back and subsequent discussions.
6. The model was finalized for implementation at all the study areas.

In the final output Health of mangroves is assessed as a map showing values from 1 to 100 (healthy to unhealthy) and can be graded as:

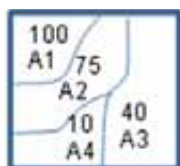
1. Mangroves in pristine health
2. Mangroves vulnerable to degradation
3. Mangrove degrading
4. Mangrove degraded

1 ha grid is generated for all the themes and average value of the indicators in each ha is taken for each grid using Avenue scripts of ArcView 3.2. All grid analyses are done using ArcView Spatial Analyst extension.

The unit size of mangrove forest to calculate mangrove health is 1 ha (100 m x 100 m square size - 10000 m² i.e. 1 ha).

Indicators

The indicator maps prepared are converted to 1 ha grids by area weighted method to assign the grid value instead of simple average value so that the accuracy of each ha grid is preserved.



$$\text{Value of the grid} = \frac{(100 * A1) + (75 * A2) + (40 * A3) + (10 * A4)}{(A1 + A2 + A3 + A4)}$$

Canopy cover – For pre and post monsoon

Very Dense Mangroves	100
Dense mangrove	75
Sparce Mangrove	40
Degraded mangrove	10

Floral diversity

More than two mangrove species	100
Two mangrove peciess	80
Less than two mangrove species	60
Less than two other species (associated species)	40
Two other species (associated species)	20
More than two other species (associated species)	10

Tree height

The average height of major mangroves of east coast of the wetlands are 4.5m in Godavari and Krishna, 6 m in Bhitarkanika and Mahanadi, 7.7 m in Andaman and Nicobar (7.7), 5 – 6 m in Muthupet and Pichavaram, 2 – 3m in Gujarat. These can be taken as reference for assigning values for healthiness of mangroves in terms of height.

Tree height – site-specific values are given (from field data)

Tree height	Index	Value
10 m and more	Healthy	100
7 –10 m	Moderately Healthy	75
3 – 7 m	Moderately Unhealthy	50
<= 3 m	Unhealthy	25

In height shape file, the index value is entered as 100 or 75 or 50 or 25 in a separate field. The range of height values are specific to Pichavaram, hence for the other sites, they are modified based on the field data on vegetation height of respective sites.

Defoliation

Leaf shedding other than *E. agallocha* and *Xylocarpus* sp. in summer (or leaf shedding season) will be unhealthy.

Defoliation	Index value
0 % Un-seasonal defoliation – healthy	100
1-10 % - Moderately unhealthy	60
More than 10% - Unhealthy	10

Obstruction to natural flow of tidal and freshwater – Remote sensing data of pre and post monsoon

Formation of sandbars across river mouths/ estuaries – Unhealthy

Formation of sandbars/ deposition across rivers/ creeks and canals – unhealthy

Abrupt change in the colour of water from black or dark blue to light blue (barrages) – unhealthy

Obstruction in 1 ha area or more for more than or equal to 6 months	20
Obstruction in 1 ha area or more for less than 6 months	40
Obstruction in less than 1 ha area for more than or equal to 6 months	60
Obstruction in less than 1 ha area for less than 6 months	80
No obstruction	100

The above classification defined earlier is modified as....

Obstruction for more than or equal to 6 months	20
Obstruction for less than 6 months	60
No obstruction	100

Pichavaram does not have this indicator and preparation of this thematic map was worked out for Godavari Sanctuary by taking the modified range of values. Proximity maps are created using grid analysis.

This has to be done in three steps: 1) assigning the above values to water ways i.e., polygon and/or line map, 2) creating proximity map for the waterways 3) updating the canopy grid map with this proximity map and 4) running the obstruction to natural flow menu similar to running “Canopy” to GRID values.

Drainage density – Remote sensing data (using Cartosat data) (For unit of 1 ha)

More than 20% percentage creek area	100
10-20%	60-80
5-9.9%	40-59.9
1-5%	20-39.9
Less than 1%	10-19.9

Create a polygon shape file for water and line shape file for drainage lines along with a field specifying width of the drainage lines.

Sedimentation pattern in waterways

> 30 %	Unhealthy
20 – 30 %	Moderately Healthy
10 – 20 %	Healthy
< 10 %	Unhealthy
Highly turbid	20
Moderately turbid	70
Less turbid	100

Create a vector file of water bodies with classification of the above sedimentation. This will then be used to generate the proximity map and then conversion of proximity grid to vector file. This proximity will be used to assign the values of sedimentation in 1 ha grid shape file by “Select by theme option” of Arc View.

Natural regeneration – Post monsoon field observation (binary value)

Areas with Natural regeneration – Healthy

Areas with no natural regeneration – Unhealthy

Field + %Area of vegetation in Intertidal Mudflat and Subtidal Mudflat (pale red or pink tone in the img)

(Presence of 1 seedling per square metre (10000 seedlings per ha) immediately after the monsoon season can be considered as 100% success in natural regeneration. This is calculated based on various publications which indicate presence of 11,000 to 17,000 seedlings of various species per ha in healthy mangrove ecosystem.

So for 10 x 10 m plot (100 sq km) in field survey;

>100 seedlings	100
80 – 100	80
60 – 80	60

40 – 60	40
20 – 40	20
<20	10

Interpolation is done from the field survey data for 10 x 10 m grid and then aggregate the values for 1 ha grid.

Single value (Natural regeneration is there (100) or not (10) as a field in the 1 ha grid shape file.)

Anthropogenic stress (RS multi-temporal)

Following are the list of anthropogenic stressors considered to influence the health of mangroves.

<u>Stessors:</u>	<u>Weightage</u>
a. Pollution – discharge / oil spill -	5
b. Dredging	4
c. Grazing in the mangrove patch	8
d. Grazing near the mangrove patch	6
e. Direct cutting of mangroves	10
f. Reclamation of mangrove forest (aquaculture/ saltpans/ residential/any other developmental activities)	10

Classification criteria:

1) Distance from the stress (More the distance from the mangrove stand less is the stress.

2) Distance from the habitation

100 m or less	10
101-500 m	20
501m –1 km	40
1km – 2.5 km	60
2.5-5km	80
>5km	100

3) Population

<100	100
101-500	80
501-1000	60
1001-5000	40
5001-10000	20
>10000	10

Average of [Map of individual anthropogenic parameter (based on the distance from the stress) + Map of Distance from the habitation + Map of Population density] x weightage of each anthropogenic parameter

a) Pollution

No pollution	100
500 m or more is the distance of the source from the mangrove stand	60
100-500 m or more is the distance from the mangrove stand	30
Less than 100 m or more is the distance from the mangrove stand	10

b) Reclamation of mangrove forest (aquaculture/salt pans/residential/any other developmental activities)

Thematic layer with either point or line or polygon features of sources of pollution

Presence/Absence: Presence is High stress (10). Absence is no stress (100)

c) Grazing in the mangrove patch

d) Grazing near the mangrove patch

e) Direct cutting of mangroves

Single value based on above (can be entered as a field in the 1 ha grid shape file)

f) Dredging – similar to embankments

Stand size/ fragmentation of the stand (RS multi temporal data)

i. Change in the size of the stand [multi-temporal]

ii. Percentage of area occupied by saline blanks [one-time]

Change in the size of the stand [multi-temporal]

No change	100
1-5%	80
5.1-20%	60
20-40%	40
More than 40%	20

Percentage of area occupied by saline blanks

No saline blanks	100
1-5%	80
5.1-20%	60
20-40%	40
More than 40%	20

a. Stand size

Shape file containing change detection of old RS data (1989-91 time frame) and latest data (2005 to 2007- total 6 change detection files). Attributes should have “mangrove to non-mangrove” or “mangrove to halophyte” or “halophyte to mangrove” or “non-mangrove to mangrove” or “no change in mangroves” and the respective values as given in “11. Change in vegetation pattern”.

b. Saline blank

One time shape file with polygons showing only saline blanks and run respective menu item.

Changing vegetation pattern (Multi temporal RS data) from 1991 to recent (2005-07)

- Mangrove to non-mangrove – UH 10
- Halophyte to non-mangrove 20
- Mangrove to halophyte – MUH 40
- Halophyte to Halophyte 50

- Halophyte to mangrove – MH 60
- Non-mangrove to halophyte 60
- Non-mangrove to mangrove – H 100
- No change in mangroves H 100

Same as stand size

Erosion / accretion (Multi temporal RS data)

Erosion – erosion of mangrove stands along shore/ river banks

Accretion – accretion of mangrove stands along shore/ river banks

- Erosion of mangroves (tide dominated mangroves) over a period is unhealthy and accretion of mangroves along the shore is healthy
- Accretion of sand inside mangrove stand is unhealthy.

Erosion	10
Accretion inside mangrove stands	20
Accretion along shore	80
No erosion	100

GIS overlay method by assigning weightages to each layer was considered to assess the health of the mangrove. Table 3.2.1 shows the weightage assigned to each health indicator.

Table 3.2.1: Weightages for each health indicator as given by mangrove experts

SN	Parameters	Weightage
1	Canopy	12
2	Floral diversity	11
3	Obstruction to natural flow	10
4	Drainage density	9
5	Natural regeneration	8
6	Anthropogenic stress	7
7	Stand size/fragmentation	7
8	Change in vegetation pattern	6
9	Height	5

10	Defoliation	4
11	Erosion/accretion	3
12	Sedimentation	2

Map of each parameter (Rank) x weightages / sum of weightages (84)* = MH
The sum of weightages is done here to bring the values in the range of 1-100
Thus MH =

Mangroves in pristine health	80.1-100
Mangroves vulnerable to degradation	40.1-80
Mangrove degrading	10.1-40
Mangrove degraded	1-10

As the unit size of mangrove forest health assessment is 1 ha, shape file of grids of 1 ha (100m x 100m) is prepared over the study area covering the mangroves (shown in Fig. 3.2.2). Thematic maps of each indicator converted to grids of 1 ha as described earlier, are given below in Figs. 3.2.2 - 3.2.11.

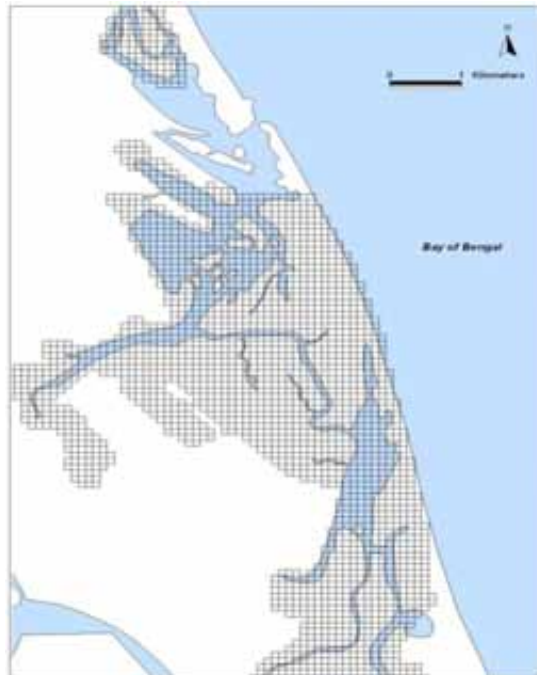


Fig. 3.2.2: Shoreline map of Pichavaram overlaid with 1 ha grids for health assessment

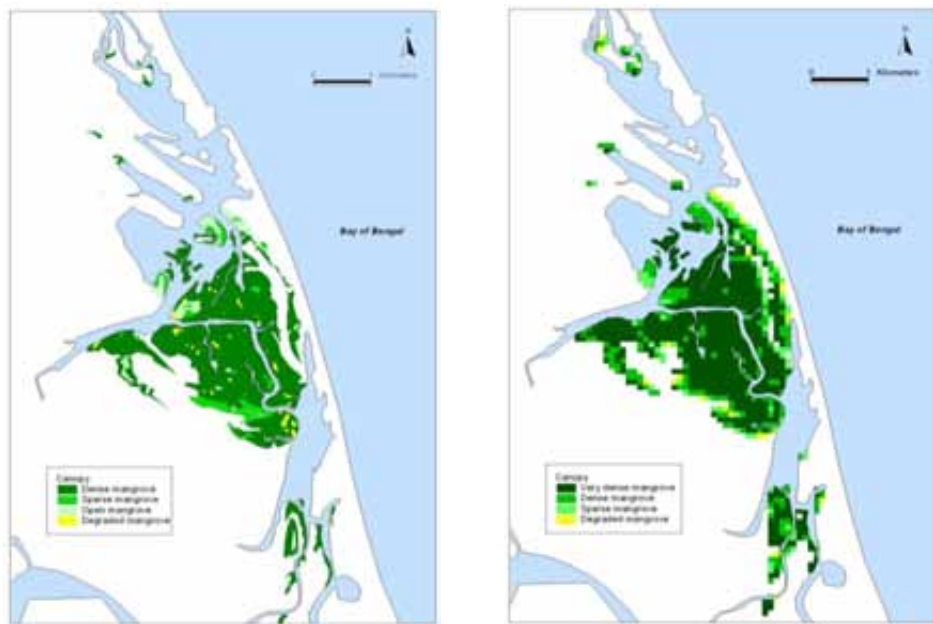


Fig. 3.2.3: Canopy map and canopy map converted into GRID of 1 ha by area-weighted assignment

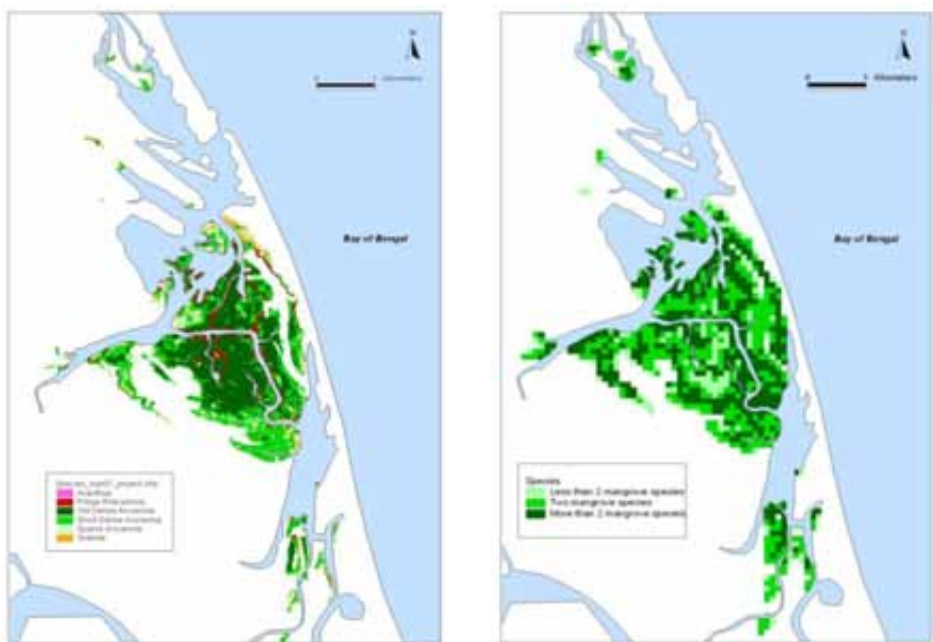


Fig. 3.2.4: Mangrove community zone map and converted into 1 ha grid

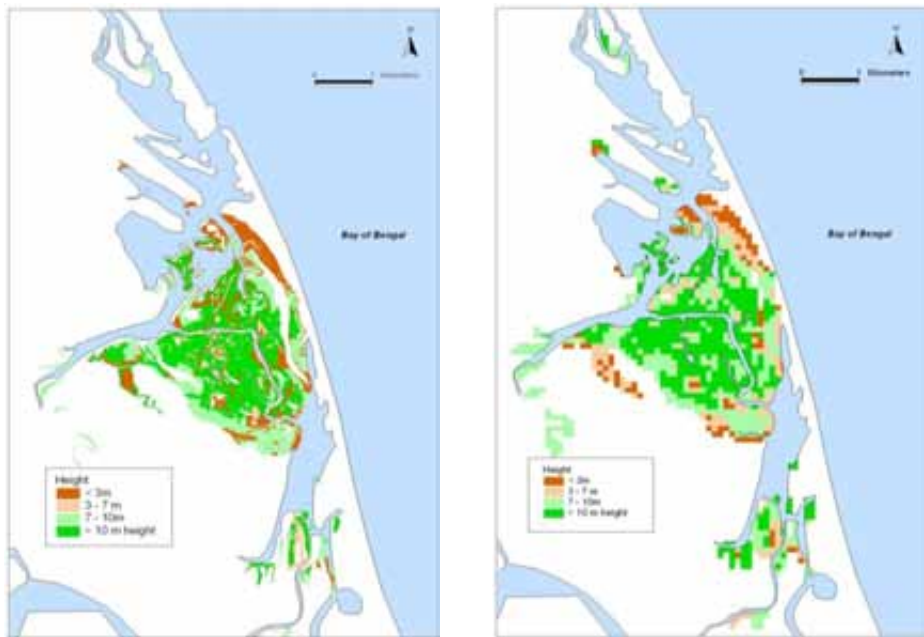


Fig. 3.2.5: Height of mangrove vegetation and converted to 1 ha by weighted area

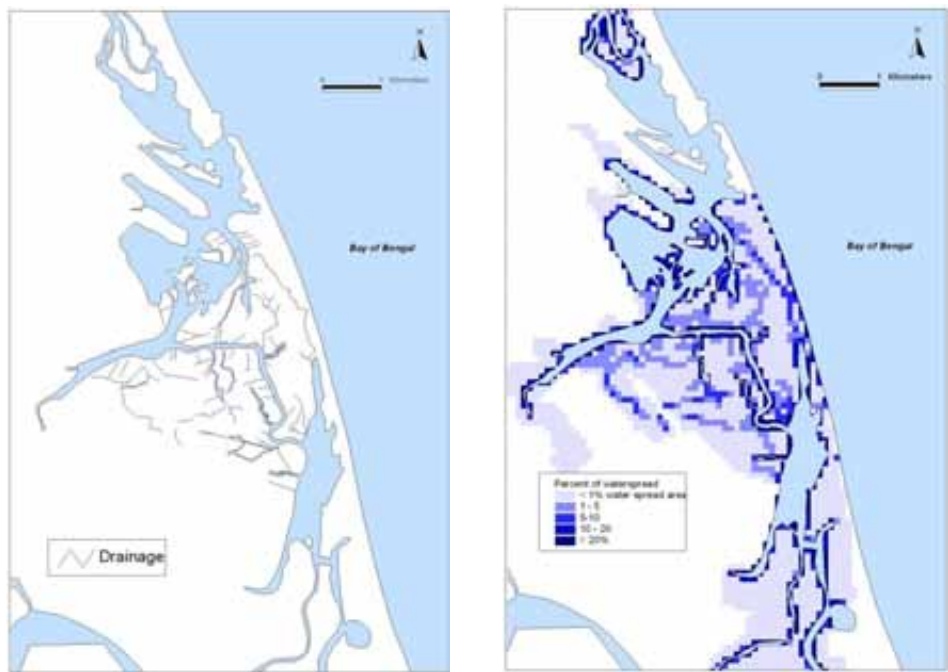


Fig. 3.2.6: Drainage map and converted water spread in 1ha grid

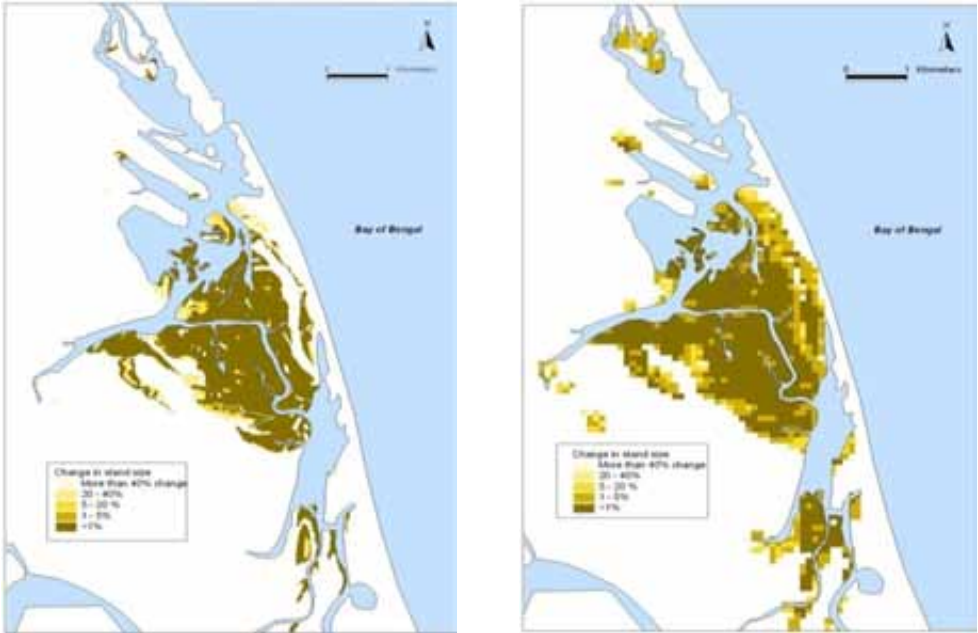


Fig. 3.2.7: Map of change in -stand size and converted change in stand size in 1 ha grid

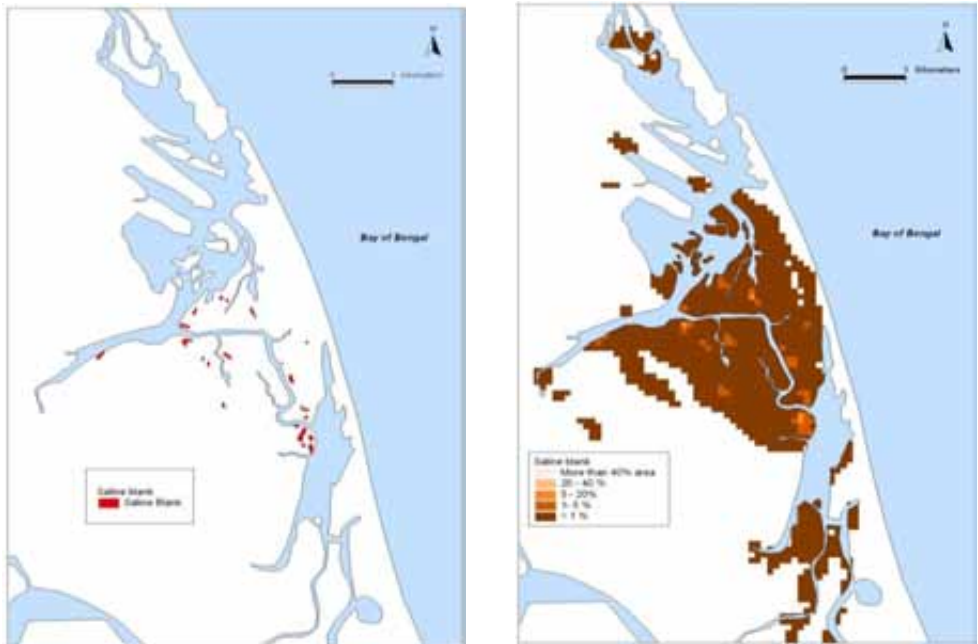


Fig. 3.2.8: Presence of saline blanks and converted GRID map for saline blanks

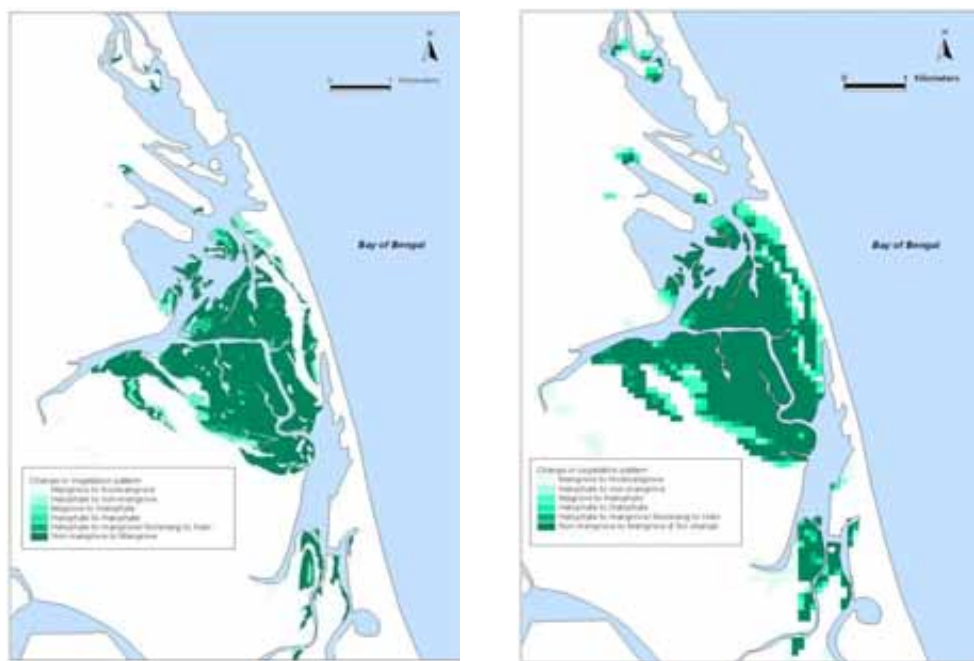


Fig. 3.2.9: Change in Vegetation pattern and converted GRID map



Fig. 3.2.10: Erosion/Accretion and converted GRID map

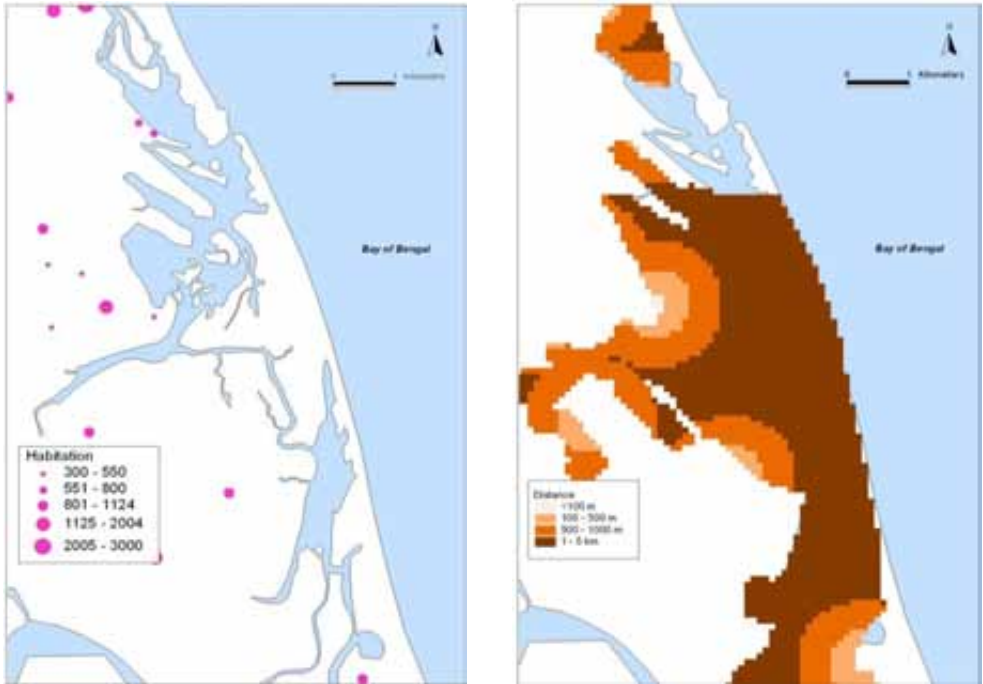


Fig. 3.2.11: Location of villages and distance between mangrove grids

As Pichavaram mangrove has no influence of anthropogenic pressure, sedimentation and dredging inside the wetland area, the indicator values are considered as 100 throughout the wetland grids. Similarly, natural regeneration is noticed in all mangroves area after monsoon period. So this indicator value is also considered as 100 for entire wetland. However, other mangrove sites such as Godavari, Bhitarkanika and Mundra forests, indicators are calculated based on the field data and observations.

Though the health index values are ranked in specific range i.e., 1- 10, 10 – 40, 40 – 80 and 80 - 100, each one ha has its own health index value based on the individual values of each indicator of that particular grid of 1 ha. Table 3.2.2 shows the further classification of health indices and the area under each category. Since the whole area is divided into grids of 1 ha, the number of grids approximates the total area under vegetation as the border grids also share some terrestrial land/ water bodies.

As described earlier, the mangrove health index is calculated for each ha grid and the result for the Pichavaram mangrove forest is shown in Figure 3.2.12.

Table 3.2.2: Area under different range of mangrove health indices

Health index	Grids (ha)
40 – 50	109
50 – 60	187
60 – 70	98
70 – 80	198
80 – 90	567
90 - 100	205

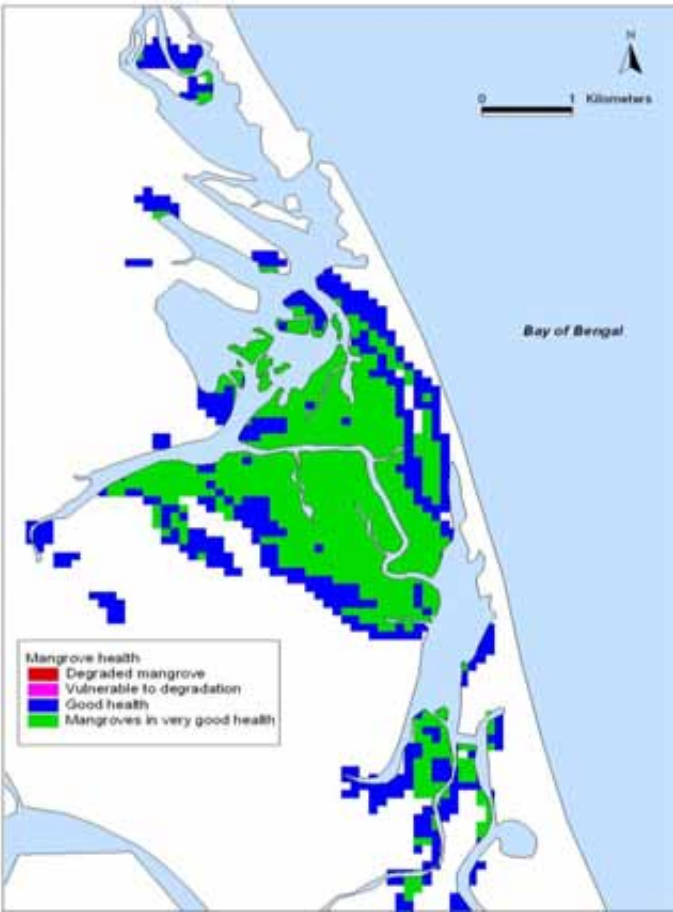


Fig. 3.2.12: Mangrove health index map for Pichavaram

Gulf of Kachchh (Core MNP)

The Bural-Chank Island complex is a group of Islands situated in the middle of the Gulf of Kachchh. The Islands are at least 35 kms away from any location from land. It is also a protected area under the Marine National Park and Sanctuary. Except for Okha, no large human settlements are located within 50 km from this reef complex. Hence, this location was most suitable for studying the mangroves least affected from the anthropogenic influence. No quantitative information existed regarding the height and density of mangroves on the Islands. The Islands also supported three core mangrove species that showed excellent natural regeneration.

Satellite data of the years 2002 and 2008 were taken for the present study. The area was surveyed twice during the project duration. Boats were hired from Salaya, a small port situated between Jamnagar and Okha. Information on the mangrove diversity, density, height and soil and water samples was collected from the study area. The collection and analysis procedures followed have been elaborated in the methodology.

Mangrove Diversity

The Islands support dense mangroves, with abundant faunal diversity and are surrounded by the fringing coral reefs. Algae and sea grass is witnessed along the reef area and mudflats. Four species of core mangroves were present on the different Islands. They are

1. *Avicennia marina*
2. *Ceriops tagal*
3. *Rhizophora mucronata*
4. *Aegiceras corniculatum*

With the exception of *Aegiceras* all the other mangrove species were found to be growing in large assemblages, they could thus be identified in the satellite imagery. In addition to the true mangrove species, several mangrove associates and salt marsh species were also observed growing in the area. They have been listed below.

1. *Suaeda fruticosa*
2. *Suaeda nudiflora*
3. *Cyperus* sp.
4. *Salvadora persica*
5. *Salicornia* sp.

Mangrove area

Mangrove vegetation is found on four of the five Islands that make up the Bural-chank Island complex. Very small patches of mangroves are found at Khara-Chusna Island located at the extreme south of the study area. These statistics have been generated from the analysis of satellite data. The statistics provided below pertain to the mangrove wetland map 2005. The mangrove wetland map has been prepared as per the procedure detailed in the methodology. Details of the mangrove statistics for the other major Islands are given below.

Noru Island

Noru Island occupies an area approximately of 840.00 hectares, showing presence of the subtidal, intertidal and high tidal mudflats. Sandy patches and carbonate rich sediments are witnessed at places.

The mangrove species observed during the traverses on this Island are *Avicennia marina*, *Rhizophora mucronata* and *Ceriops tagal* along with the mangrove associates *Suaeda* sp., *Cyperus* sp., *Salvadora persica*.

Total area covered by mangroves on the Noru Island is 669.89 ha (Table 3.2.2), out of 840 ha; i.e. 79.74 % of the total area of the Island; as compared to the 495 ha in 1998 (Singh 2002).

Chank Island

Chank Island covers up area approximately of 35.00 hectares. It is one of the smaller Islands, surrounded by the reef area, showing high density of

mangroves. The hightidal area occupies the centre of the Island covering area of about 0.52 hectares.

Avicennia marina, *Rhizophora mucronata* and *Ceriops tagal* were the mangrove species present here.

Total area covered by mangroves on the Chank Island is 26.21 ha, out of total area of 35 ha; i.e. 74.88 % of total area of the Island.

Table 3.2.3: Mangrove area for Noru and Chank Islands

Sr. No.	Class	Noru Island	Chank Island
		Area (in ha.)	
1.	Mangroves	669.89	26.21
2.	Mudflat area	138.87	0.81
3.	Others	34.21	8.01
	Total	842.98	35.02

Mangrove Community Zonation

A definite zonation pattern is exhibited here owing to their responses to the surrounding geomorphology and environment. IRS 1D LISS III data for the year 2002 and IRS P6 LISS III data of 2005 was used to study the zonation pattern of different mangrove communities of these Islands.

The zonation of the mangroves is based on many factors such as the local geomorphology, specific physico-chemical environment, etc. The mangrove vegetation shows distinct zones characterized by dominance of a particular species or communities of species, owing to its specific responses to the surrounding. Studying the spectral behavior of the mangroves facilitates in identification as well as determination of the spatial distribution and delineation of major mangroves communities. Three distinct zones; *Avicennia marina* (Forsk.) Vierh. zone, *Ceriops tagal* (Perr.) C.B. Roinson - *Rhizophora mucronata* Poir. zone and salt marsh – saline blank zone are observed from satellite data and the same could be identified on the ground during the field visit. The study shows that the mangrove zones on these Islands are

characteristically on the basis of the preferences of the specific genus to the specific geomorphological unit and its location. On both of the Islands dense fringe zone and the central hightidal region, comprising of salt marsh vegetation and saline blanks, devoid of the mangrove vegetation is observed. Noru Island has total area of about 840.00 ha and shows presence of the subtidal, intertidal and hightidal mudflats. The mangrove species observed during the traverses on this Island are *Avicennia marina*, *Rhizophora mucronata* and *Ceriops tagal* along with the salt marsh vegetation *Suaeda sps* and *Salicornia* sp. and mangrove associate *Salvadora persica*. Chank Island is one of the smaller Islands, with total area of about 35.00 ha, surrounded by the reef area and showing high density of mangroves. *Avicennia marina*, *Rhizophora mucronata* and *Ceriops tagal* are the mangrove species present here.

Zonation at Noru Island

At Noru Island, except for the central hightidal region and the south-western part, the mangroves inhabit whole of the Island. *Avicennia marina* forms the dense fringe of the mangrove zone. This is the major category of this mangrove habitat. Towards the centre of the Island open patch of *Avicennia marina* is observed. The *Ceriops* – *Rhizophora* zone is found immediately behind the dense *Avicennia marina* zone (except for the south eastern part of the Island) and also growing along the creeks and a dense patch is found on the south-western part of the Island. Sparse patch of *Avicennia marina* is found behind this zone, with the open *Avicennia marina* patches present towards the centre of the Island. Small-scattered patches of salt marsh vegetation belonging to *Suaeda* sp. and *Salicornia* sp. are observed in the hightidal regions. Saline blanks are present at some places towards the central portion and the south-eastern part, which are devoid of any vegetation owing to its high salinity. Mangrove associate *Salvadora persica* is also observed here.

Zonation at Chank Island

Here also distinct zonation pattern is observed as the dense *Avicennia marina* patch is observed at the fringe of the Island. *Avicennia marina* has dense canopy coverage and the tallest plants are observed in this region. A very

dense *Ceriops-Rhizophora* patch follows this zone. Behind this dense *Ceriops-Rhizophora* patch is a relatively sparser *Ceriops-Rhizophora* patch. Sparse *Avicennia marina* surrounds this dense patch, towards the centre of the Island. The high tidal area and hence salt marsh vegetation comprising of *Suaeda* sp. and *Salicornia* sp. occupy the central region with a prominent saline blank towards the western side.

Fig. 3.2.13: shows the mangrove community zonation map for Bural Chank based on November 2005 LISS III data, while Table 3.2.4 gives the details for the different zones.

Table 3.2.4: Mangrove area for Noru and Chank

Sr. No.	Class	Noru Island	Chank Island
		Area (in ha.)	
1.	<i>Avicennia marina</i> zone	434.59	14.86
2.	<i>Rhizophora</i> - <i>Ceriops</i> zone	56.74	7.03
3.	Mixed mangroves zone	178.56	4.32
4.	Mudflat area	138.87	0.81
5.	Others	34.21	8.01
	Total	842.98	35.02

Phytosociological Analysis

The phytosociological analysis was carried out for the island Chank. Phytosociological assessment helps in the determination of the forest structure. Figure 3.2.14 is the diagrammatic representation of the cross-sectional view of the mangrove forests of Chank Island.

Two transects were undertaken. Transect 1 (from west to the centre of the Island) has mean overall density of 0.5593 stems per mtr square (i.e. 559 stems per 0.1 ha). The Relative density of *Avicennia marina* is 71% (Table 3.2.5) and that of *Ceriops tagal* is 29% whereas the relative frequency is 66% and 34% respectively. Although *Rhizophora mucronata* was present along this area but as it did not fall in the sampling area, no data for it could be generated. Transect 2 (from centre to the eastern end of the Island) shows quite different

scenario. It has a mean overall density of 1.509215 stems per square metres or say 1509 stems per 0.1 ha. Here the relative density of *Avicennia marina* is 19%, 77% for *Ceriops tagal* and that of *Rhizophora mucronata* is 4% whereas the relative frequency is 28%, 65% and 7% respectively. Therefore, as compared to transect 1, transect 2 have more of *Ceriops tagal* individual then *Avicennia marina*, with very few *Rhizophora mucronata*.

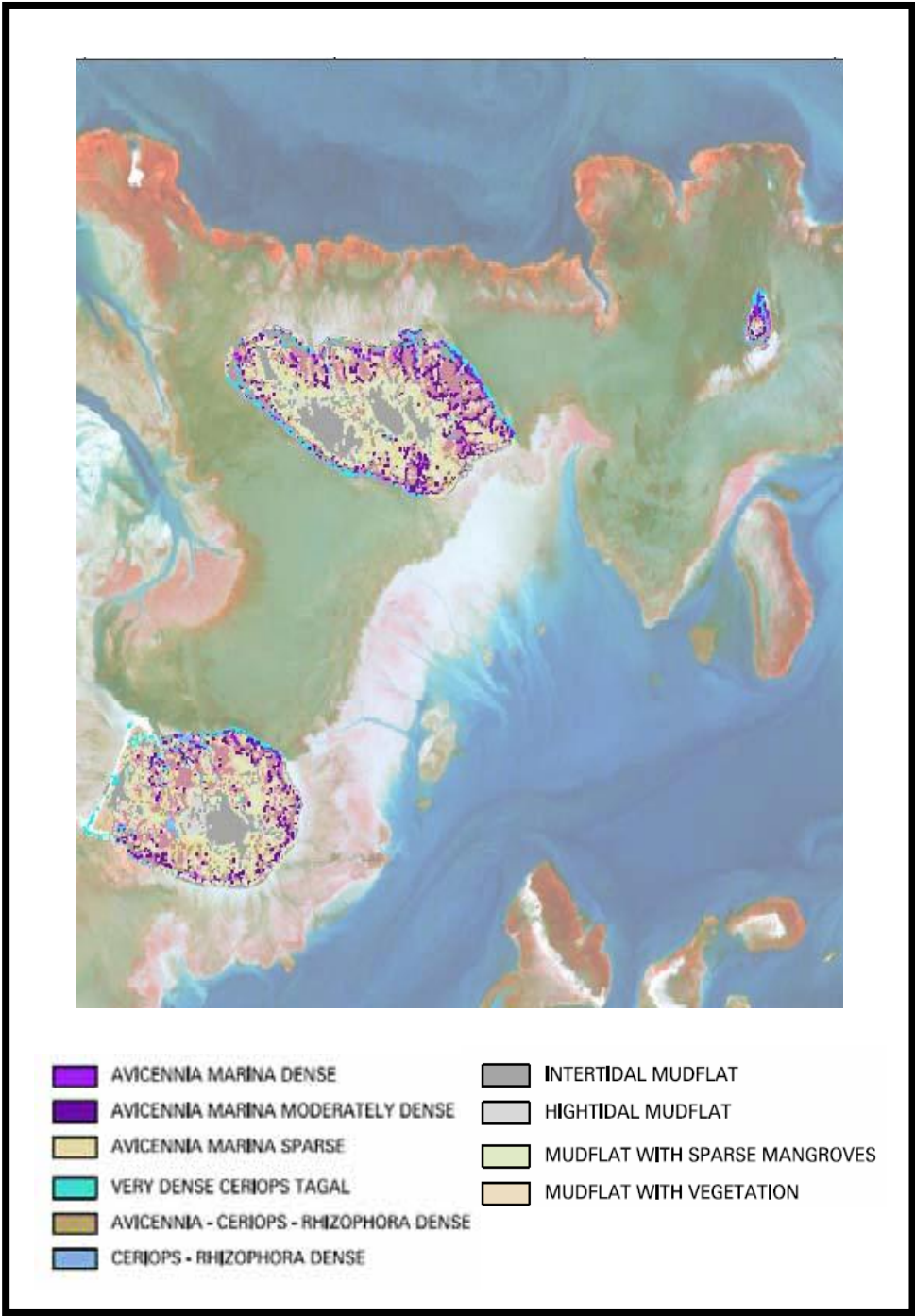


Fig. 3.2.13: Mangrove Community Zonation map of Noru and Chank

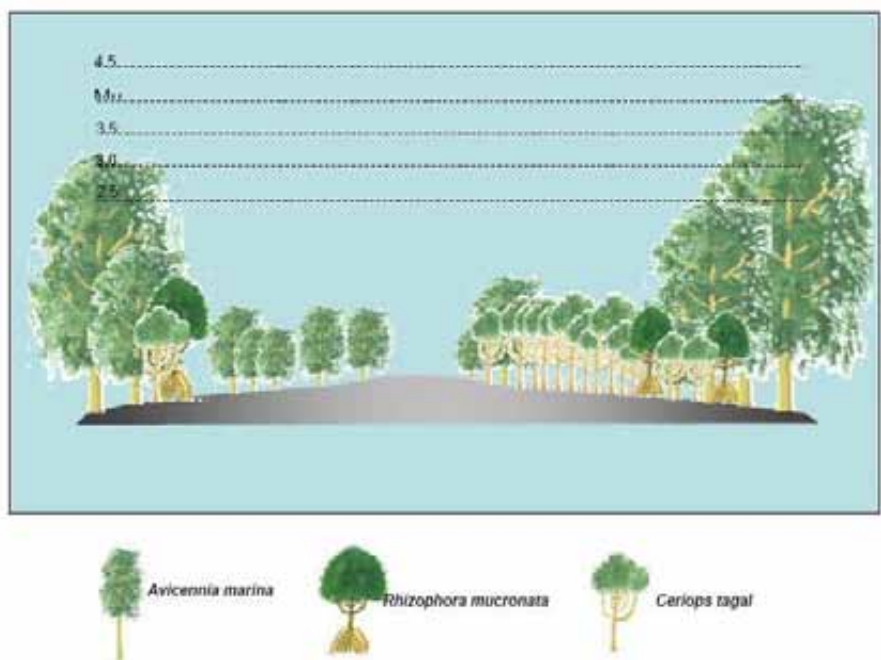


Fig. 3.2.14: Cross section of Mangrove vegetation at Chank Island

Table 3.2.5: Mangrove phytosociology from Chank Island

Transect	Species	Relative Density (%)	Relative Frequency (%)	Mean Overall Density Of Stems (Per m Square)
I*	Avicennia marina	71	66	0.5593 (i.e., 559/0.1 ha)
	Ceriops sps	29	34	
II	Avicennia marina	19	28	1.509215 (i.e., 1509/0.1 ha)
	Ceriops sps	77	65	
	Rhizophora mucronata	4	7	

(*Although *Rhizophora mucronata* was present along this area but as it did not fall in the Sampling area, no data for it could be generated.)

As observed from the above table (Table 3.2.5), as compared to transect 1, transect 2 has more of *Ceriops tagal* individual then *Avicennia marina*, with

very few *Rhizophora mucronata*. The phytosociological pattern of Chank however, shows different results in both transects, which might indicate that there is a co-dominance of the *Avicennia marina* and *Ceriops tagal* on the island of Chank. For this, it can be concluded that, Chank, although being a small island, still shows distinct zonation pattern.

Mangrove Height

Avicennia marina was the tallest of all the mangroves of both the islands, attaining height of 4-5 m. *Ceriops tagal* were of about more than 2 m high at places whereas *Rhizophora mucronata* were about 3-3.5 m high. Any previous information regarding the height of the mangroves on these islands is lacking (Singh, 2006). This information has thus added up to the already existing height data of the mangroves of other islands of the MNP.

- The reason for the good density, diversity as well as 4-5 m of height of these mangroves could be because of its considerable distance from the mainland and thus no apparent anthropogenic pressure on the mangroves of these islands. It is important to mention here, that the conservation status attributed to the mangroves of this part ensures for the better health of these mangroves.
- On the basis of field survey and taking readings from GPS positions, a height map was generated and overlaid on the zonation map.

Soil physico-chemical Analysis

The soil samples were collected from different mangrove areas. For calculation of Soil pH, a field soil-water analysis kit was used using the standard procedures. The pH for the soil samples for this study area showed a variation from 8.52 to 9.05. As most of the soil samples collected from mangrove areas had a high proportion of clay, sieving alone did not provide the complete results. To get a thorough grain size analysis pipette analysis was carried out. The results are indicated in Fig 3.2.15 given below.

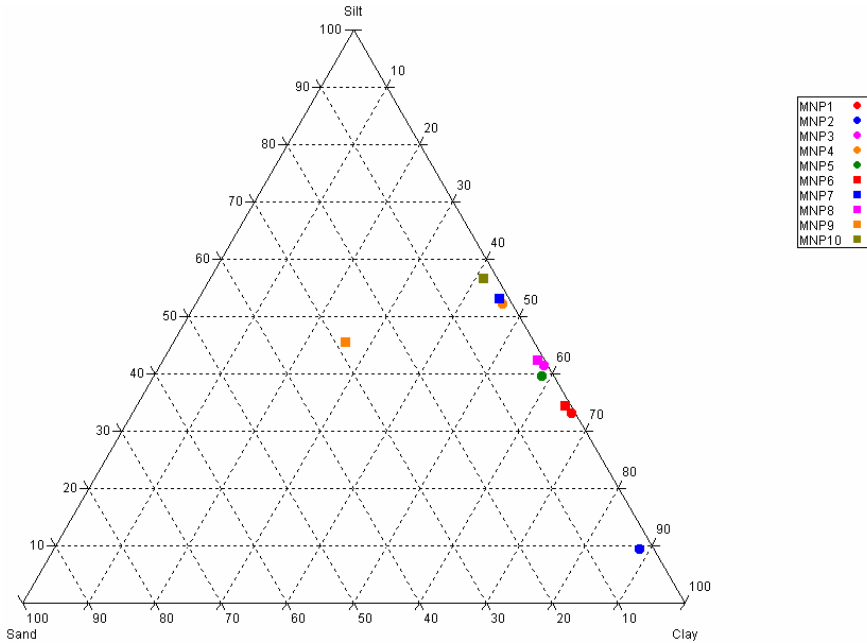


Fig. 3.2.15: Grain-size analysis for soil samples from Noru-Chank

Anthropogenic Influence

The Bural-Chank Island complex is located at least 35 km from land. It is also a protected area under the Marine National Park and Sanctuary. These factors have helped reduce the effect of anthropogenic factors on it. No direct cutting of mangroves was observed on any of the Islands visited. Also there was no grazing by camels or other livestock. The nearest human habitation was restricted to Ajad Island that was located about 25 km in the southeast direction. The population here however is less than 300 individuals. Once in a year, a few thousand people gather at Mitha-chusna Island on the southern tip for the annual ‘Urs’ festival. These mangroves thus represent among the most isolated mangroves in the Gulf of Kachchh.

Erosion and Accretion

The different island on this area actually raised areas of the Bural-Chank reef complex. Due to the accretion of sediments they now harbor mangrove

vegetation. Erosion and accretion are thus part of an ongoing process of geomorphic change. However with regard to the mangrove vegetation, erosion has been observed along the south-eastern margin of Noru Island. Though not severe, mangrove vegetation in a strip of 10 m width has been washed away in the last 7 years.

Mangrove Health

The information that has been generated in the field, laboratory as well as from satellite image analysis have provided a valuable input in the generation of a mangrove health model. Different themes were generated from it using the procedure that has been detailed in the methodology. The following figures (Figs. 3.2.16 to 3.2.19) show the results obtained. Plate 3.2.1 exhibits a view of different mangrove classes, while Plate 3.2.2 shows how phytosociological analysis is being carried out in the forests.

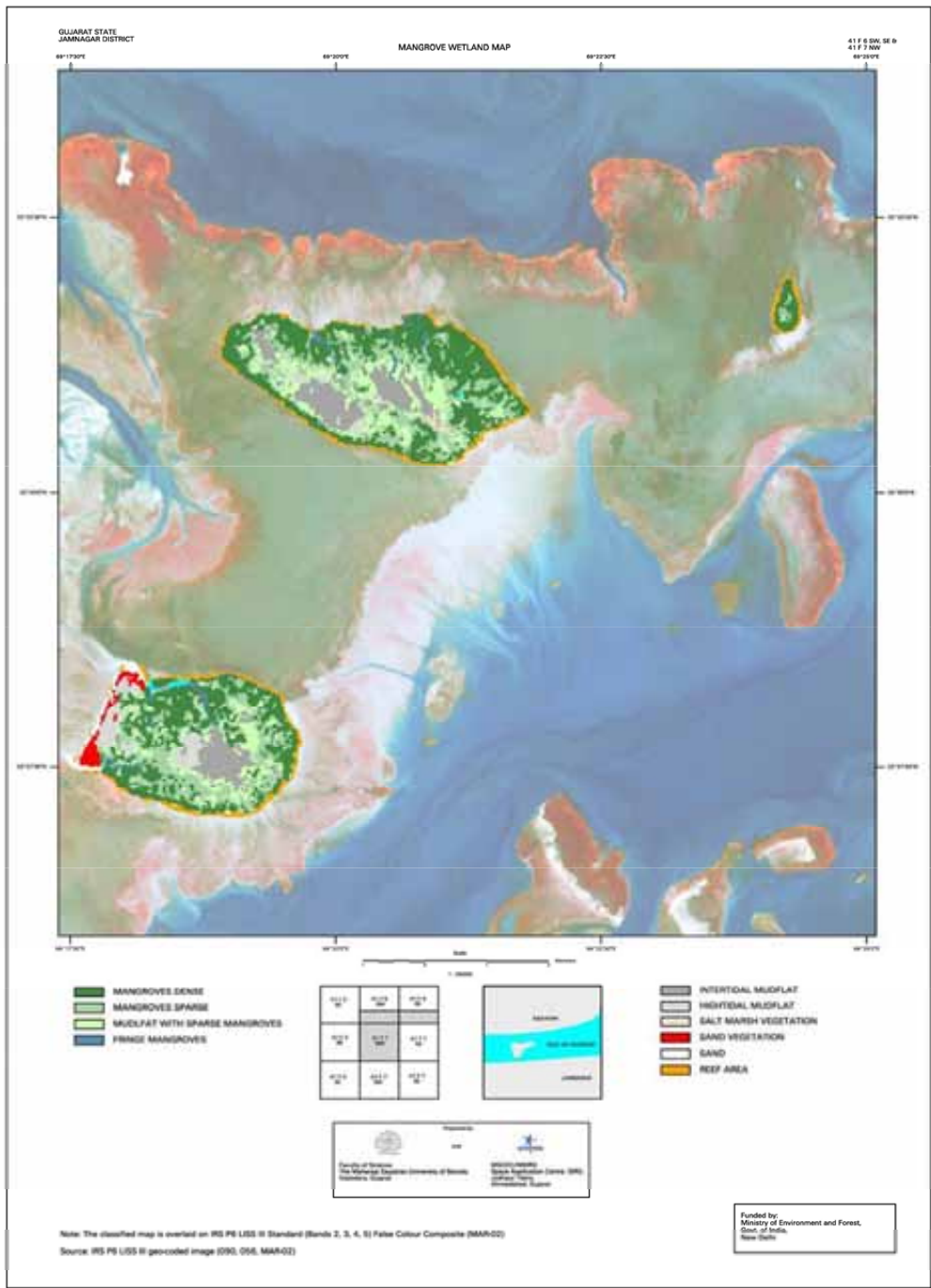


Fig. 3.2.16: Mangrove Map 2002 for Noru and Chank, Gujarat



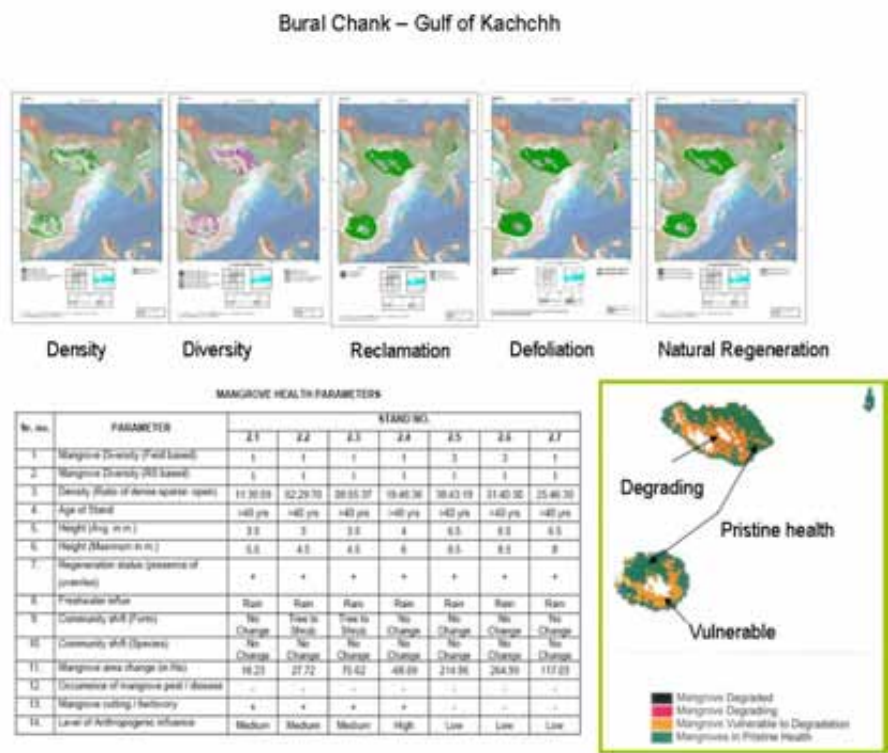


Fig. 3.2.18: Model output of Mangrove Health Model for Bural Chank, Gulf of Kachchh

The overall density of mangroves of MNP and S is good and diversity is better than most of the other parts of state. The study area also has dense mangrove patch with three mangrove species being present. 4-5 m of height of mangrove trees is considered healthy for the mangroves of Gujarat, which is exhibited by the *Avicennia marina* on these islands. The reason for the good density, diversity as well as 4-5 m of height of these mangroves could be because of its considerable distance from the mainland and thus no apparent anthropogenic pressure on the mangroves of these islands. In addition, the conservation status attributed to the mangroves of this part ensures for the better health of these mangroves.



Plate 3.2.1: Sparse *Avicennia marina* (Avi.) and dense *Ceriops tagal* (Cer.) in the foreground and *A. marina* in the background



Plate 3.2.2: Phytosociological analysis; *Ceriops tagal* and *Avicennia marina*

Mundra Mangroves

Mundra, a coastal taluka of Gujarat, is located at the northern flank of the Gulf of Kachchh. It has a wide inter-tidal zone, which supports a unique marine ecosystem dominated by mangroves and natural creek formations. The

mangrove vegetation was found on the Navinal Island, Bocha Island and the adjoining inter-tidal mudflats. This whole situation changed in the early 1990s when the site was selected for the construction of a private port. The area, which was a sleepy coastal town, has now been transformed to one of the largest private ports in India. These changes have had a great influence on the mangrove vegetation growing in the vicinity. The results indicate how industrial development is impacting the health of mangrove forests.



Plate 3.2.3: A tall *Avicennia marina* tree

Satellite data of several years were taken for the present study. The area was surveyed in four times during the project duration. Most of the mangrove assemblages were approachable from the adjoining saltpan or port roads. The area was thus surveyed on foot. Information on the mangrove diversity, density, height and soil and water samples was collected from the study area. The collection and analysis procedures followed have been elaborated in the methodology.

Mangrove Diversity

The islands of Bocha and the adjoining mangrove areas including the Bharadi-Mata creek area support dense mangroves on the fringe areas only. Most of the other areas have sparse mangroves. Only one species of true mangrove was found here. The species was *Avicennia marina*

In addition to the true mangrove species, several mangrove associates and salt marsh species were also observed growing in the area. They are listed below:

1. *Suaeda fruticosa*
2. *Suaeda nudiflora*
3. *Suaeda maritima*
4. *Urochondra setulos*
5. *Cyperus* sp.
6. *Salvadora persica*
7. *Salicornia* sp.

Mangrove Area

The area under mangrove vegetation has undergone a large change in the past few decades. The development of the port has decimated the mangroves on Navinal Island, except for a few patches on the west and east of the port complex. There has been a change in the mangrove area surrounding the Mundra GMB port. The saltpans adjoining it have been reclaimed and even much of the mangrove area has been taken over. On the extreme south are present some of the tallest mangroves in the Gulf of Kachchh. The heights of the mangrove trees here reach 5 meters. Another locality, where good mangroves are found is the Bharadi-Mata Creek area to the west of the study area. This area is currently far away from the port and thus not under its influence so far. But with the approval of the SEZ in the vicinity, the mangroves of this area are also under threat.

Mangrove Height

Avicennia marina is the tallest of all the mangroves of both the islands (Plate 3.2.3), attaining height of 4-5 m. This information has thus added up to the already existing height data of the mangroves of other islands of the MNP.

On the basis of field survey and taking readings from GPS positions, a height map was generated and overlaid on the zonation map.

Soil Physico-chemical Analysis

The soil samples were collected from different mangrove areas. For calculation of soil pH, a field soil-water analysis kit was used using the standard procedures recommended. The pH for the soil samples for this study area showed a variation from 8.13 to 8.96. As most of the soil samples collected from mangrove areas had a high proportion of clay, sieving alone did not provide the complete results. To get a thorough grain size analysis pipette analysis was carried out. The results are given in Fig. 3.2.20.

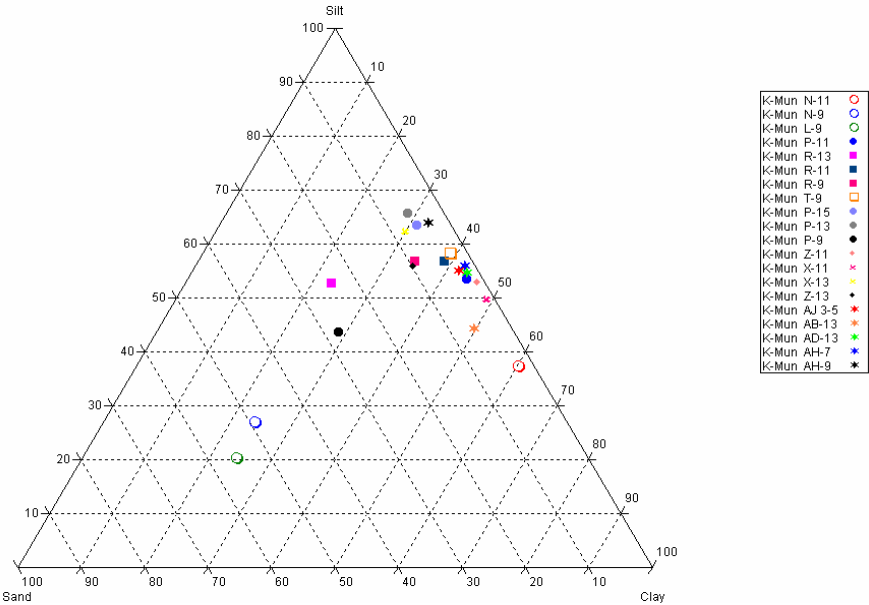


Fig. 3.2.20: Grain size analysis for soil samples from Mundra

Anthropogenic Influence

The mangrove vegetation near Mundra is one of the most impacted mangrove assemblages in Gujarat. The area has seen the development of one of the largest private ports in the country. The development of the Port has also led to the establishment of a Special Economic Zone (SEZ) in the vicinity of the port. The development has had a substantial impact on the natural vegetation of the area. The Island of Navinal on which the main port is situated is now devoid of mangrove vegetation except for small patches on the east and west sides. The development of a Private railway for the movement of goods has also caused damage to mangrove vegetation. Though occupying only a small area, its development has led to filling up of several creeks that has stopped the movement of water within the mangroves. The mangrove area, east of Bocha Island represents one of the best patches on the north Gulf of Kachchh coast. This area has borne the brunt of direct cutting of mangroves as well as burying of mangroves under sand. Sand that is dredged from the nearby creeks is used to completely bury the mangroves so that there is no need to cut them. This has slowly progressed from the central region and is gradually moving to the outer fringe. Plates 3.2.4 and 3.2.5 show glimpses of the level of anthropogenic influence on the study area.



Plate 3.2.4: Camel Grazing on Mundra mangroves



Plate 3.2.5: Burying of mangroves by sand dumping (the stumps of the mangroves can also be seen)

Erosion and Accretion

The mangrove areas on the Island of Bocha and its surrounding have also been affected by erosion by the sea. On account of high wave action, a dense mangrove strip measuring has been washed off from the seaward margin of the above.

Mangrove Health

The information that has been generated in the field, laboratory as well as satellite image analysis have provided a valuable input in the generation of a mangrove health model. Different themes were generated from it using the procedure that has been detailed in the methodology. Figs. 3.2.21 to 3.2.26 show the results obtained.

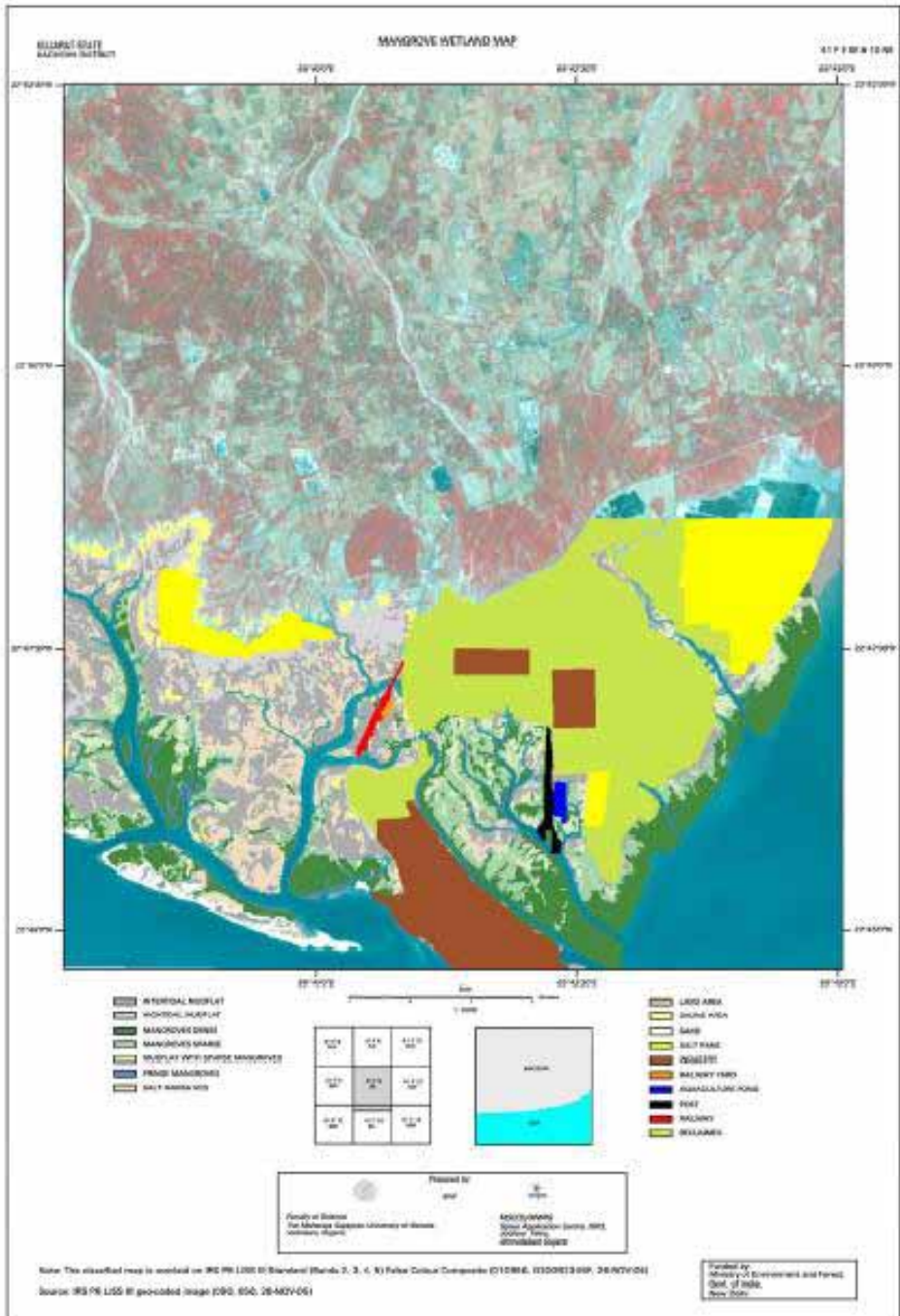


Fig. 3.2.21: Mangrove Map of Mundra (2005)

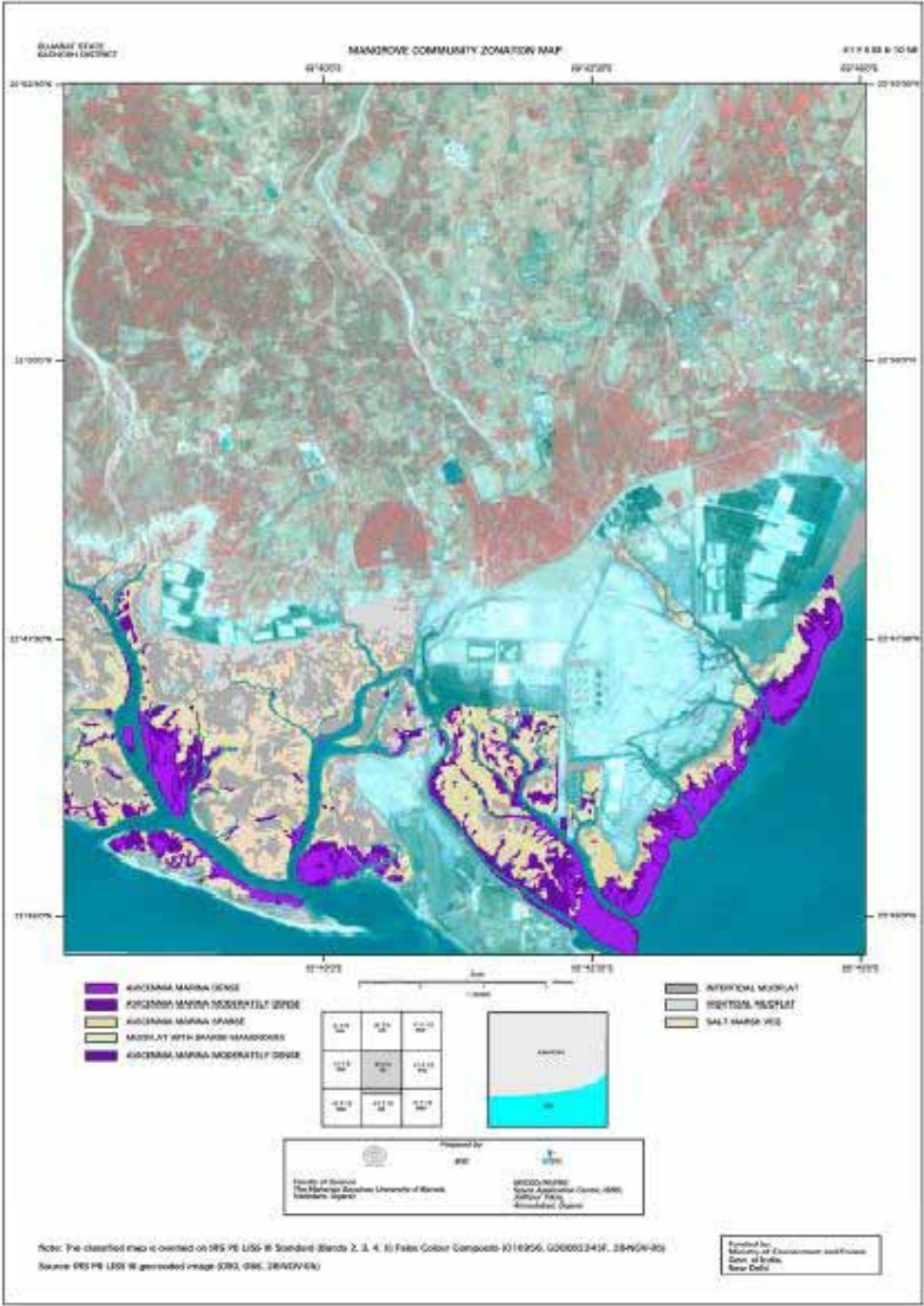


Fig. 3.2.22: Mangrove Density Map, Mundra

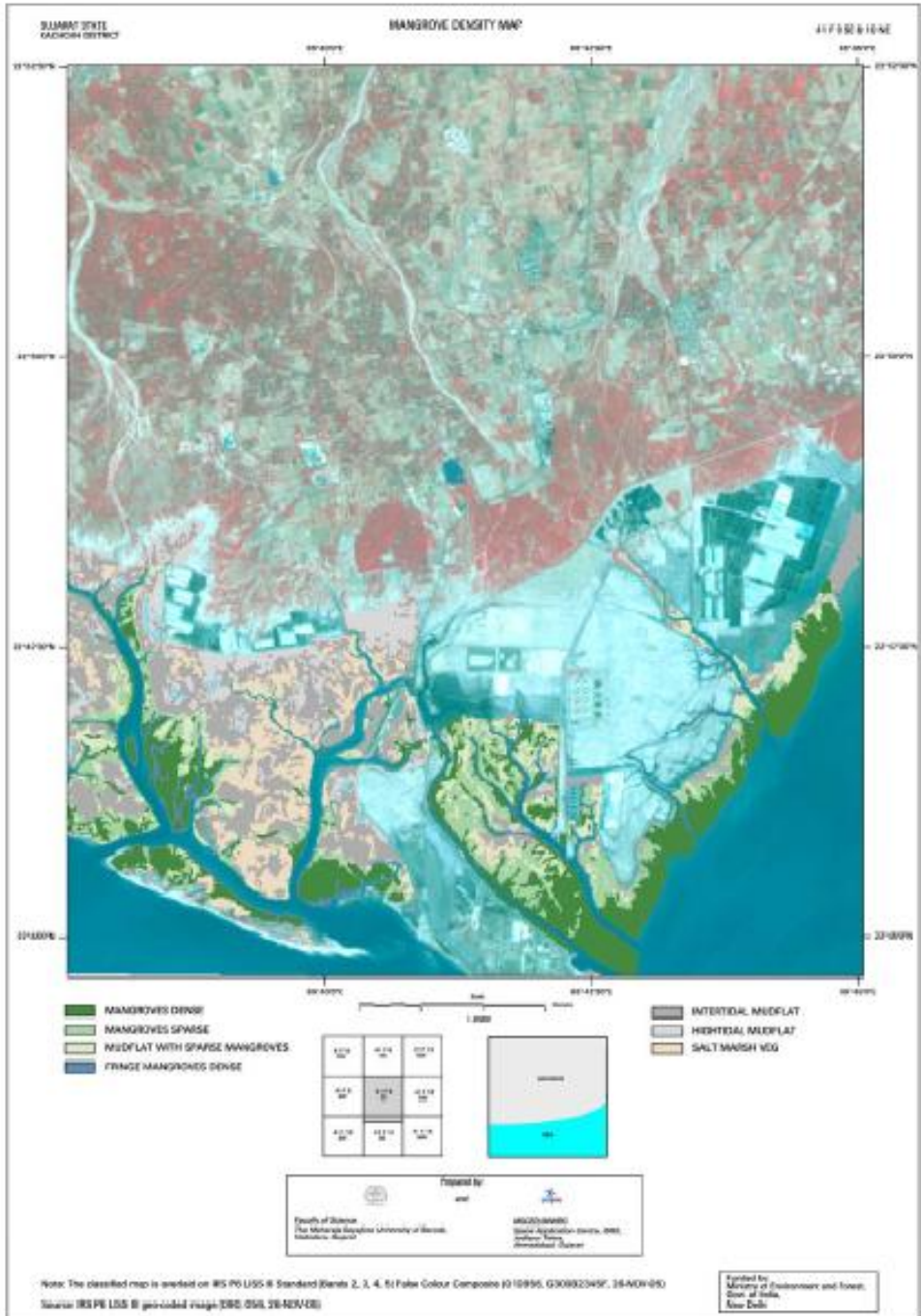


Fig. 3.2.23: Mangrove Diversity Map, Mundra

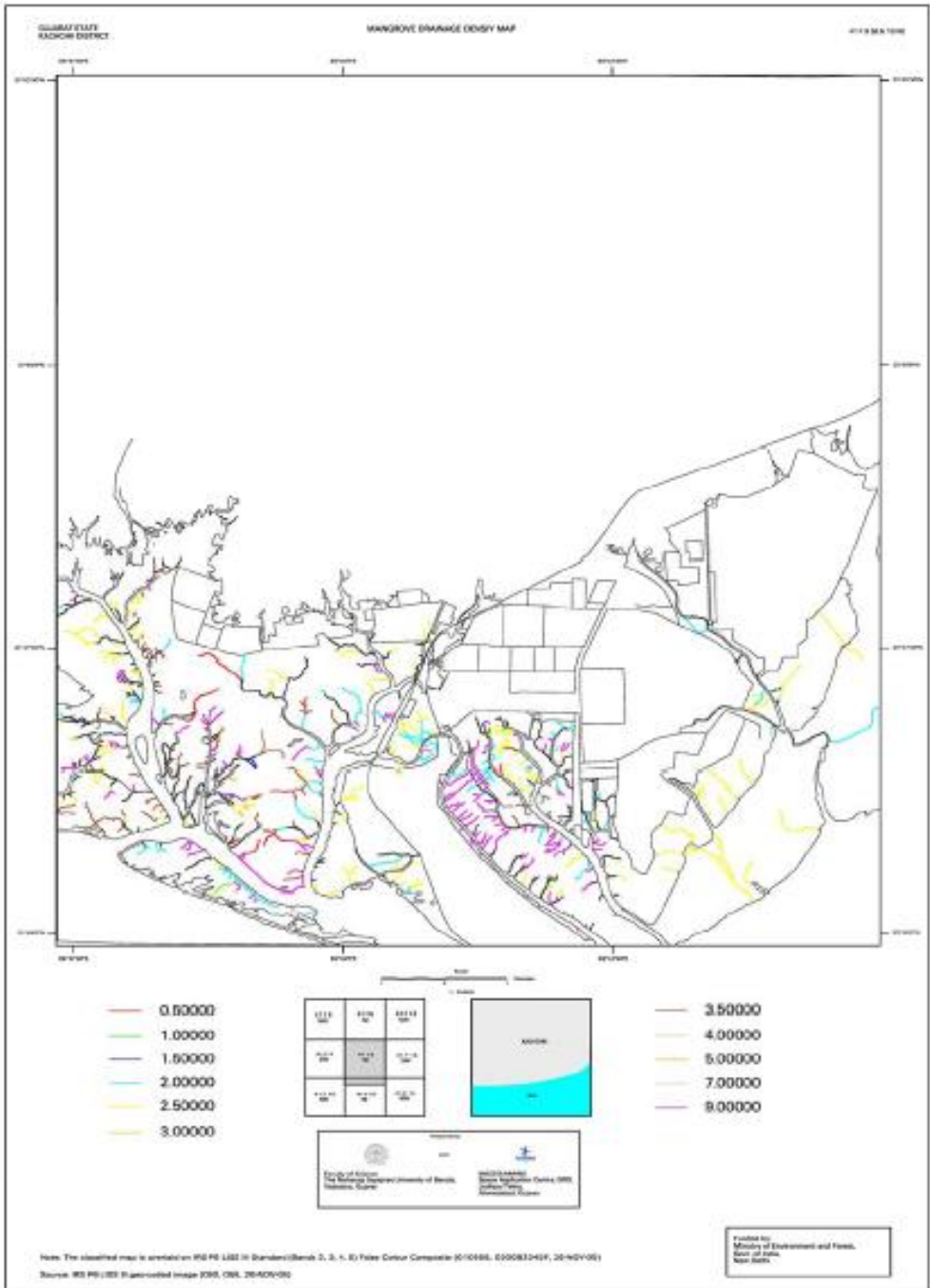


Fig. 3.2.24: Creek Network Map, Mundra

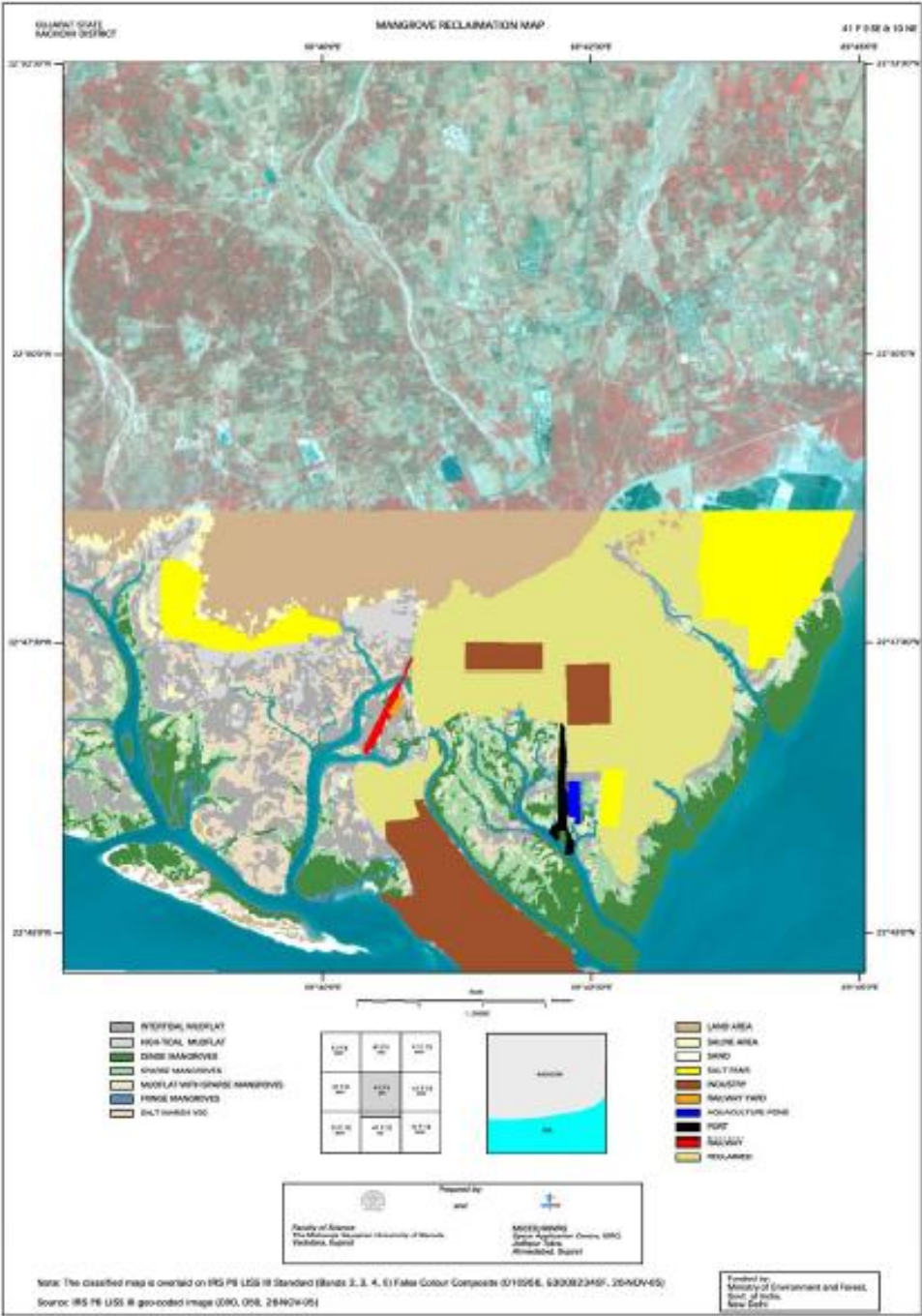


Fig. 3.2.25: Reclamation Map, Mundra

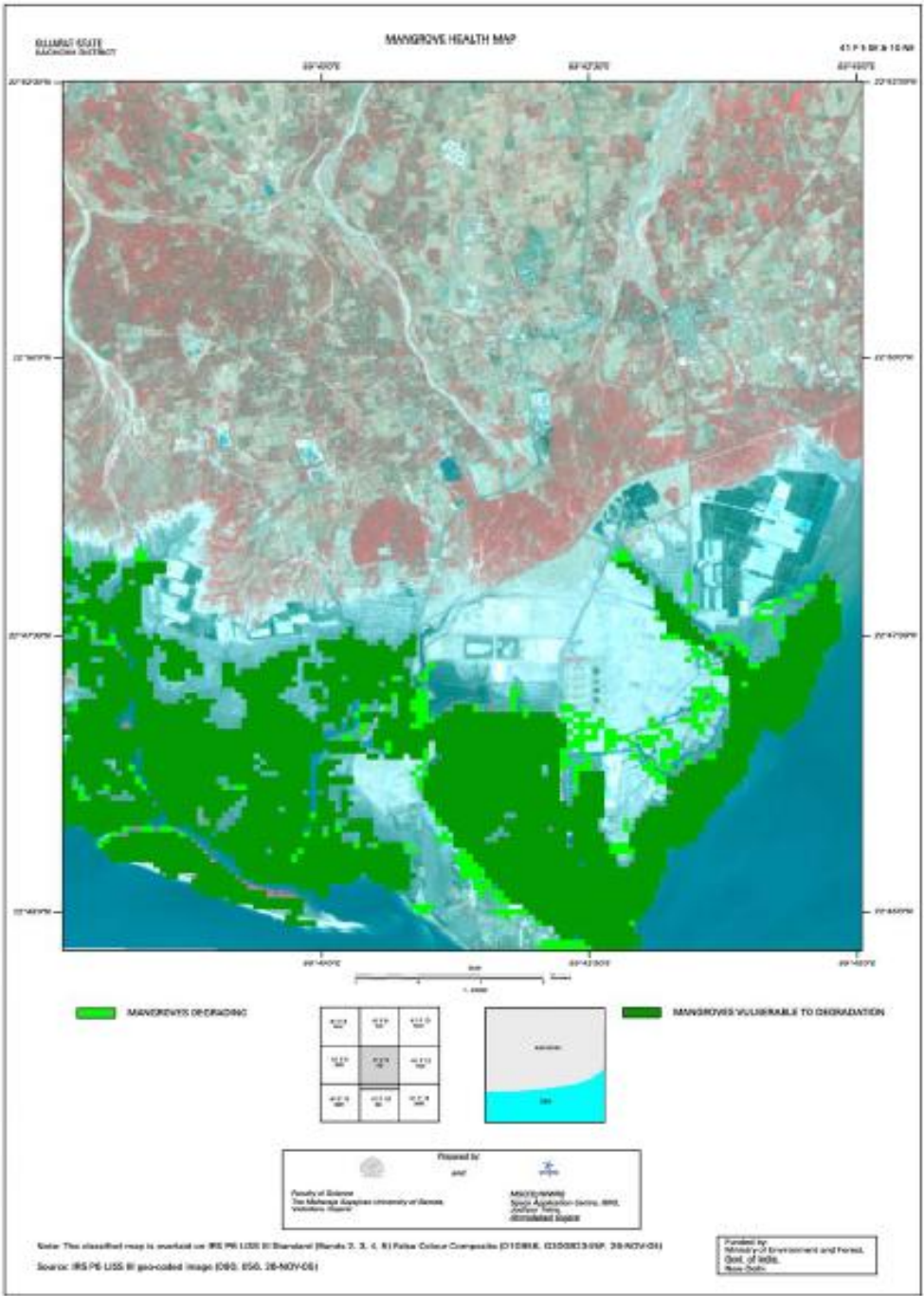


Fig. 3.2.26: Mangrove Health Map, Mundra

Jakhau Mangroves

Jakhau Port is located at the western tip of the northern coast of the Gulf of Kachchh. It is the western most minor port of the Country. It is the major fish landing port for vessels fishing on the Northern part of the Arabian Sea within the Indian EEZ. During the fishing season, fishermen from all over the state, make Jakhau and Okha as their primary landing points. Several islands are located to the North of Jakhau port, covering an approximate area of 15 sq kms, they show mangrove patches ranging from dense to sparse in density. This region also forms one of the earliest reserve forests declared. The erstwhile rulers of Kachchh had declared these islands as reserve forests since the late 1880s. The nearest island is located about 4.3 km from Jakhau port. The study area falls in the grid of Latitude 23°20' N to 23°10' N and Longitude 68°30' E to 68°40' E as part of SOI topographical sheet 41 A/11 and 12. Plate 3.2.6 shows mangrove forests along the Jakhau creek.



Plate 3.2.6: The mangrove forests along Jakhau Creek

Mangrove Diversity

The islands support dense mangroves, with abundant faunal diversity. Three species of core mangroves were present on the different islands. They are

1. *Avicennia marina*
2. *Ceriops tagal*
3. *Rhizophora mucronata*

The forest department has undertaken plantation of other mangrove species for which they have brought propagules from Bhitarkanika (Orissa) and Goa. They include the following

1. *Exocaria agallocha*
2. *Briguiera gymnorrhiza*
3. *Sonneratia apetala*

As the propagules were planted on the last visit that the study team made to the area, it is not known what has the establishment of the above species. The dominant species in the area is *Avicennia marina*. The other two species of *Ceriops tagal* and *Rhizophora mucronata* have been located at a few patches along the Jakhau creek and near Chibli Thar. As they do not grow in large extensive patches, they would not be detected on the satellite data. In addition to the above core mangrove species, the following species of mangrove associates and salt marsh vegetation were also located.

1. *Suaeda fruticosa*
2. *Suaeda nudiflora*
3. *Sesuvium prortulacastrum*
4. *Salvadora persica*
5. *Salicornia* sp.

Mangrove Area

The study is part of the Western Kachchh Mangrove reserve forest. This is one the earliest mangrove reserve forests in India. The mangroves have seen an increasing trend since 1965, the earliest date since which authentic data is available. The mangrove area in 1965 stood at around 893 ha. It has seen an increasing trend and till 2005 the area has increased to 1543 ha. The areas covered by other categories have been summarized in table 3.2.6. The coastal wetland map of Jakhau prepared from IRS data of 2005 is given in Fig. 3.2.27.

Table 3.2.6: Statistics of different categories of coastal wetlands in 1965 & 2005

Sr. No.	Category	Area (ha)	
		1965	2005
1.	Sea	4604.52	5048.06
2.	Mudflat	9410.09	-
3.	IMF		5306.13
4.	HMF		1192.63
5.	Sand	2344.72	730.61
6.	Mangroves	893.60	1543.35
7.	Marsh	-	34.08
8.	Algae	-	310.67
9.	Salt Pan	583.73	2588.73
10.	Saline area	-	1387.83
11.	Land	2093.80	2069.16
12.	Port	43.26	28.97
13.	Islands	683.21	420.18
	Total	20656.93	20660.39

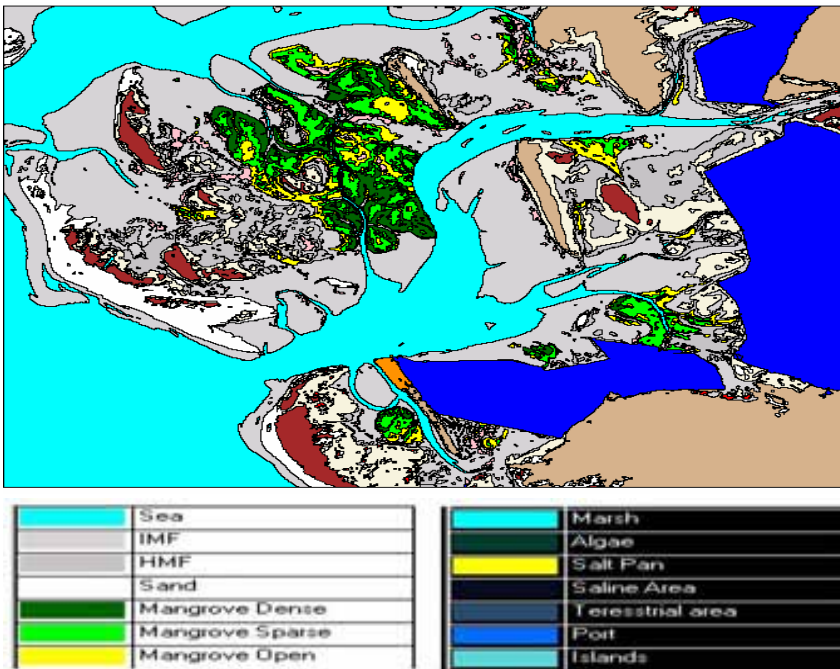


Fig. 3.2.27: Coastal Wetland Map of Jakhau (2005)

Mangrove Community Zonation

Three species of true mangroves are found to be growing in the Jakhau region. While only a few individuals of *Rhizophora mucronata* were observed, *Ceriops tagal* was located at several places. However, the size of each assemblage was not of a size that could be identified on satellite image. They grew in a narrow fringe on raised intertidal mudflats along the creeks (Plate 3.2.7). Thus, on satellite image the whole area would have only the *Avicennia marina* community.



Plate 3.2.7: *Ceriops tagal* patch near a raised mudflat along the Jakhau Creek

Mangrove Height

The tallest mangroves in the Gujarat barring a few locations in South Gujarat are found in Jakhau. The height of the mangrove trees, in a few areas has reached 8.5 m. The average height in most of the mangrove stands is more than 3.5 meters, which is the lowest average found near Chibli Thar. This mangrove stand is approachable by foot from the adjoining saltpans. The highest average height of 6.5 m is found on the mangrove islands found to the west of Jakhau Creek where there is the least anthropogenic influence. Plate 3.2.8 shows a glimpse of a mangrove tree with a height of 4.3 m near Chibli Thar.



Plate 3.2.8: Mangrove tree near Chibli Thar

Soil Physico-chemical Analysis

The soil samples were collected from different mangrove areas. For calculation of soil pH, a field soil-water analysis kit was used using the standard procedures recommended. The pH for the soil samples for this study area showed a variation from 8.5 to 8.92. As most of the soil samples collected from mangrove areas had a high proportion of clay, sieving alone did not provide the complete results. To get a thorough grain size analysis pipette analysis was carried out. The results are given in Fig. 3.2.28.

Anthropogenic Influence

The mangrove forests of Jakhau are broadly divided into four regions. The forests near the old Jakhau Port as well as the forests near the New Jakhau Port have a high level of anthropogenic influence. As the fishermen colony is nearby, people frequent them and a few of them are actually cut for domestic use. The mangroves near Chibli Thar and Mohadi Thar form the third broad region. They are frequented by villagers from nearby settlements who cut the green leaves and use it as fodder for the camel and other livestock. The mangroves on the islands on either side of the Jakhau creek are not generally frequented and are the least impacted by humans. The development of a huge

Cement Industry to the North of the current mangroves has caused an increase in the movement of vessels in the vicinity and could probably have a detrimental effect on the mangrove vegetation if not regulated. There has been a large expansion of the saltpan industry on the high tidal mudflat to the east of the old Jakhau port. They have not damaged the mangrove vegetation till date but if any further increase in area of the saltpans is planned then it could be at the cost of mangroves. The efforts of the forest department have gone a long way in conserving the mangroves at Jakhau.

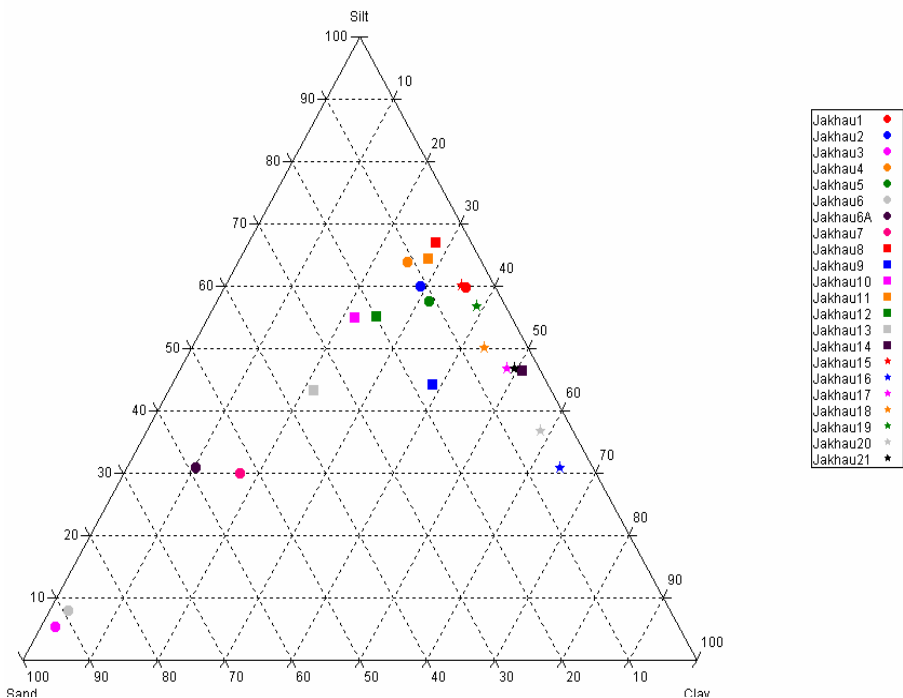


Fig. 3.2.28: Grain size analysis for soil samples from Jakhau

Erosion and Accretion

Both erosion and accretion can be observed along the creeks of Jakhau. The Bhangori Creek near Jatwari Thar is slowly filling up and mangroves have started colonizing the area. The creek is now no longer navigable during high tide. On the other hand the main Jakhau creek is eroding the mangroves on its western bank.

Mangrove Health

The information that has been generated in the field, laboratory as well as satellite image analysis have provided a valuable input in the generation of a mangrove health model. Different themes were generated using the procedure that has been detailed in the methodology. Figs. 3.2.29 and 3.2.30 show the mangrove diversity and health maps.

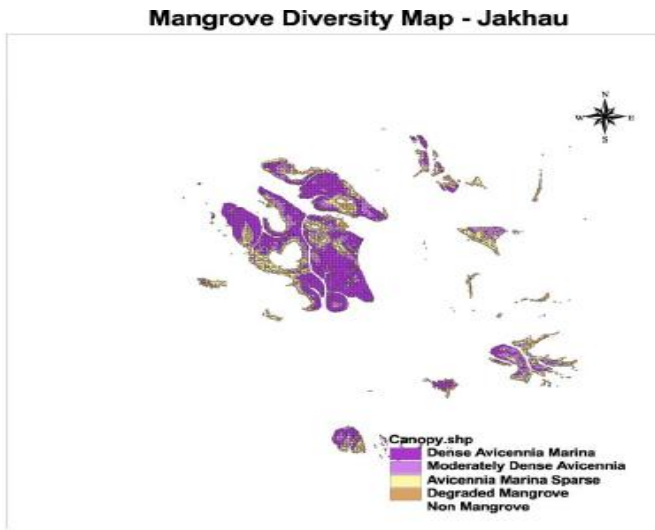


Fig. 3.2.29: Mangrove diversity Map – Jakhau

Bhitarkanika R.F

Bhitarkanika Reserve forest of the Wildlife Sanctuary area is the one of the largest contiguous mangrove forest in India. It is largest in the east coast of India. It lies between the latitude $20^{\circ}30' - 20^{\circ}50' N$ and the longitude $86^{\circ}45' - 87^{\circ}10' E$ in the northeast of the Mahanadi delta in Kendrapada district. In 1975 Bhitarkanika was declared as a sanctuary under the Wild Life protection act, 1972 and comprises Bhitarkanika, Kalibhanjadian and Gahirmatha mangrove area. It is fed by the Dhamara River, Manipura River and Bhitarkanika River. The Dhamara River in the north, the Hansua in the west and the Bay of Bengal in the east and south bound the sanctuary. Gahirmatha mangrove area comprises Sunirupi R.F, Habilikunti P.F and Gahirmatha P.F.

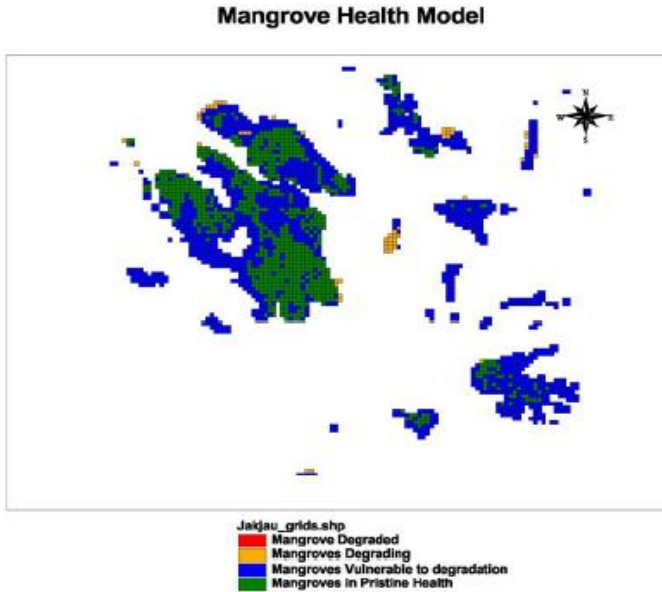


Fig. 3.2.30: Mangrove Health map– Jakhau

The area is under laid by alluvial deposits, which are brought down by the rivers. The average annual rainfall is 1300 mm and the main rainy months are July to September. The area is also prone to severe cyclonic storms during April to June and October to November. The humidity is high throughout the year varying between 75 to 95 %.

Geomorphology

The northern portion of the Mahanadi Delta forms the Bhitarkanika wildlife sanctuary, which comprises sandy beaches, mudflats and dense mangrove forest and is interrupted by a number of small creeks and streams. The entire coast has flats sand spits with a number of small sand dunes of about 0.5 –1.0 m and covered with beach vegetation. As a result of high wind action some dunes have grown up to 20 m height.

Hydrological condition

Tidal amplitude: Tidal level varies from estuarine mouth towards the inland areas subjected to wide seasonal variation. The area is influenced by high tides

and low tides twice a day at an interval of 12 hours. The tidal amplitude ranges from 2 - 3.5 m upstream and 3.5 – 6 m near the river mouth (MSSRF 2002).

Soil properties

Bhitarakanika region is covered with sediments of flood plain deposits of sub-recent origin and Pleistocene. Due to regular inundation through tidal action the soil is mostly clayey loam and highly slushy. The surface soil is composed of silt loam and clayey loam and is about three to four meter in depth. The soil though well aerated is saline. In the elevated areas away from the creeks and channels the soil is more sandy and comparatively less moist and saline. The soil pH varies from 6.73 to 7.3 (MSSRF, 2002). Due to constant deposition of humus the soil is fertile even though it is saline.

Landuse around Mangroves

Cropping pattern: Agriculture is the major landuse around the mangrove villages and paddy is the major crop. Cultivation is done only once during the monsoon from June to November. The crop is mainly rain fed. Coconut plantation is also found in the villages.

Forests: Out of the 215 sq km of mangrove forest of Orissa, Bhitarakanika occupies 202 sq km. The Kendrapara district has 184 sq km and Bhadrak district has 18 sq km of mangrove vegetation cover.

Aquaculture: Aquaculture ponds are seen surrounding the RF and are sporadically distributed. The aquaculture ponds are seen adjacent to the saline embankments made by the Irrigation department to check the saline water intrusion into the agriculture field. Now many agricultural lands are being converted into prawn farms.

Flora of the mangrove forest

According to Kanvinde (2003) the mangroves of Bhitarakanika comprises 70 species, including mangrove and their associates with 4 species of *Bruguiera*, 3 species of each *Avicennia*, *Sonneratia*, *Heritiera*, *Rhizophora* and *Xylocarpus*.

The mangrove species are mostly concentrated along only the network of creeks and channels and extend from the sheltered bay to the elevated banks of the upper riparian zone, where the composition of the mangrove community is due to the presence of non- mangles and transitory mangles. Pattnaik and Choudhury (1988) classified Bhitarkanika vegetation into mangal and saltbush formation.

Mangals: They are classified into three categories namely, eumangals, semi-mangals and transitional mangals.

Eumangals: These typical mangroves are found in water logging area and adopted for high salinity variation. The dominant trees of this type are *Rhizophora apiculata*, *R. mucronata*, *Avicennia officinalis*, *Bruguiera gymnorrhiza*, *Ceriops decandra*, *Aegiceras corrniculatum*, *Sonneratia apetala* and *S. caseolaris*. These are generally evergreen and show various morphological and reproductive adaptations. A dominant grass *Porteresia coarctata* are found along the banks, which are submerged during high tide.

Semimangal: They grow close to riverine and creeks. The main species are *Heritiera formes*, *Cerberia mangals*, *Cynometra mimosoides*, *Xylocarpus granatum*, *Excoecaria agallocha* and *Tamarix indila*.

Transitional mangals: These plants are well adapted to terrestrial habitat. Many of them are deciduous and few are evergreen. They are mostly found in less tidal action or low salinity. The common species found intransitional mangroves are *Hibiscus tiliacens*, *Excoecaria agallocha*, *Flagellaria indica*, *Ponga pinnata*, *Derris trifoliolate* and *Salvadora persica* and shrubs such as *Synostemous besiforme* and *Syzigum ruscfolmu*.

Fauna

The diversity in fauna is very high. The animals that are associated with mangroves have a wide range of invertebrate and vertebrate fauna (Kar, 1981; Kar, 1991; Dash and Kar, 1990; Kar et. al, 1998; Kar and Satpathy, 1996; Chadha and Kar, 1999). In Bhitarkanika the fauna is distributed throughout the sanctuary often in distinct zones related to frequency of tidal flooding, soil

type, salinity and the type of surrounding plant community. There are several species of mammals, birds, amphibians, reptiles, fish that live in Bhitarkanika. There are about 172 species of birds, 94 species of reptiles, 26 species of mammals and 5 species of amphibians recorded in the Bhitarkanika. The important mammals are wild boar, monkey, spotted deer, sambar and fishing cat. The star attraction during monsoon is the “Baga Gahan” in Bhitarkanika, which thronged thousands of nesting aquatic birds. It has been estimated that more than 80,000 birds nest together (community nesting) and majority of birds (60% approx) include open – billed storks. The forest department of Orissa established a salt water crocodile research and conservation center at Dangmal in 1975 with purpose of quickly multiplying population of this endanger reptiles using the “grow and release” technique (Kar, 1981; 1999 a, b, c). The longest Indian lizard, water monitor *Varanus salivator*), the largest non-poisonous snake Python (*Python molurus*) and deadly poisonous snake, king cobra (*Ophiophagus Hannah*) are seen in Bhitarkanika (Kar et al., 1998). The amphibians like Indian toad, tree frog, skeeping frog and other frogs are also seen in Bhitarkanika area. Fish and prawns spend most of their adult life at sea and return to the mangrove area for spawning. Some of the commercial important fishes are Ilisa (*Hilsa illisha*), Bhekti (*Lates calcarifer*), Kantia (*Myctus* sp.), *Anchovella* sp. etc. Prawns such as tiger prawn (*Penaous monodon*), *P. indicus*, *Metapenaus affinies* etc. and crabs (*Scylla serrata*) etc. are available in Bhitarkanika wild life sanctuary.

Socio-economic conditions

There are more than 100 villages in and around the sanctuary with a total number population of more than 41296 (Kanvinde, 2003). A study of the populations of these villages for the past few decades shows that most of them are immigrants who have settled here after tow events, one following the partition in 1947 and after the Bangladesh Liberation war in 1971. The original people of the area are a tribe of honey gatherers and hunters. Local communities cultivate paddy and also engage in fishing for subsistence. Paddy yield is very poor, which about 0.8 to 1 ton per hectare which may be due to poor soil conditions (MSSRF, 2004).

The following satellite data have been used for Bhitarkanika R.F

1. IRS P6 LISS III, November, 2005
2. IRS P6 LISS IV - 102-088, April, 2005
3. IRS 1D - LISS III + PAN, 2000
4. SOI toposheet - 1972 - 73

Characterization of Mangrove vegetation

The vegetation shows distinct zonation characterized by the presence of particular species of plants. The zones have specific physico-chemical environment and related dominant genus. They are dependant on the extent and frequency of inundation, tidal waves, salinity and soil characteristics. The freshwater and seawater mixing is a very important factor controlling the salinity and ultimately the vegetation composition. The currents also play an important role in the distribution of seeds, seedlings and plant parts. On the basis of structure and composition of species, the mangrove areas have different mangrove communities of species association.

There are 10 types of major and associate mangroves and non-mangrove classes identified in the Bitarakanika (Fig. 3.2.31)

Avicennia and Excoecaria community (Dense)

The Avicennia and Excoecaria community formation is found towards the landmass where the inundation is frequent. Both constituents form their pure patches in association with one another. Sometimes the association of Excoecaria species at few places goes upto 90 per cent. The height of the both species varies from 5 to 8 feet. The association is more prominent in north-eastern part of Bhitarakanika.

Heritiera long

Heritiera fomes are found in less saline area in hard muddy substratum. It is generally found in the western part of the Bhitarakanika Island along the Khola creek. The height of species is generally 10-20 meter. With dense packed canopy it mainly shows association of *H. littoralis*, *Xylocarpus* sp., *Pongamia pinnata*, *Thespesia populnea*, *Hibiscus*, *Excoecaria agallocha* etc.

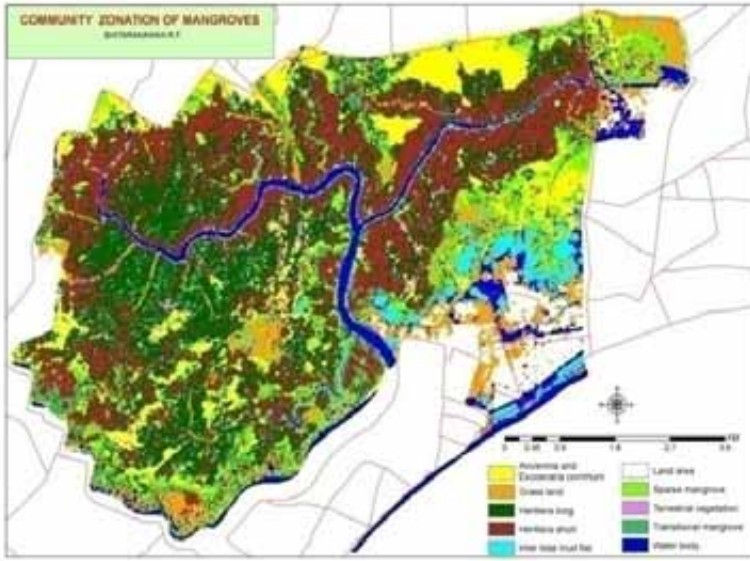


Fig. 3.2.31: Mangrove Zonation Map, Bhitarkanika R.F

Heritiera short

Heritiera fomes in association with *H. littoralis* cover maximum area of the Bhitarkanika. They are grown mainly as a pure patch and some times are associated with *Excoecaria agallocha*, *Xylocarpus* sp., *Hibiscus tiliaceous* etc. The height of the trees ranges from 8 to 10 m. It generally occurs in eastern and western part of the Bhitarkanika.

Transitional Mangrove

The transitional mangroves grow landward starting from water to high-elevated areas. The transitional mangroves are dominated by *Dalbergia* sp., *Excoecaria* sp., *Acanthus* sp., *Acrosticum* sp. The transitional mangroves are grown in north-eastern peripheral side of the island.

Sparse Mangrove

The sparse mangroves were grown in the peripheral areas of Bhitarkanika. Sparse mangroves are being resulted because of human interference. The

dominant species occurring in this region are *Dalbargia* sp., *Excoecaria* sp., *Acanthus* sp. They are mostly found in western part of Bhitarkanika.

Grassland

Grasslands are seen in the eastern side of the island area near Mahinsamunda. Besides, some grass meadows are seen in both side and on the way to Bhitarkanika village.

Terrestrial vegetation

The terrestrial vegetation is the non-mangrove species growing in the peripheral areas of Bhitarkanika. They are mostly found in northern side of the island. A strip of non-mangrove patch starting from Sanjognadi to Bhitarkanika village is seen on the both sides of the newly constructed road. They do not get much influence of tidal inundation. The dominant species are *Strichnous nux- vomica*, *Ceiba petendra*, Banyan trees etc.

Health Assessment Model

Maps are generated for the following indicators affecting the health of mangroves (Figs. 3.2.32 to 3.2.47) and corresponding values in the scale 1 to 100 are given.

Canopy cover

Very Dense mangroves	-	100
Dense mangroves	-	75
Sparse mangroves	-	40
Degraded mangroves	-	1-10

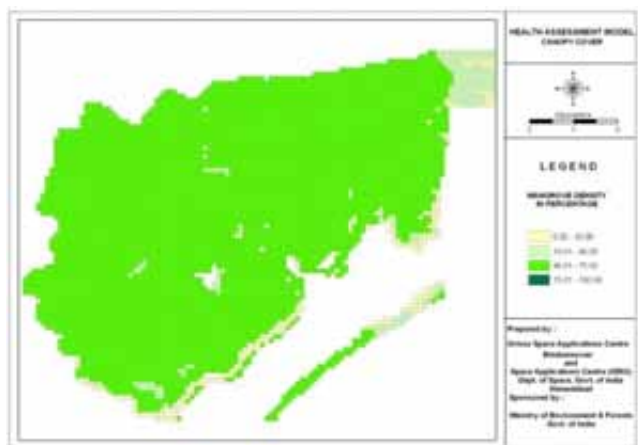


Fig. 3.2.32: Canopy Cover Map, Bhitarkanika R.F

Floral Diversity

More than three mangroves	-	100
Two to three mangrove species	-	80
Less than four mangrove species	-	60
More than one associate	-	40

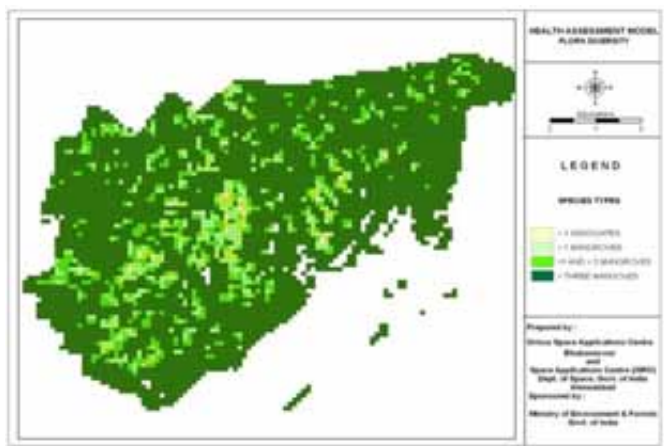


Fig. 3.2.33: Floral Diversity Map, Bhitarkanika R.F

Tree height

The average height of 6 m of major mangroves is considered as the healthy mangrove:

Healthy (100)	-	Tree height 10 m and more
Moderately healthy (75)	-	7-10 m
Moderately unhealthy (50)	-	3-7 m.
Unhealthy (25)	-	<3 m.



Fig. 3.2.34: Tree Height Map Bhitarkanika R.F

Defoliation

0%	-	UN seasonal defoliation - healthy -	100
1-10%	-	Moderately unhealthy -	60
More than 10%	-	Unhealthy –	10

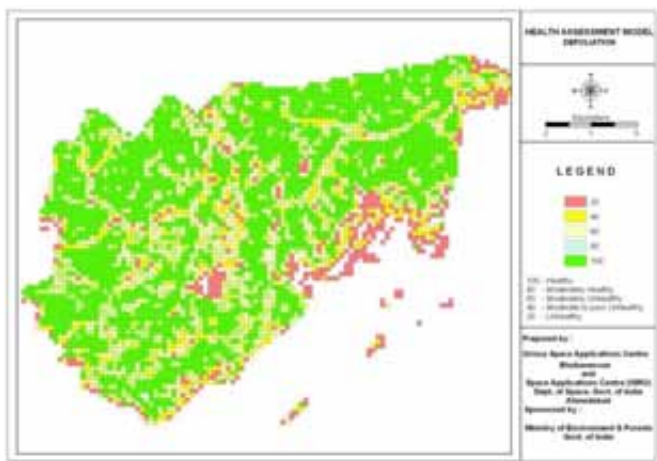


Fig. 3.2.35: Defoliation Map, Bhitarkanika R.F

Obstruction to natural flow of tidal & freshwater:

Formation of sand bars across river mouths/ estuaries – unhealthy

Formation of Sandbars / deposition across rivers / rocks and canals - Unhealthy

Abrupt change in water colour black or dark blue to light blue-- Unhealthy

Obstruction in 1 ha area or more for more than or equal to 6 months-20

Obstruction in 1 ha area or more for less than 6 months – 40

Obscuration in less than 1 ha area for more than or equal to 6 months- 60

Obstruction in less than 1 ha area for less than 6 months – 80

No obstruction -100

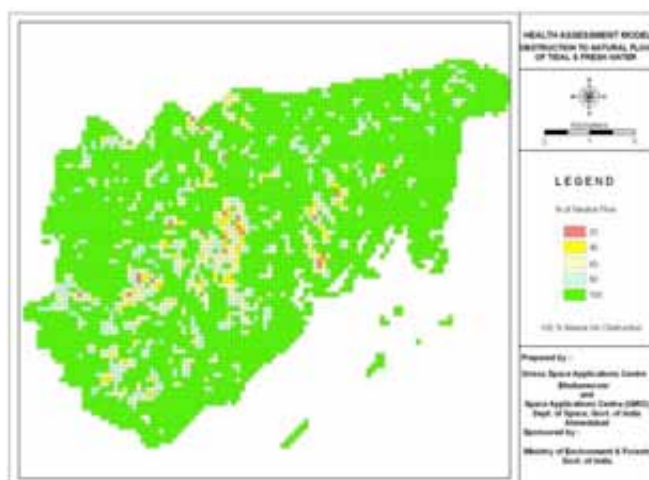


Fig. 3.2.36: Obstruction to natural flow of tidal & freshwater Map

Drainage Density

More than 20% creek area	-	100
10 – 20%	-	60- 80
5 -- 9.9%	-	40 – 59.9
1-- 5%	-	20- 39.9
<1%	-	10- 19.9

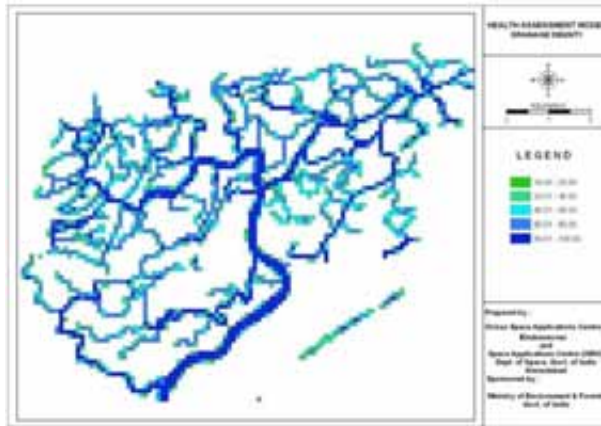


Fig. 3.2.37: Drainage Density Map

Sedimentation pattern in water body

Highly turbidity	-	20
Moderately turbidity	-	70
Less turbidity	-	100

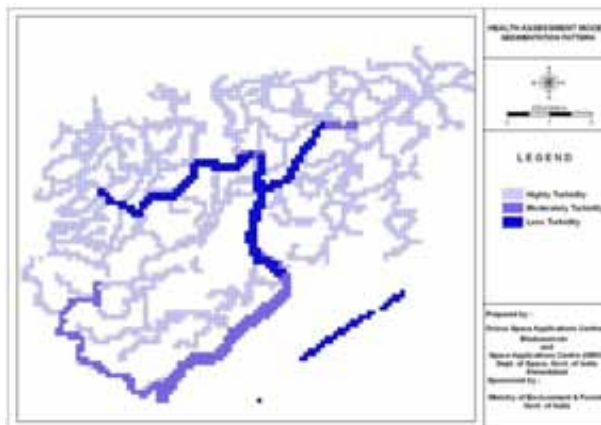


Fig. 3.2.38: Sedimentation pattern in water body Map

Natural regeneration

Areas with natural regeneration	-	healthy
Areas with low natural regeneration	-	unhealthy

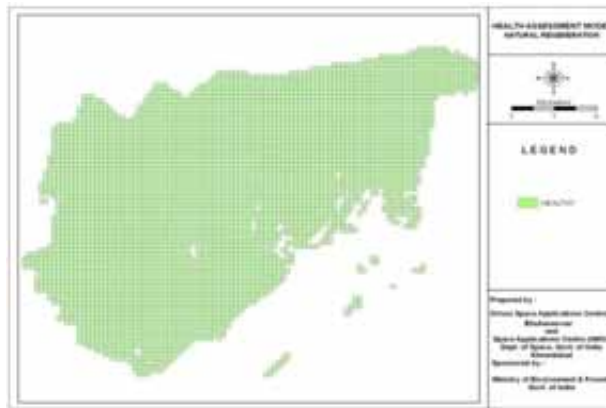


Fig. 3.2.39: Natural Regeneration Map, Bhitarkanika R.F

Anthropogenic Stress

Classification criteria:

1. Distance from stress (more the distance from the mangrove stand less is the stress)
2. Distance from the habitation

100m or less	-	10
101-500 m	-	20
501 m – 1 km.	-	40
1km – 2 km.	-	60
2.5 –5 km.	-	80
>5 km.	-	100



Fig. 3.2.40: Distance from the Habitation Map

3. Population		
<100	-	100
101-500	-	80
501-1000	-	60
1001-5000	-	40
5001-10000	-	20
>10,000	-	10

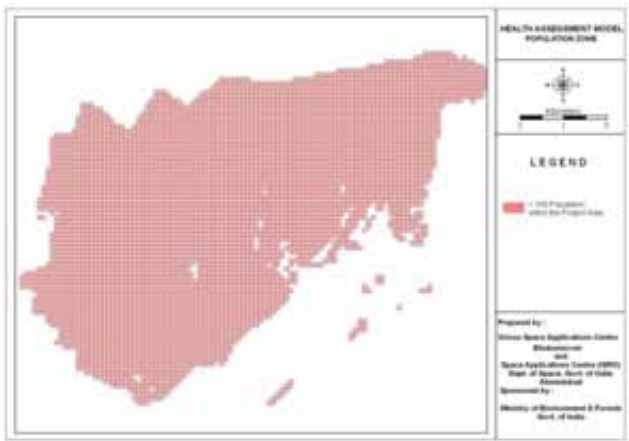


Fig. 3.2.41: Population Map

4. Embankment
- Presence of embankment in a creek which is the only source of freshwater for a patch will be unhealthy - 10



Fig. 3.2.42: Embankment Map

5. Grazing

Presence / absence – presence is high stress (10), Absence is no stress (100)

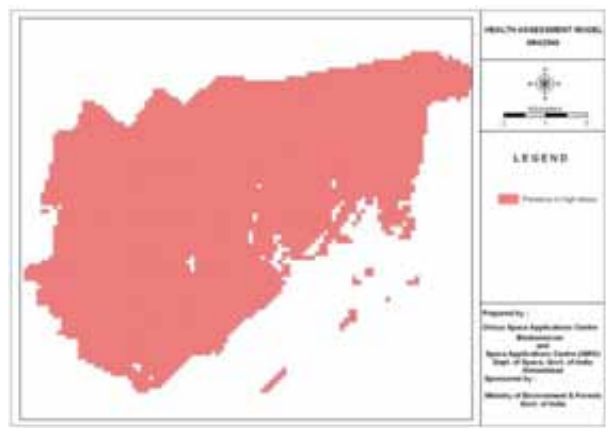


Fig. 3.2.43: Grazing Map

6. Reclamation of mangrove forest (aquaculture/ saltpan/ residential/ any other development activity) – 10



Fig. 3.2.44: Reclamation of mangrove forest Map

7. Stand size/ fragmentation of the stand

Change in the size of the stand

No change	-	100
1-5%	-	80

5.1-20%	-	60
20-40%	-	40
More than 40%	-	20



Fig. 3.2.45: Stand size Map

8. Change vegetation pattern – from the year 2000 to 2005

a.	Mangrove to non- mangrove	-	10
b.	Halophyte to mangrove	-	60
c.	No change in mangrove	-	100

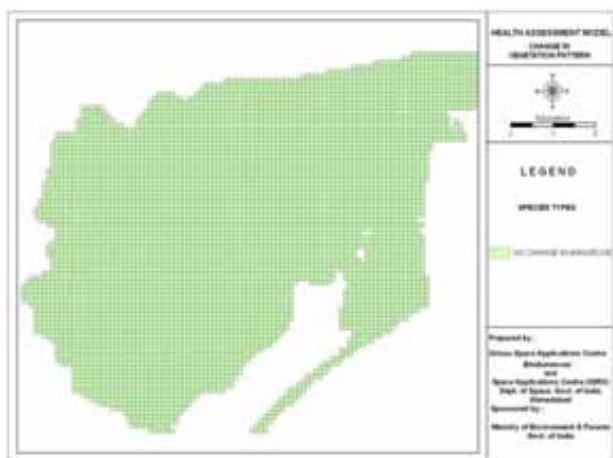


Fig. 3.2.46: Change Vegetation Pattern Map

9. Erosion / accretion

Erosion	-	10
Accretion inside mangrove stand	-	20
Accretion along shore	-	80
No erosion	-	100

All intersected layers with grid generate a separate grid showing the averaged values for each indicators of health.

Each cell = $\sum$ value of indicators / $\sum$ polygons

Lastly, each grid is recalculated assigning weight ages to each layer and the health of the mangrove is predicted as follows:

Parameter	Weightage
Canopy	12
Flora density	11
Obstruction to natural flow	10
Drainage density	9
Natural regeneration	8
Anthropogenic stress	7
Stand size/ fragmentation	7
Change in vegetation pattern	6
Height	5
Defoliation	4
Erosion/ accretion	3
Sedimentation	2

MH =

$\sum$ (Map of each parameter (Rank) X Weightages/ sum of weightages (84))

(The sum of weightages is done here to bring the values in the range of 1-100.)

Thus,
Mangrove Health, MH =

Mangroves in pristine health	80.1 - 100
Mangroves vulnerable to degradation	40.1 - 80
Mangrove degrading	10.1 - 40
Mangrove degraded	1 - 10

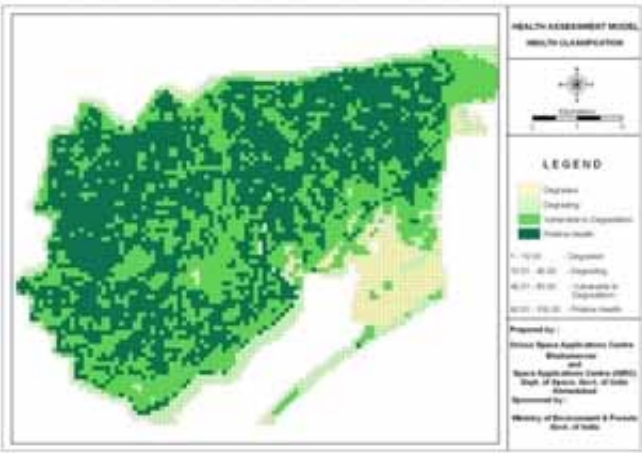


Fig. 3.2.47: Mangrove Health Map, Bhitarkanika R.F

Porlob Jig

Canopy Area

Porlob Jig is located in the Middle Andaman facing the Andaman Sea in its eastern side. There are two major islands namely the Long Island and Porlob Island. Porlob Island is located near to the main land. Our study area includes the channels between the Porlob Island and main land along with the other two bifurcated sub channel in its north. The name of the two mangrove fringed sub channels are Boroin jig and Yol jig. Dense variety covers nearly 45% and sparse coverage has 49% of the total mangrove covered area. Degraded cover occupies only 2% of the total area. Degradation is pronounced towards the landward margin of this habitat.

Density	Area in sq km	Percentage of total area
Dense	22.94	45.51
Sparse	25.09	49.78
Degraded	2.37	4.70
	50.40	

Floral Diversity

Categories	Area in sq km
<i>Ceriops, Avicennia, Excoecaria</i>	3.07
Fringe mangrove mainly <i>Rhizophora</i>	3.66
Mixed mainly <i>Rhizophora</i> and <i>Bruguiera</i>	5.93
Mud covered with salt	2.37
<i>Phoenix</i> and <i>Avicennia</i>	6.08
<i>Rhizophora</i> Dense	10.28
<i>Rhizophora</i> Sparse	15.94
Sparse pure <i>Phoenix</i> patch and <i>Acrosticum</i>	3.06
Total	50.39

Tree height

Average tree height is about 20 meter but at some places it attains height of 28-30 meter. It is not possible to measure the height inside the creek as it is Jarwa tribe infested area.

Defoliation

Defoliation has not been observed along the fringe area during our field visit time. It is not possible to collect information from the inner part of the forest. Effect of storm surge, during tsunami has not been noticed in this part.

Obstruction to natural flow of tidal and freshwater – Remote sensing data of pre and post monsoon

These creeks fall directly into the Andaman Sea but Long Island protects the creek from the open sea environment. Although in some places erosion is more pronounced due to wave activity. Sand bar or any deposits has not been noticed across the channel.

Sedimentation pattern in waterways

Inside the creeks, the colour of the water shows little more turbid as compared to the area where they meet the main Andaman Sea. Overall, water is less turbid.

Natural regeneration – Post monsoon field observation

Natural regeneration was observed in some places but it was impossible to collect information in the field, as it is Jarwa infested area and Forest department hardly allow anyone to enter within the forest.

Anthropogenic stress (RS multi-temporal data)

Being nearness to the habitation, the anthropogenic intervention cannot be ruled out in this part also. Degradation is observed at the peripheral area towards the landward side. The strict protection from the forest department and inaccessibility of the region help to keep the forest resource out of the reach of human intervention.

Stand size/fragmentation of the stand (RS multi temporal data)

Patchy occurrence of mud flat, about 2.3 sq km area in total has been mapped.

Erosion/accretion (Multi temporal RS data)

The mouths of the Borain and Yol creek are well protected from open sea environment and insignificant deposition is observed along the fringe border. But at the north-eastern and north western boundary of the Porlob jig, a considerable amount of erosion has taken place with respect to the condition that prevailed in 1968-69 (SOI toposheet 86D/15).

The porlob jig area is located near to habitation but the presence of Jarwa tribe has made this Island, almost inaccessible to common people. This part of the middle Andaman is not affected by differential land movement due to 2004 tsunami but uprooted trees were noticed along the fringe area.

Shoal bay

Canopy Area

Total mangrove area of the creek is about 67 sq km, out of which sparse variety comprises of 60.5% of the total canopy. Sparse variety includes mainly *Rhizophora* in the fringe and middle portion of the three-layered structure. Degraded mangrove covers nearly 20%. The dense mangrove occupied 19% of the total area.

	Area in sq km	Percentage of Total area
Dense	12.71	18.83
Sparse	40.87	60.57
Degraded	13.89	20.59
	67.47	

Floral Diversity

Categories	Area in sq km	% Total coverage
<i>Rhizophora</i> , less dense	14.93	22.13
Sparse mangrove dominated by <i>Rhizophora</i> , <i>Xylocarpus</i>	25.94	38.45
Dense <i>Rhizophora</i>	3.45	5.12
<i>Xylocarpus</i> dominated	5.37	7.96
Fringe mangrove (mainly <i>Rhizophora</i>)	3.88	5.76
Very sparse assemblages of <i>Rhizophora</i> and <i>Bruguiera</i>	13.89	20.59
	67.46	

Tree height

The average tree height of the mono species dominated *Rhizophora* is about 25 mt but at some places the height reaches up to 30 m. *Xylocarpus* occupying in the landward area is having an average height of 20mt but its girth at breast level is wider than that of *Rhizophora*.

Defoliation

This incident had not been observed during our field visit (in the month of February, March and January of the year 2007, 2008, 2009, respectively). Some defoliated stems of *Rhizophora* were observed at some places along the fringe area which could be due to saline water inundation at the time of tsunami but rest of the *Rhizophora* tree at the middle part did not show this feature.

Obstruction to natural flow of tidal and freshwater – Remote sensing data of pre and post monsoon

The Shoal Bay creek is located at the eastern coastal fringe area in the south Andaman's Jarkatang area. Accretion or sand bar formation has not been noticed across the river. Erosion is not prominent.

Sedimentation pattern in waterways

Water is less turbid rather clear water signature is evident from satellite image. Sedimentation pattern apparently indicate a healthy state of the vegetation.

Natural regeneration – Post monsoon field observation (binary value)

Regeneration is observed along the intertidal flat in front of the fringe *Rhizophora*. 40-50 seedlings of *Rhizophora* per 100 sq meter area have been calculated approximately in the fringe zone but in the inner zone the rate is quite low. In some places where *Avicennia* has grown in the intertidal area as a pioneer species, their reformation rate is nearly 30 per 100 sq m.

Anthropogenic stress (RS multi-temporal)

Anthropogenic activities are of significant concern in this area. A part of the eastern side of the creek is reclaimed for residential and agricultural purpose. A patchy habitation parallel to the length of the creek has been mapped from satellite image. Wrightmyo is one of the populated areas in South Andaman, located in the vicinity of the mangrove cover within a distance of 10 m or even

less than it. Reclamation for residential purpose is one of the major threats, followed by direct cutting and grazing activities. Some patches of mudflat inside the mangrove coverage have also been for fishing related activities. Discharge of oil from fishing trawler and launches is there but this is not an 'Oil Route' and also the effect of oil spill has not been visualized in this mangrove island.

Stand size/ fragmentation of the stand (RS multi temporal data)

Mudflat patch inside the dense *Rhizophora* strand has been observed in the satellite image, dated 2006 but in the field an extremely scatter growth of *Rhizophora* and *Bruguiera* have been noticed and accordingly this mudflat class has been mapped within the very sparse variety of mixed *Rhizophora* and *Bruguiera*.

Erosion/accretion (Multi temporal RS data)

Accretion is dominant in the sheltered parts of the creek, where wave influence is less. At the mouth where it meets the Andaman Sea, erosion has been noticed as like a typical creek but overall accretion is predominant over erosion.

Shoal bay creek, having a length of about 30 km and average width of 700 m empties into the Andaman Sea along the eastern coastal part of the South Andaman. The stretch of mangrove land surrounding the creek has subsided after the earthquake of 2004. Land subsidence has increased the water residence period in this area and as a result the three-layered structure within the mangrove area has started to modify.

Dhanchi Island

Canopy Area

64% of the total mangrove area (out of 27 sq km excluding creek, mud flat, marshy area) is occupied by dense variety of different species. Sparse canopy accounts nearly 18% whereas degraded category cover up 0.8% of the above-

mentioned total figure. Saline blank formation is also evidenced in this island, which accounts 14% of the total canopy.

Category	Area in sq. km	% cover
Dense	17.55	64.34
Sparse	5.11	18.74
Degraded	0.23	0.84
Saline blank	4.38	16.07
	27.27	

Category	Area in sq km
<i>Aegialitis -Excoecaria</i> Dense	2.60
<i>Avicennia</i> Dense	0.69
<i>Avicennia</i> Sparse	5.11
<i>Excoecaria agallocha</i> Dense	1.90
Fringe mangrove	2.94
Mangrove Degraded	0.23
Marsh vegetation	4.92
Mix Dense	3.57
Phoenix Dense	5.85
Saline blank	4.38
Sand/beach vegetation	0.02
	32.21

Tree height

The average tree height along the fringe of the island is almost same as that of Lothian, which is in average 5-8 mt tall. But mangroves at the centre of the island where sparse *Avicennia* and *Phoenix* jungle are there, it is not possible to infer the height due to inaccessibility of the region.

Defoliation

This island, now almost inaccessible, only part of the north- eastern side is accessible. Defoliation has not been observed, it has not been reported by local people as well.

Obstruction to natural flow of tidal and freshwater – Remote sensing data of pre and post monsoon

Dhanchi is located towards east of Lothian and the river Thakuran flows towards its east. The Jagdal gang separates the island from the nearby-inhabited block of Pathar Pratima along the western boundary. North- eastern side of the island is under accretion but the pointed tip of the island at the southern side has been eroded considerably to attain present rounded shape. Just like Lothain Island, wave activity is strong along the southern border.

Sedimentation pattern in waterways

Moderately turbid water except in the east and south- eastern corner where wave action and erosion have made the water slightly more turbid as evidenced from sandy spit formation in that area.

Natural regeneration – Post monsoon field observation (binary value)

Regeneration is observed in the north and north- eastern part of the island along its periphery. Re-formation rate is nearly 60-80 seedlings per 100 sq m. *Avicennia alba* is the only species that has grown in the newly accredited mud flat region. Re formation rate is quite high in the newly formed fringe area but for rest of the island, this regeneration rate cannot be calculated due to inaccessibility of the terrain.

Anthropogenic stress

Among all the anthropogenic aspects, tree felling and reclamation owing to aquaculture and sericulture could be considered as important factors in this island. Although it is difficult to enter inside the forest due to wild creatures like tiger and snakes but nearness of the inhabited areas make this island more vulnerable to above activities. Reclamation activity, which is quite evident from temporal changes, (analyzed from Survey of India topographical sheet no 79C6 surveyed in 1968, Landsat image of 1989 and the latest IRS P 6 image) had shown that sericulture started much after 1968 and continued up to the year 1989. But due to court verdict, Forest Department discontinued that

practice and subsequently planted mangrove saplings in those areas. Within 20 years the 40% of the reclaimed area has been covered with sparse variety of *Avicenna*, *Aegialites* etc. There is no approachable road inside the forest and being nearness to habitation reclamation although has stopped by rule but cannot be prevented. But it is hardly possible to collect actual evidence. Discharge of oil from fishing trawler and launches is there but this is not an 'Oil Route' and also the effects of oil spill have not been visualized in this mangrove island.

Stand size/ fragmentation of the stand

Among all the factors, saline blank area has been documented for this region, which is about 16% of the total canopy cover except marshy area.

Erosion/accretion

Accretion is quite significant in the north and especially in the north- eastern sector. But south, south - east and especially eastern sector shows intense erosion. Rest part of the island does not depict any significant changes.

The above information has been generated from IRS P- 6 image provided for mangrove-health study and from ground truth checking along outer fringe of the island. It is not possible to collect any field information for this island as it is not approachable due to wild animals. So the information like natural regeneration, tree height and defoliation etc are difficult to interpret properly and we have kept null value for the layer. When the model was run in Arc-view, the model did not run.

Dhanchi is located just east of Lothian island and as per floral diversity is concerned, it shows almost the same categories but with different proportion. Phoenix and *Avicennia* sparse cover almost 10 sq km area of the Island out of total 27 sq km canopy cover. Saline blank area figures about 4 sq km. The above mangrove categories and saline blank together indicate a much elevated nature of the terrain, as these mangroves hardly need daily inundation. This island has attained a shape like inverted bowl as a result of differential tidal fluctuation over the years. The island grow longer in north and north – eastern

direction as a result of accretion during ebb tide condition but shrinks toward south as consequence of intense wave activity over the certain time frame. Sand deposition is prominent in the south- eastern part of the island, which in future could lead to a wave dominated set up, ideal for growth of sandy vegetation like Casuarinas. Thus, the mangrove vegetation in this patch would have been replaced due to less supply of mud and intense wave effect. Except this sandy area, which faces the state of open coast environment, the rest of the island grows or shrinks due to tidal effect in sheltered condition. Fresh water and silt input to the system is almost negligible but salinity has not increased considerably as this channel is connected to Hooghly River on its eastern side. Previously (i.e. nearly 20 years back) the northern part of the island had reclaimed due to Silviculture and aquaculture practices but later initiatives from forest department had stopped this practice and mangrove had been planted by them and 40% of the reclaimed area has now been covered up with sparse mangrove. Although canopy density and species diversity suggest a good condition of the forest but intense wave activity i.e. open coastal nature in the south eastern part may cause a severe damage to the island in the long run and as a consequence mangroves will be more vulnerable to degradation.

Lothian Island

Canopy Area

61% of the total mangrove area (out of 29 sq km excluding creek, mud flat, marshy area) is occupied by dense variety of different species. Sparse canopy accounts nearly 17% whereas degraded category cover up 7% of the above-mentioned total figure. Saline blank formation is also evidenced in this island, which accounts 14% of the total canopy.

Category	Area in sq. km	Percentage of total area
Dense	17.94	60.80
Sparse	5.05	17.10
Degraded	2.16	7.30
Saline blank	4.37	14.80
Total	29.52	100

Floral Diversity

Category	Sum_Area in sq km
<i>Aegialitis -Excoecaria</i> Dense	4.57
<i>Avicennia</i> Dense	3.67
<i>Avicennia</i> Sparse	5.05
<i>Excoecaria agallocha</i> Dense	1.50
Fringe mangrove	1.80
Mangrove Degraded	2.16
Marsh vegetation	3.20
Mix Dense	2.81
Phoenix Dense	3.59
Saline blank	4.37
Sand/beach vegetation	0.20
Total	32.92

Tree height

Average tree height along the fringe of the island is about 5-8 mt. But at the centre of the island, where sparse *avicennia* and other degraded variety are present, tree height is about 2-3 meters.

Defoliation

This island is now almost inaccessible, only part of the northern side is accessible along a road that had been built to reach the watchtower, which is not far away from the Jetty. Although the road runs along the central part of island towards the southern part, but the areas beyond the road area is totally inaccessible. This is due to mainly two reasons – one is dense forest and due to snake infestation. It is almost impossible to enter the forest to make any ground verification. Defoliation has not been observed, nor been reported from local people.

Obstruction to natural flow of tidal and freshwater

Lothian is the western most mangrove island located near the mouth of Saptamukhi estuary within 1.5 km of the inhabited area. Accretion or sand bar formation has not been noticed across the river. Rather accretion is going on unabated along the northern tip and north – western part of the area where the island almost touches another island in its north, leaving a gap of only 185 m instead of an earlier opening of 1.4 km in the year 1968.

Sedimentation pattern in waterways

Moderately turbid water except in the east and south- eastern corner where wave action and erosion have made the water slightly more turbid as evidenced from sandy spit formation in that area.

Natural regeneration – Post monsoon field observation (binary value)

Regeneration is observed in the north and north- western part of the island along its periphery. 60-80 seedlings have been counted in 100 sq m areas, and *Avicennia alba* is the only species that has grown in the newly formed mud flat region. Reformation rate is quite high in the newly formed fringe area but for rest of the island, this regeneration rate cannot be calculated due to inaccessibility of the terrain.

Anthropogenic stress

Among all the anthropogenic aspects, tree felling can be considered as an important factor in this area. Although it is difficult to enter inside the forest due to wild creatures like snakes and crocodiles but nearness of the inhabited area makes this island more vulnerable to tree felling activity. However, this has been declared as a Wildlife sanctuary. Even though it is a sanctuary but approachable road inside the forest and being nearness to habitation can not ruled out this direct cutting option. But it is hardly possible to collect actual evidence. One forest beat house is located on the island. Discharge of oil from fishing trawler and lunches is there but this is not an 'Oil Route' and also the effects of oil spill have not been visualized in this mangrove island.

Stand size/ fragmentation of the stand

Among all the factors, saline blank area has been documented for this region, which is about 14% of the total canopy cover except marshy area.

Erosion / accretion

Accretion is quite significant in the north and especially in the north- western sector. But south and south –east sector shows intense erosion. Rest part of the island does not depict any significant changes.

The above information has been generated from IRS P 6 image provided for mangrove-health study and from ground truth checking along outer fringe of the island. It is not possible to collect any field information for this island as it is not approachable due to wild creatures. So the information like natural regeneration, tree height and defoliation etc are difficult to interpret properly and we have kept null value for the layer. When we run the model in Arc-view, the model did not run.

Lothian is the western most mangrove island located near the mouth of Saptamukhi estuary within 1.5 km of the inhabited area. The island grow longer in north direction as a result of accretion during ebb tide condition but shrinks east- west direction as consequence of intense wave activity over the certain time frame. Spit forms along south- eastern margin and casurina have grown over that stretch. Thus a change in habitat condition has taken place from low energy tide dominated environment to high-energy wave dominated one. The River Saptamukhi on the western and northern side of the island gets constricted with time as a change in the river dynamics in its upstream side. The constriction of the channel is due to less discharge of water during ebb tide from its upstream channel. Since this channel has blocked in its upper part as reclamation owing to aquaculture so discharge basically related due to tidal effect only. Fresh water and silt input to the system is almost negligible but salinity has not increased considerably as this channel is connected to Hooghly River on its eastern side through a small channel. Previously i.e. before nearly 30-40 years back tidal water during ebb tide come back to sea through this inlet mainly but after that the main discharge during low tide go back to sea

through another channel thus allowing less flow of water through it. As a result it gets constricted due to siltation and mangrove has started to grow in the north and upstream part of the channel. Although canopy density and species diversity suggest a good condition of the forest but off site hydrodynamic condition in long run make this mangrove on this island more vulnerable to degradation.

Ajmal mari Island

Canopy Area

Dense mangrove covers 47% of the total canopy, where as sparse variety occupies nearly 26 %. Degraded and saline blank area together cover up 26% cover.

Tree height

Average height of the tree is about 3-7 m range which indicate moderately unhealthy as per given mangrove health document.

Defoliation

Leaf shedding has not been observed or informed by local people.

Floral Diversity

Category	Area in sq km
<i>Avicennia</i> Dense	0.12
<i>Avicennia alba</i> - Sparse	1.80
Fringe mangrove- Dense	1.48
Mangrove - Sparse	17.59
Mix (<i>Avicennia-Excoecaria-Ceriops</i>) Dense	13.02
Mix (<i>Ceriops-Excoecaria-Phoenix</i>) Dense	20.80
Saline blank	19.61
Tidal Flat Inter-tidal	11.55
Total	85.97

Obstruction to natural flow of tidal and freshwater

This island is embedded within 14 km wide Matla river. Two small islands have formed on the left bank of the island within the main channel itself. Deposition has not been noticed across the creek or main river course. Although the aquaculture practice in the 60 km up streamside has blocked the stream. There is as such no obstruction to natural flow of tidal water. However, other than precipitation, there is hardly any scope for getting the freshwater flow along Matla, since upland discharge along this river has stopped completely.

Sedimentation pattern in waterways

Moderately turbid water

Natural regeneration – Post monsoon field observation

Field verification with accurate measurement of seedling in per 100sq meter area has been done roughly from eye estimation as the inaccessibility of the area is the major problem for this kind of detail study. Approximately 20-40 seedlings have been counted visually at the south- eastern part of the island.

Anthropogenic stress

None the anthropogenic factors has crucial impact on the ecosystem of this forest. Since this island is tiger infested so the direct stress factors such as grazing near or within the island, reclamation etc are not pertinent in this region. But the effect of oil spill, if any, has not been yet documented. There is hardly any scope for oil spill along this area also, since it does not fall along the 'Oil Route'. However small-scale leakage from mechanized boats and trawlers are always there.

Stand size/ fragmentation of the stand

Among all the factors, saline blank area has been documented for this region, which is about 22% of the total island area.

Erosion / accretion

The south-eastern and north western corner of the island shows accretion and natural regeneration of *Avicennia* but in the rest part of the island erosion is prominent.

Conclusion

The above information has been generated from IRS P 6 image provided for mangrove-health study. It was not possible to collect any field information for this island as it is tiger infested jungle. So the information like natural regeneration, tree height and defoliation etc are difficult to interpret properly and we have kept null value for the layer. When the model was run in Arc-view, the model did not run.

This island fringed by the river Matla on all sides is abode of royal Bengal tiger. It is expected that human intervention is less in this part. Satellite image analysis also indicates less anthropogenic intervention within and also in the nearby area. The canopy density shows that dense variety is 47% but sparse and degraded together with saline blank constitute nearly 52% of the total canopy cover. This shows a degraded stage of the forest. Floral diversity again confirms the degradation of the forest as the % of *avicennia* (0.12+1.8+1.4) as mono species comprise 3.3 sq km out of total 85 sq km of the total island area. In case of Sundarban *Avicennia* appears as pioneer species behind *proterosia* along creek. *Ceriops*, *Phoenix*, *excoecaria* and *avicennia* with small height makes up major portion of the forest (59 sq km). Saline blank has covered about 19 sq km, which is 22% of the total area of the island. The formation of salt encrusted area could be related to change of the tidal range, silt supply and increase of salinity in this zone. The river Matla and also the other estuaries along the middle part of the Sundarban have lost their connections with the original Hooghly river due to reclamation mainly for aquaculture. In some area along the newly developed intertidal regions, agricultural practices had started. Thus, agriculture also occupies the river in its upstream part. This reclamation leads to less inflow of fresh water and silt in the system.

4. Coral Reefs

The Indian coastal zone is endowed with spatially limited, but strategically located coral reef habitats which form an integral part of the island ecosystems of the country.

The continental coastline of India has a rather limited coral reef development compared to other tropical, maritime nations due to the natural adverse conditions of high turbidity, fluctuating salinity and high wave energy. Occurring in two major Gulf locations (namely Gulf of Kachchh in the Arabian Sea and Gulf of Mannar in Bay of Bengal) and two major Island groups: Lakshadweep in Arabian Sea and Andaman and Nicobar in the Bay of Bengal side, Indian coral reefs offer a myriad of marine biodiversity combined with unique regional characteristics.

Coral reefs, essentially the tropical (occurring between 30° North and 30° South latitudes), marine ecosystem, represents one of the keystone ecosystems of the planet earth, characterized by high biological productivity and environmental complexities. Shallow water, tropical coral reefs exhibit comparable habitats over a wide geographical range even though they appear as discrete systems occurring within a narrow range of environmental and biological parameters. Coral reef ecosystems possess a unique capability to maintain greater diversity of organisms and high biomass in spite of occurring predominantly in low nutrient (oligotrophic) environments. The high productivity of coral reefs owes to the combination of its own primary production (symbiosis with zooxanthellae) and support from the surrounding habitat. Coral reef organism's capability of recycling scarce nutrients among them in the otherwise oligotrophic environment is enormous. The exotic marine life of different hues, shapes and structures, remarkable ability of building physical habitat- limestone framework and high biological productivity – all contribute to the coral reefs becoming an amazing marine habitat with either coastal or offshore settings.

Coral reefs primarily function as a forage ground for the ocean's productivity and provide habitat for a large variety of marine organisms (flora and fauna)

including some of the rare avifauna. Coral reefs are also the largest biogenic calcium carbonate producer. Reefs also function as a natural protective barrier to the coastline against erosion, storm surges, tsunamis etc. Coral reefs have been recognized as an important bio-indicator of environmental and climate change as well as a geological indicator of palaeo-climate and sea-level changes. Coral reefs also harbour potential economic interests in terms of fishing, tourism and marine sports and medicine extraction.

Natural as well as anthropogenic stressors (stress-factors) continuously threaten the coral reef ecosystems' vitality and challenge the process of reef resilience. Sea-surface temperature (SST) anomalies twined with the El Nino Southern Oscillation (ENSO) phenomena bring about mass coral bleaching – an episodic, regional or global scale event whose frequency is on the rise in the recent period. Natural processes of sediment and nutrient loading lead to coral mortality coupled with harmful macro-algal invasions on the reef degrading the over-all reef health. Dependency of coastal/inland population on reef related ecosystem goods and services, mechanization of fishing practices, urban and industrial use of the coastal zone and marine pollution – all add to deteriorate the reef health all the more faster!

Coral reef mapping for the entire Indian coast has been carried out recently by Space Applications Centre (SAC) using IRS data of 2004-07 (Navalgund et al 2010). As per the inventory, the coral reefs area for India is 2383.873 sq km. The coral reef areas in different region of the country are: Gulf of Kachchh 352.50 sq km, Malvan 00.28 sq km, Lakshadweep 933.70 sq km, Gulf of Mannar 75.93 sq km, Andaman and Nicobar 1021.463 sq km. The objective in the present study was to make the eco-morphological zonations of the reefs on 1:25,000 scale for the entire country.

4.1 Eco-morphological Zonations

The global cry for conservation (since the 1980s) of this endangered, ancient ecosystem of the planet earth has caused a reappraisal in the intrinsic value of reef resources. The protection and conservation strategies adopted (mostly by bringing coral reefs under Marine Protected Areas/ Marine Biosphere

Reserves' cover) have helped to a considerable extent in maintaining the reefs. However, an optimum and effective management strategy calls for regular monitoring of coral reefs. Space borne remote sensing technology with finer resolutions has proved its utility in satellite based routine reef monitoring (through digital reef database/habitat map creation on GIS platform) over any other conventional, field based reef monitoring protocols.

Eco-morphological zonations of the coral reefs have been carried out for all the four major coral reef regions of India, viz. Gulf of Kachchh ($22^{\circ}20'N$, $68^{\circ}30'E$ - $22^{\circ}40'N$, $71^{\circ}00'E$), Lakshadweep ($08^{\circ}00'N$, $71^{\circ}30'E$ - $12^{\circ}00'N$, $74^{\circ}30'E$), Gulf of Mannar ($08^{\circ}30'N$, $78^{\circ}12'E$ - $09^{\circ}45'N$, $79^{\circ}30'E$) and Andaman ($10^{\circ}30'N$, $92^{\circ}00'E$ - $13^{\circ}40'N$, $94^{\circ}00'E$) and Nicobar ($06^{\circ}30'N$, $92^{\circ}30'E$, - $09^{\circ}30'N$, $94^{\circ}00'E$) group of Islands along with one off-shore reef of Malvan ($16^{\circ}00'N$, $73^{\circ}27'E$, - $16^{\circ}07'N$, $73^{\circ}30'E$), Maharashtra.

Conceptual Basis:

Coral reef habitat mapping through remote sensing technique has become popular over the field survey methods by the virtue of coral reefs being optically shallow water targets on the planet earth. In the Optical Infra-red (OIR) domain, the common principle in reef remote sensing is that coral reefs modify the incident light (from sun) in a different manner than to its surroundings: viz. adjacent open ocean water, seagrass beds, sand or other habitats. The reflected light (the backscattered portion of the sun's Electro-magnetic spectrum) modified by the coral reef is captured by the space-borne passive sensors and allow to distinguish coral reef *signatures* from other adjacent habitats.

Coral reef remote sensing has attained a significant success in habitat mapping as characterization of reef geomorphology (Green E.P. et. al., 1996) on a global scale and major ecological/benthic substrates have become possible with the available combination of increasingly higher spatial resolutions and broad spectral bands in the visible and infra-red (IR) regions of the electromagnetic spectrum. Space Applications Centre, ISRO has developed and evolved a comprehensive, four-level classification system for the Indian coral reefs considering both ecological and morphological components (in

terms of major reef types; geomorphological zones and sub-zones) of the reef (Table 4.1.1). With the availability of high resolution multi-spectral data the task of reef zonation has also improved significantly. The high spatial resolution enables to detect the morphological details of a reef whereas different spectral channels help in distinguishing spectral signatures of different ecological (viz, corals, algae, sea grass etc.), benthic substrates. The interpretation of reef's eco-morphological features is based on the optical properties of reef features and on their relative location and association.

Hopley's (1982) morphological classification of reefs has been taken into consideration while developing the morphological component of the reef classification system. Ecological components are limited to assemblages of plants (algae, seagrass) and animals (live corals) and the inhabited substrata. Assemblages of species and/or substrata often exhibit considerable variability and several assemblages may inhabit each morphological zone. Details of ecological and morphological classes are described in annexure 4.1.1. Morphological zones have more distinct boundaries than ecological habitats, which tend to exhibit change along gradients. Extensive ground surveys, existing coral reef maps and knowledge of the study areas have also aided in the process of developing the classification system.

Table 4.1.1: Classification Scheme for Eco-morphological Zonation of Coral Reefs of India

Coral Reef	Level I	Level II	Level III	Level IV
	Reef Type	Geomorphological Zones	Geomorphological Sub-zones	Ecological Zones
	Fringing Reef			
	Platform Reef			
	Patch Reef			
	Coral Pinnacle			
	Atoll			
	Ribbon Reef			
		Reef Front/ Windward Reef Front		
			Reef Slope	
			Reef Crest	
		Reef Flat		
				Dense Algae

				Sparse Algae
				Live Corals
				Mixed Coral Zone
				Dense Algae and Live Corals
				Seagrass
				Microalgae
				Algae and Seagrass
				Algae on Backwash
		Reef Flat (Outer)		
			Algal Ridge	
			Moat	
		Reef Flat (Inner)		
			Sanded Reef Flat	
			Muddy Reef flat	
			Sandy Muddy Reef Flat	
		Exposed Reef Flat		
			Exposed Reef Flat (Sand)	
				Exposed Reef Flat (Algae)
		Reef Flat (Degraded)		
		Deeper Inner Reef Flat		
		Deeper Reef Flat		
		Shallow Pools		
		Lagoon		
			Deep Lagoon	
			Intermediate Lagoon	
			Shallow Lagoon	
			Sand Sheet	
			Lagoonal Reef Patch	
			Coral Knoll	
		Rock		
		Submerged Rock		
		Boulder Zone		
		Submerged Reef		
		Channel		

		Coral Heads		
		Sand Cays		
		Beach / Sand Patch		
		Coralline Shelf		
Mudflat				
	Shallow Turbid Water			
	Polluted Water			
	Shore protection Structure			

The details of the methodology for ecomorphological zonations of coral reef is given in Fig 4.1.1

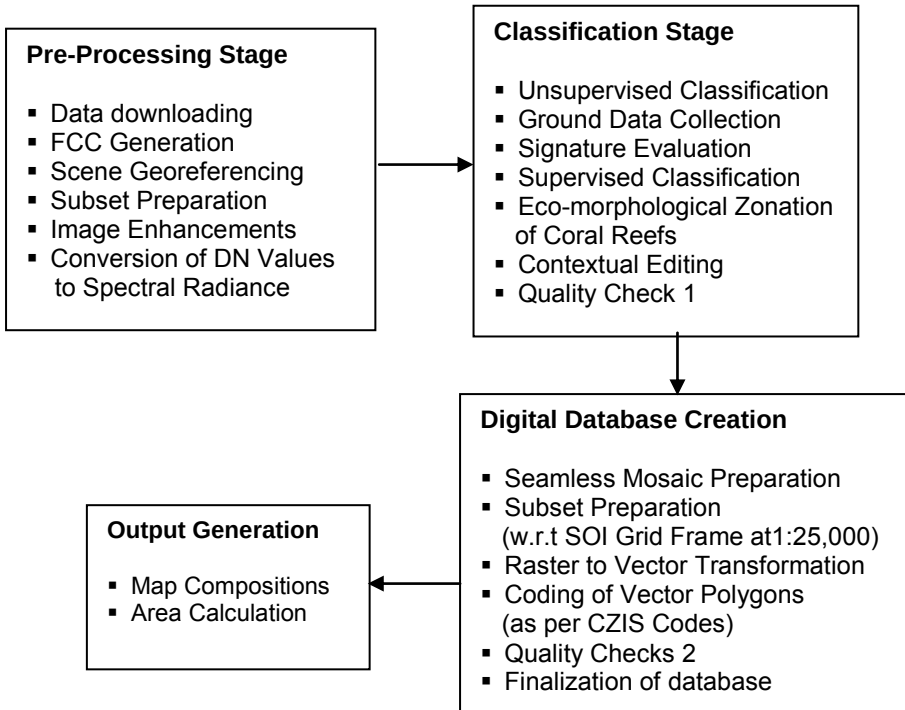


Fig. 4.1.1: Methodology for eco-morphological zonation of coral reefs

Resourcesat-1 (IRS-P6) LISSIV and LISS III data (pertaining to 2004-2008 period) have been used for preparation of the spatial inventory of Indian coral reefs (Fig. 4.1.1). Low tide and cloud-free exposures of the reefs have been

considered for one time mapping at eco-morphological level. The data mostly conform to the cloud-free period between the months of October and May. This period also take care of seasonal vegetation (like algae) on reef.

Level 2 (radiometrically and geometrically corrected Standard Product) and Level 3 (Precision Geocoded Product) digital data products in LGSOWG or Super Structure Format and GeoTiff formats respectively have been used for the project. The original data was registered to Polyconic projection and Everest Datum.

Original digital data were downloaded and False Colour Composites (FCC) were prepared using the Erdas Imagine image processing software. In order to increase the accuracy of the data, scenes were again geo-referenced using the “Geometric correction” utility of the software with reference to SOI toposheet wherever necessary. Area of interest (i.e. the coral reef area) was extracted from the original image using the “Subset” function of the software. Subset images of coral reefs were enhanced (either Standard deviation stretch or linear stretch were commonly applied) for better visual appreciation.

Pixel values in the satellite imagery represent the radiance of the earth’s surface in the form of Digital Numbers (DN) which is calibrated to fit a certain range of values for comparative analysis of images taken by different sensors. Since each sensor has its own calibration parameters, conversion of DN values to absolute radiance values is essential to understand the appearance of different types of reef structures.

Usually, detectors are calibrated so that there is a linear relationship between DN and spectral radiance. The linear function is described by three parameters – the range of DN values in the image, and the lowest ($L_{\min}$) and highest ($L_{\max}$) radiances measured by a detector over the spectral band corresponding to the minimum value (usually a value of 0). $L_{\max}$ is the radiance corresponding to the maximum DN value (usually the value of 255). Not only each sensor, but each band within the same sensor has its own $L_{\min}$ and $L_{\max}$. The information about the sensor calibration parameters ($L_{\min}$ and $L_{\max}$) is usually supplied with the data in header information. DN to spectral radiance conversion is defined by the expression:

$$L_{\text{rad}} = \{(DN/\text{Max grey}) \times (L_{\text{max}} - L_{\text{min}})\} + L_{\text{min}}$$

where: L_{rad} = spectral radiance;

DN = Digital Number;

Max grey = Maximum grey level value, e.g. 255 for 8 bit data

L_{max} = Maximum radiance value for a given band (in $\text{mWcm}^{-2}\text{sr}^{-1}$)

L_{min} = Minimum radiance value for a given band (in $\text{mWcm}^{-2}\text{sr}^{-1}$)

In order to obtain radiometrically comparable spectral radiance data, the integer DN values for each band of all images were transformed into continuous data using the spectral calibration data with the help of 'Modeller' module available in Erdas imagine software.

Reef/island wise subsets were extracted from the radiometrically corrected images. Iterative Self-Organizing Data Analysis (ISODATA) clustering algorithm available in the Erdas Imagine software has been used for Unsupervised Classification. The classification is based on spectral properties of each pixel pertaining to different reef features/categories. The numbers of classes were neither similar for all areas nor known; hence classification operation was performed for approximately 65 to 75 classes for a maximum of 10 iterations. 65-75 classes were later merged / grouped into a lesser number of classes conforming to reef categories based on FCC signatures, familiarity and prior field knowledge. The classes/reef categories were labelled as per the Coral Reef Classification System. Preliminary checks were carried out on these pre-field maps.

Field surveys were carried out to establish the signatures of coral reef categories and also to validate the mapping accuracy of the pre-field maps. Random sampling of point locations on coral reefs following Line-intercept Transect methods aided with, handheld, single frequency Trimble Geo-XT GPS was carried out as a part of ground-truth data collection. Next, signature evaluation of the reef features observed on the field was carried out in the laboratory.

Supervised classification based on Maximum Likelihood Classifier (MLC) was performed at the next step in order to improve the thematic accuracy of digital

classification and incorporate the field-knowledge into the automated process. However, for the coral reef subsets where significant improvement was not attained by supervised classification due to optical similarity between the reef features and lack of intensive ground truth data for that particular reef, unsupervised classification was only performed.

A statistical median filter of 3x3 kernel size was applied on all the classified raster images in order to get a smooth image and decrease data volume prior to vectorization. Merging of optically similar classes leads to the problem of reduction in accuracy of the map. Hence, contextual editing was performed on the resultant vector data wherever necessary in order to correct the inaccuracies thus introduced.

Quality check on thematic accuracy is carried out on these maps before creating the digital database.

Seamless mosaics of classified raster images for each reef region were created using Erdas Imagine (version 9.0) and ArcGIS (version 9.2) softwares. Edge corrections were done in order to have a continuous seamless data. The attributes for class/category names and Coastal Zone Information System (CZIS) codes were updated for vectorized polygons pertaining to different reef categories. Quality checks (Database and Thematic) were carried out in order to finalize the digital database.

Reef Zonation

The seamless vector data (on eco-morphological zones of coral reefs) were clipped as per the 1:25,000 scale SOI toposheet grids. These grid-wise vectors were overlaid on corresponding FCC images and have been transferred onto the map template with appropriate category legend as given in Annexure: 4.1.2. The map compositions were finalized by attaching marginal details.

Percent reef area has been automatically generated from the digital database summing the area of the polygons falling into different reef categories. Eco-morphological zonations for each of the coral reef regions of the country are discussed below.

Gulf of Kachchh

Gulf of Kachchh, Gujarat coast, abounds in marine wealth and is considered as one of the biologically richest marine/coastal habitat along the west coast of India. This region is endowed with a variety of Ecologically Sensitive Areas (ESAs) such as coral reefs, seagrass beds, mudflats, mangroves, beaches and sand dunes along with rock shore platforms at places.

In Gulf of Kachchh (Fig. 4.1.2), coral reefs occur within the geographical limits of 22°20' to 22°40'N latitudes and 68°30'to 71°00'E longitudes in the coast of Jamnagar and Dwarka districts of the Gujarat state. The gulf is about 170 km long and 75 km wide (NNW-SSE) at the mouth, narrowing down abruptly with a distinct constriction at 70°20' E and divides into a creek system. The Gulf has an area of 7350 sq km. Depth varies from 20 m at the head (Kandla-Navlakhi) to 60 m at the mouth. The average depth is around 30m and the minimum is around 3m above chart datum in the inner creeks. The coral growth occurs in the form of fringing reefs on the wave-cut sandstone banks around 32 islands among the 42 that adjoin the southern flank of the Gulf. This area falls under the semi diurnal macro-tidal environment with average tidal amplitude around 4-7 m (Chauhan and Vora, 1990; Pradhan *et al.*, 2004).

Because of the geographical isolation and the extreme environmental variations (temperature range 15 - 35 °C, salinity range 25-40 ‰), strong tidal currents and heavy sediment load, the diversity of corals is quite low in this region: All coral species are either massive or encrusting, with a total absence of arborescent and racemose forms.

The Gulf of Kachchh coral reefs degraded with time as and when industrial development became intensive along the southern coast. Onshore developmental activities affected the coral reefs, coral reefs were dredged for cement industries. Loss in mangrove cover has also resulted in sediment loading in the coral reef environment and has caused degradation to the inter-tidal corals.

The southern coast of Gulf of Kachchh between Okha to Navlakhi of Jamnagar district is declared as Marine National Park and Sanctuary (MNP & S) to protect and conserve the fragile ecosystem particularly the live inter-tidal and sub-tidal coral reefs and mangrove habitats of the Gulf. Major part of the MNP & S consists mainly of inter-tidal zones and intricate network of Islands with coral reefs and mangrove forests. Inter-tidal zones of Dwarka, Kalyanpur, Khambhalia, Lalpur, Jamnagar and Jodia Taluks along with 42 Islands in the district have been included in the marine protected area.

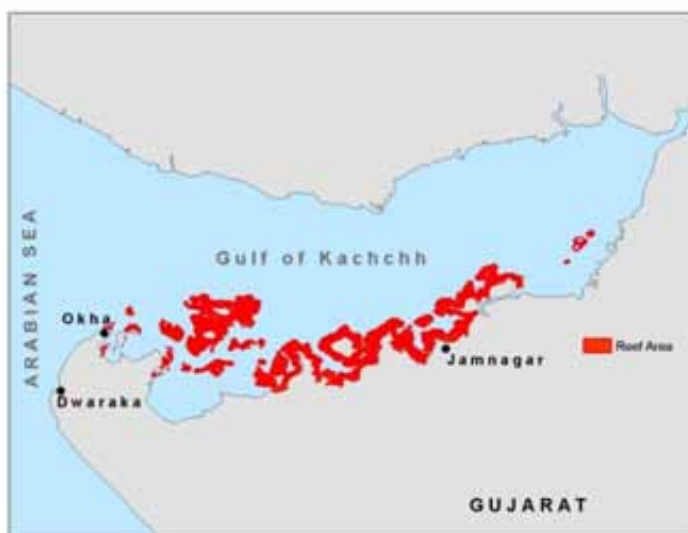


Fig. 4.1.2: Coral Reef Areas of Gulf of Kachchh

Based on the existing classifications these reefs are classified into fringing reefs (north of Okha, north of Bet Shankodar fringing the mainland from Dhani Bet to Sikka, Jindra and Chad, Pirotan, near Valsura), platform reefs (Bural Chank, and Kalubhar), patch reefs (Paga, Goose and Ajad) and several coral pinnacles (Plates: 4.1.1 and 4.1.2, given at the end of the chapter).

The reef area of Gulf of Kachchh covers total 22 SOI (1:25,000 scales) sheets. The GOK has an assemblage of ecologically sensitive ecosystems, consisting of mangrove, sea grass, algae and seaweeds along with coral reef classes. Algal ridge marking the inward limit of the outer reef crest is the most distinct feature. A well marked line of algal ridge is noticed at Bural Chank, Dhani Bet, Kalubhar reef, Narara Bet, Pirotan and Goos Island. Live coral zone has been

observed in Bural Chank reef and a small patch near Poshitra Island. Around the Bural Chank reef a patch of shallow turbid water observed. The seasonal growth of macroalgae (Photo: 4.1.3, 4.1.4) over some of the reef areas are in profuse manner resulting in dense algae over the reef areas. In case of Changri Island dense algae covers the reef flat. The same is also observed in islands near Poshitra. Mixed coral zone classes have been found in the areas of Bhaidar Tapu (Photo: 4.1.1, 4.1.2). In the north and western part of Kalubhar reef, sparse algae on muddy reef flat and sanded reef flat is found where as in south and in the eastern part muddy reef flat observed. Also a patch of dense algae is present in the northern part. A well marked inner and outer reef flat is present in Narara bet interspersed with dense algae. The maximum area of Dhani bet is reef flat covered with sand and mud. Along some coastal locations reef classes associated with mud were observed due to excessive sedimentation.



Photo 4.1.1: Reef Flat, Paga Reef



Photo 4.1.2: Live coral, *Goniopora sp.*, Paga Reef

A total of 21 numbers of Eco-morphological classes/categories of coral reefs have been observed in Gulf of Kachchh region. The major classes (Fig. 4.1.3) of Gulf of Kachchh reefs are Reef Flat (23.83 %), followed by Muddy Reef Flat (15.53 %), Sparse Algae on Reef Flat (11.31 %), Inner Reef Flat (09.49 %) and dense algae (09.31 %). An area of 3.33 sq km has been observed as live coral. The classes towards sea ward side reef front, reef crest, reef slope and submerged reef are 0.18 %, 1.99 %, 0.03 % and 0.29 % respectively.



Photo 4.1.3: Macroalgal (*Ulva sp*) overgrowth on Bural Chank Reef



Photo 4.1.4: Macroalgal Assemblage in Bural Chank Reef

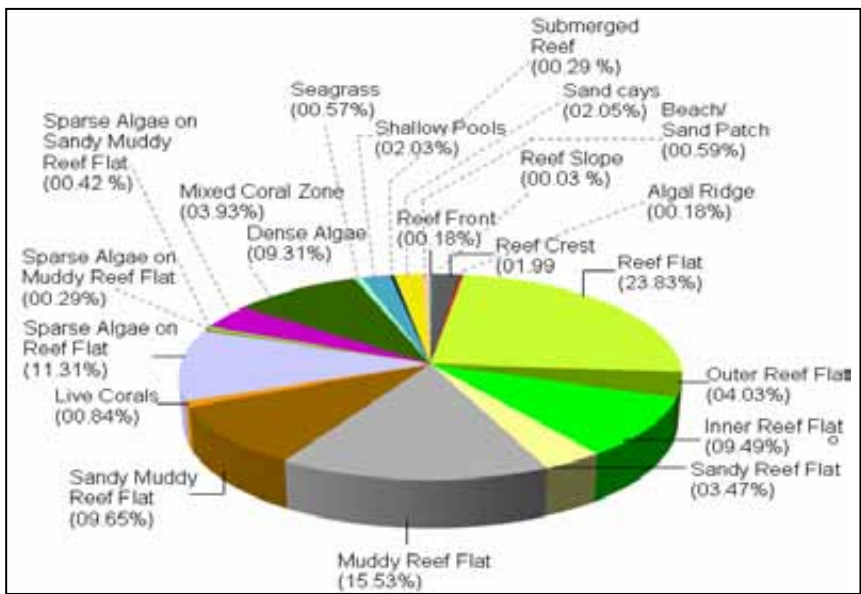


Fig. 4.1.3: Distribution of Coral Reef Categories (% Area) in Gulf of Kachchh

Malvan:

Malvan (Fig. 4.1.4) lies in Sindhudurg district towards south western part of the coastal Maharashtra, a part of Konkan coast along the west coast of India with its immense stretch of shimmering sands, and thick cashew, coconut, jackfruit and mango groves. Malvan reef lies within the co-ordinates of

16°00'-16°07' N latitudes and 73°27'-73°30'E longitudes. Malvan coast forms part of Western Ghats where Sahyadri ranges gradually meet the Arabian Sea. From Vengurla point the coast trends towards north for about 22 km. From Malvan bay a chain of submerged and exposed rocky islands extend straight towards south. In this chain, several islands exist including Vengurla Rocks at the southern tip and Sindhudurg Fort at the northern tip. Other small islets around Sindhudurg Fort are Mandal Rock, Malvan Rock etc. Here the reef is of fringing type and greatly damaged and less diverse. Sindhudurg is a low fortified island on the coastal fringing reef. The coast mainly consists of granites and gneisses and in a few gneissic interruptions the rocks are covered by laterite beds (ICMAM-PD, 2001).



Fig. 4.1.4: Off-shore Coral Reef of Malvan

Malvan is an offshore coral reef in west coast of India. The reef of Malvan is covered in only one SOI (1:25,000 scale) sheet (Plate: 4.1.3). Coral reef of Malvan has recorded four eco-morphological classes. The dominant class is Reef Flat followed by Sanded Reef Flat, Submerged Reef and Sand Cays.

Major coral reef classes of Malvan (Fig. 4.1.5) are Reef Flat (76.20 %), Sanded Reef Flat (18.42 %) and the minor class is Submerged Reef (5.38 %).

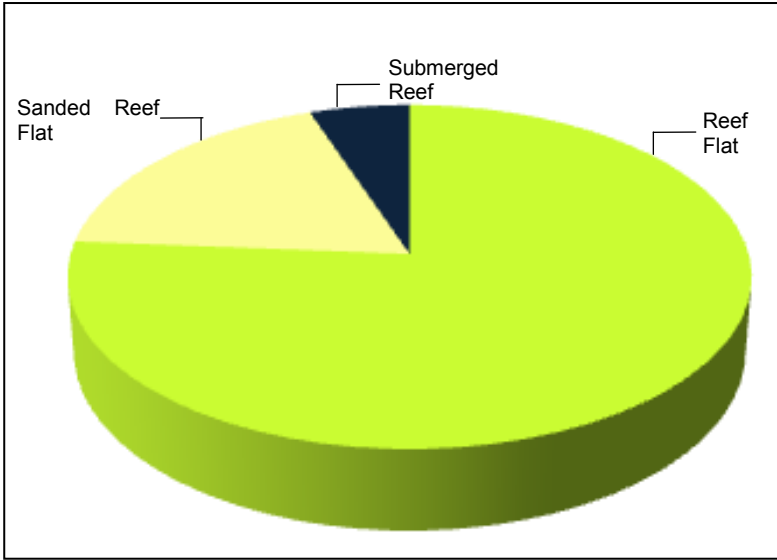


Fig. 4.1.5: Distribution of Coral Reef Categories (% Area) in Malvan

Lakshadweep:

The Union Territory of Lakshadweep (Fig. 4.1.6) is an archipelago situated in the Arabian Sea between 08°00' N and 12°00' N latitude and 71° 30' E and 74°30' E longitude and at a distance of 220-440 km from the west coast of India. The length of the coastline is 132 km, which is approximately 1.6% of India's total coastline. The islands are flat, rarely rising more than two meters, and consist of fine coral sand and boulders compacted into sand stone.

The total area of the Island is divided between the inhabited and uninhabited islands, coral reef stretch, atolls, lagoons, sunken banks and sand banks. The Lakshadweep group of islands comprises 36 islands with Kavaratti as the Capital. Lakshadweep comprises of 11 inhabited islands, 16 uninhabited islands attached islets, 4 newly formed islets and 5 submerged reefs. The islands consist of coral formations built up on the Laccadive-Chagos submarine ridge rising steeply from a depth of about 1500 m to 4000m in the west coast of India. The inhabited islands are Kavaratti, Agatti, Amini, Kadmat, Kiltan, Chetlat, Bitra, Androth, Kalpeni and Minicoy. Kavaratti is the Administrative headquarter and Agatti is the only island with an airport.



Fig. 4.1.6: Coral Reefs of Lakshadweep

Some of the uninhabited islands, formed on the Lakshadweep atolls are: Perumal Par, Viringili, Cheriya, Kodithala, Tilakkam, Pitti, Thinnakara, Parali, Kalpitti, Suheli Valiyakara, Suheli Cheiyakara and Pitti. According to the provisional population Data sheet of 2001 Census, Lakshadweep reefs have the distinction of being the only atolls in seas of India. Most atolls have a northeast, southwest orientation with an island on the east, a broad well developed reef on the west and a lagoon in between. Atolls are having high biodiversity. The coral fauna of Lakshadweep is known to harbour a total of 105 species divided among 37 genera (Pillai: 1996).

The eco-morphological zonation of Lakshadweep coral reefs (from North to South) is described as the following (Plate: 4.1.4, 4.1.5, 4.1.6 and 4.1.7):

Baliyapaniyam Island is one of the uninhabited islands of the Lakshadweep Islands. The Baliyapaniyam reef is among the two isolated north western reefs in Lakshadweep.

The Cheriapaniyam reef is blessed with a massive lagoon. Ecomorphological zones such as reef flat, lagoonal reef patch, deep lagoon, intermediate lagoon, shallow lagoon, deeper reef flat have been identified.

Chetlat is one of northern most islands. The northern side of the lagoon bottom covered up to 80% with large dome shaped colonies of *Heliopora caenilea*, *Psammocora contigua*, *Porites andrewsi* and *Porites convexa*. No sign of large-scale death of corals recorded. The *porites* species were dominant in the reef slope followed by the coral *Diploastrea sp.* *Acropora* and *Montipora* species grow here quite fast. Ecomorphological zones such as sanded reef flat, lagoonal reef patch, sand sheet intermediate lagoon, shallow lagoon reef slope, reef crest, coralline shelf, beach/sand patch have been identified.

Bitra is the smallest inhabited island (0.09 sq km) in the archipelago. It has the largest lagoon and the land was once covered with Pemphis thickets and undergrowths. The island is situated on the northern tip of the lagoon. The island has a wide beach in the southern and the northwestern end. The specialty of the Bitra island is that land area is very small compared to the lagoon. Bitra islands consisted of good live coral cover particularly *Acropora* and *Montipora* compared to the other islands. Ecomorphological zones such as algal ridge sand sheet, deeper reef flat, reef crest, intermediate lagoon reef crest live corals lagoonal reef patch, shallow lagoon reef flat, deep lagoon, coral knolls; beach/sand patch reef slope have been identified in the Bitra Island.

Kiltan, which is 1.49 sq km in area, has a large shallow lagoon. There is a high storm beach along the northern and southern ends of the island. Large coral colonies of *Pocillopora*, *Platygyra*, *Porites*, *Goniastrea* and *Diploastrea* species are reported. The western side of Kiltan Island consists of reef flat, which get exposed during low tide. Reef crest, shallow lagoon, coralline shelf, beach/sand patch, reef flat (inner), reef flat (outer), intermediate lagoon deep lagoon, reef slope have been identified.

The island of Kadmat with its land area of 2.83 sq km is the largest island. The eastern side of the reef is exposed at low tide (Photo: 4.1.5) and forms a level platform stretching from the beach. A high ridge of sand runs down in the western side of the island. Along the middle of the island is a solid lime

substratum where limestone is used to be cut for building purposes. There are many types of corals in the lagoons (Photo: 4.1.6) most of which are dead. On the sandy bottom, there are batches of racemose corals of *Acropora* and *Porites*. Western side of Kadmat Island consisted of extensive reef flat. Ecomorphological zones such as sanded reef flat (inner) live corals, deep lagoon, sand sheet, sanded reef flat, reef flat (outer), coralline shelf, windward reef front/ reef front, beach/sand patch, shallow lagoon have been identified.



Photo 4.1.5: Exposed Reef Flat, Kadmat Island



Photo 4.1.6: Heliopora Coral, Kadmat Island

Amini Island has an area of 2.32 sq km, with a completely filled interior of ring reef and a very small lagoon on the western side. The Amini beach used to be free of all coral debris. The lagoon habitat is unsuitable for any significant coral growth. Only occasional racemose colonies are seen. The inner side of leeward harbours noticed some corals but in the southern half, it was mostly dead. There is fairly rich growth of reef at the northern side of the windward side. Coral growth is richer in the reef habitat than in the lagoon. There is excessive silting on the western side and the reef is mostly covered with sand that prevents any coral growth near the shore on the windward side of the island. Ecomorphological zones such as reef flat, sand sheet, sea grass, shallow lagoon, island land, shore protection structures, coralline shelf, windward reef front /reef front, deeper reef flat, beach/ sand patch have been identified.

Perumal Par lies 26 km North West of Agatti Island. This is a reef enclosing a lagoon. It is very important Tuna bait fishing ground. Perumal par is one of the most beautiful but uninhabited island of the Lakshadweep group of islands.

Although uninhabited, the Perumal par island is frequently visited by people from neighbouring islands. The total area of the island is around 85.74 sq km. Perumalpar is gradually turning into a tourist hub, owing to its tourism potential. Ecomorphological zones such as intermediate lagoon, sanded reef flat, reef crest, reef flat, lagoonal reef patch, shallow lagoon, sand sheet, deep lagoon, deeper reef flat, reef slope have been identified.

Bangaram is a beautiful tourist island which is enclosed by a vast lagoon. The island with an area of 1.04 sq km is surrounded by a sandy beach. Ecomorphological zones such as a beach/ sand patch, sand sheet, algal ridge, reef flat (inner), reef flat (outer), sanded reef flat, sea grass, shallow lagoon, windward reef front/ reef front, coral knolls, intermediate lagoon, coralline shelf, boulder zone, deep lagoon, lagoonal reef patch (Photo: 4.1.7 and 4.1.8) have been identified in the Bangaram reef.

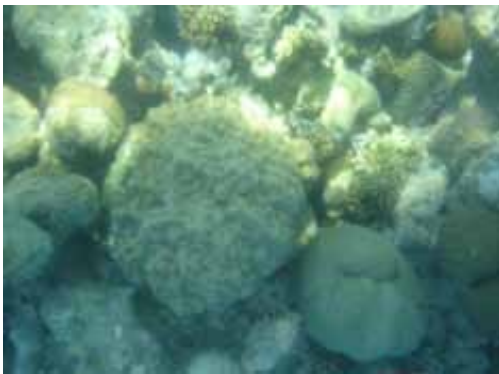


Photo 4.1.7: Massive Corals, Bangaram Lagoon



Photo 4.1.8: Digitate Corals, Bangaram Lagoon

Pitti is alternatively called Pakshi Pitti, meaning 'Island of birds', it is a vitally important nesting place for a kind of sea swallow, and has been listed as a wildlife sanctuary. It is a small rocky island sprung over an area of 1.21 hectares of land. Pitti Island is a breeding place of Tern birds from the month of January to March. From 1962 onwards it has been regarded as a bird sanctuary. The barren Island of Pitti constitute of a reef of the shape of a square with a sandy bank at its southern end. It is situated 24kms on the northwest of the capital city of Kavaratti.

Androth is an island with an area of 4.55 sq km, which has an east-west orientation and has no lagoon. The island occupies the whole interior of a platform reef. Except at the northeast extremity the reef flat is generally gets exposed at low tide. Androth is having the largest land area viz. 4.8 sq. km.; there is sparse lagoon fishery in the islands. The western side of Androth witnesses a unique phenomenon every year during and after monsoon. This area called ‘Moola’ has a block of shifting white sand, which keeps moving from the north to south. Ecomorphological zones such as Island/ land, reef flat, reef slope, beach/sand patch, coralline shelf in the Androth Island.

Agatti is a long island (2.61 sq km) situated towards the west of the main group of islands. The eastern shore is composed of only sand rising from the level of the reef flat, which gets exposed at low tide. To the south, lies a small island named Kalpitti which is separated from the main island by a narrow channel. The coral colony is dominated by *Acropora sp.* with high to very high diversity. Almost all corals in the reef flat of eastern side are dead. Ecomorphological zones such as reef slope, reef crest, deeper reef flat, reef flat, sanded reef flat fat, deep lagoon, intermediate lagoon, sands sheet, sea grass and beach/sand patch (Photo: 4.1.9 and 4.1.10) have been identified.



Photo 4.1.9: Beach facing Lagoon, Aggatti Island



Photo 4.1.10: Seaward beach, Aggatti Island

Kavaratti, the capital Island has a land area of 3.35 sq km. At the northern end the lagoon is shallow and coral growth is maximum there. The reef of windward side of the atoll has reasonable growth of racemose and massive corals. However, at the southwest of the atoll, an excessive deposit of silt has

caused significant damage to the corals. At the central part of the lagoon, corals are mostly dead with living layers of the over growth on some. The reef near the entrance and the east of the entrance are almost dead and almost covered with sediments. Towards the southern coral reef, diversity and live coral cover increases. *Acropora* sp. (Photo: 4.1.12) is the dominant coral form. Coral diversity is average. Deeper reef flat, windward reef front/reef front, reef flat (outer), reef flat (inner) sand sheet, intermediate lagoon, shallow lagoon, deep lagoon, beach/sand patch, seagrass (Photo: 4.1.11) have been classified on this reef.

Suhelipar consists of two islands with an aggregate area of 0.63 sq km, namely Valiyakara and Cheriyaakara. The reef flats have luxuriant live coral coverage. Lagoon and lagoon reefs have massive and racemose corals. The lagoons of these islands are large and consist of coral patches. Porites were dominant in lagoon and they were in good condition. Turtle nesting takes place in sand bar between the two islands. The island is frequented by fishermen from the neighboring islands of Kavaratti. Ecomorphological zone such as deeper reef flat deep lagoon reef flat (inner), shallow lagoon beach/ sand patch intermediate lagoon sand sheet, algal ridge, lagoonal reef patch, coralline shelf have been identified in Suhelipar Islands.



Photo 4.1.11: Seagrass patches in Kavaratti Lagoon

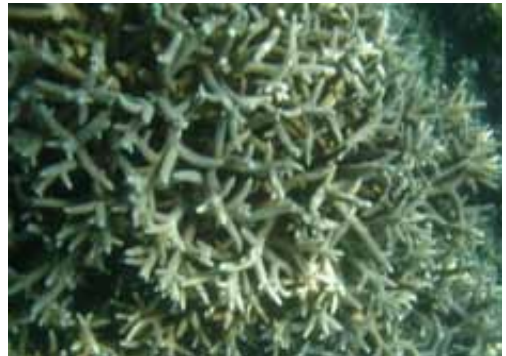


Photo 4.1.12: *Acropora* sp., Kavaratti Lagoon

Kalpeni with a land area 2.83 sq km is an island flanked by 5 smaller islands. A sea-bank of coral stones was formed along the east and southeast shore. A reef has formed between Cheriyaam and Kalpeni and at a low tide one can walk

across. The action of sea has spilt the two islands of Thilakkam and Pitti on the southwest of Kalpeni. At the northern end of Kalpeni there is a small promontory called Kodithala. These groups of islands are enclosed in an extensive lagoon. Kalpeni was particularly rich in its catch of seafish, skate, shark, octopus and swordfish. Kalpeni has two small individual islands connected by a reef. Seagrass, intermediate lagoon, shallow lagoon, beach/sand patch, sanded reef flat, sand sheet, reef flat (outer), reef flat (inner), deep lagoon, lagoonal reef patch, deeper reef flat reef slope, reef crest have been identified.

Minicoy Island (4.35 sq km) is unique and has the social and cultural characteristics of Maldives more than of the other islands in the archipelago. Minicoy has a strategic position in the Arabian Sea and is separated from the rest of the Lakshadweep by the Nine Degree Channel. Minicoy has cluster of 10 villages, which are called Athiris. The reef flat of eastern side consisted of dead coral boulders. Coral growth in the lagoon is in patches. Most of corals seen in lagoon were *Porites sp.* Reef flat (inner), beach/sand patch, shallow lagoon, algal ridge, sanded reef flat, coral knolls, lagoonal reef patch, intermediate lagoon, live corals, sand sheet, seagrass, reef slope, deep lagoon, deeper reef flat have been identified.

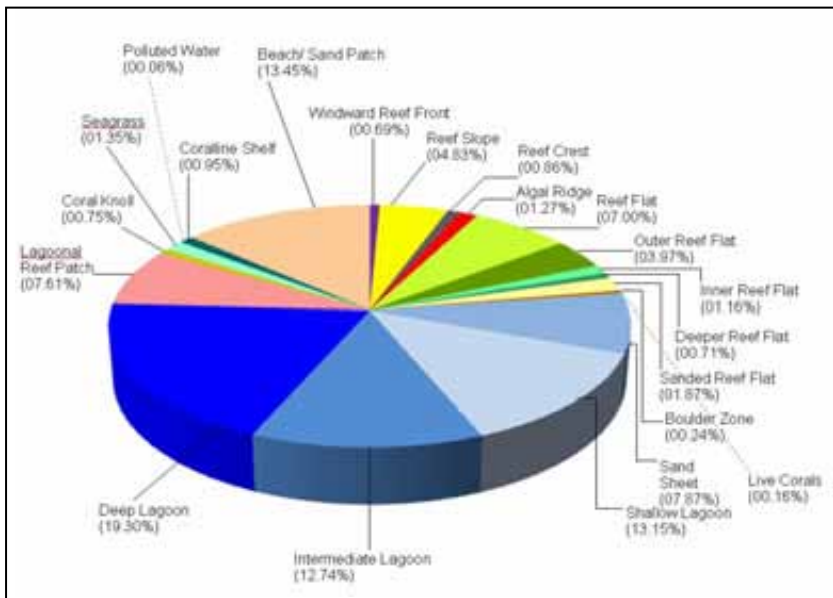


Fig. 4.1.7: Distribution of Coral Reef Categories (% Area) in Lakshadweep

For Lakshadweep coral reefs, of lagoon class occupies the majority of reef area (53.06%). Beach/sand patch (13.45%) and lagoonal reef patch (7.61%) are the next two major classes (Fig. 4.1.7). Reef flat consists of 14.71% of total reef area whereas live coral category detected from satellite data occupies only 0.16%.

Gulf of Mannar:

The Gulf of Mannar (Fig. 4.1.8) Marine National Park (MNP) is a protected area of India consisting of 21 small islands and adjacent coral reefs in the Gulf of Mannar in the Indian Ocean. This region lies in the east coast between Tuticorin and Dhanushkodi. It is the core area of the Gulf of Mannar Biosphere Reserve which includes a 10 km buffer zone around the park including the populated coastal area. The park has a high diversity of plants and animals in its marine, intertidal and near-shore habitats.

The area of the MNP is also a part of Mannar barrier reef. The Gulf of Mannar reef formations are of fringing type, developed around 20 islands located in a chain between Tuticorin and Rameswaram, on the south east coast of India. The reef around the Rameswaram Island extends into the Palk Bay as a long fringing reef along the mainland coast. Tidal amplitude in the area is less than a meter. The islands are uninhabited except for Krusadai, Musal and Nalla Tanni islands where antipoaching sheds are operating. There are about 125 villages which support about 100,000 people who are mainly Marakeyars, a local fishing community along the coastline of Marine National Park.

In South India the coral reefs have been used as a source of calcium carbonate, building blocks and rubble for construction of roads (Mahadevan and Nayar, 1972). Blasting and dredging activities result in high sedimentation on the coral reef of Gulf of Mannar thereby leading to its degradation. In general, coral reefs in Gulf of Mannar can be categorized as “degrading”, and hence, monitoring and management of these valuable marine resources are of prime importance.

The reefs of this area are fringing types of reef along with two atolls (Plate: 4.1.8, 4.1.9 and 4.1.10). Corals of this area are thriving in very shallow waters

encircling few islands. Growth of seagrass beds are observed in Gulf of Mannar reefs and some places it is in association with algae. The area to the south of the Dhanushkodi, the ribbon type of barrier reef is found with sand cays within the shallow turbid waters. Submerged reef is observed in Manouli Reef Complex.

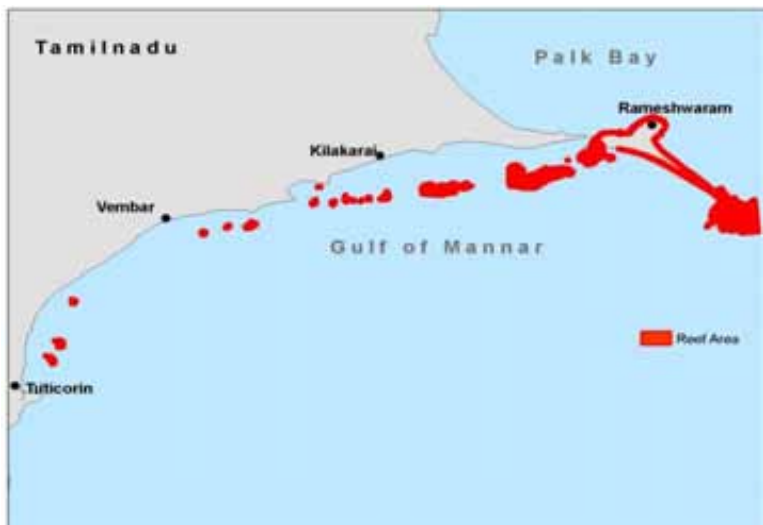


Fig. 4.1.8: Coral Reef Areas of Gulf of Mannar

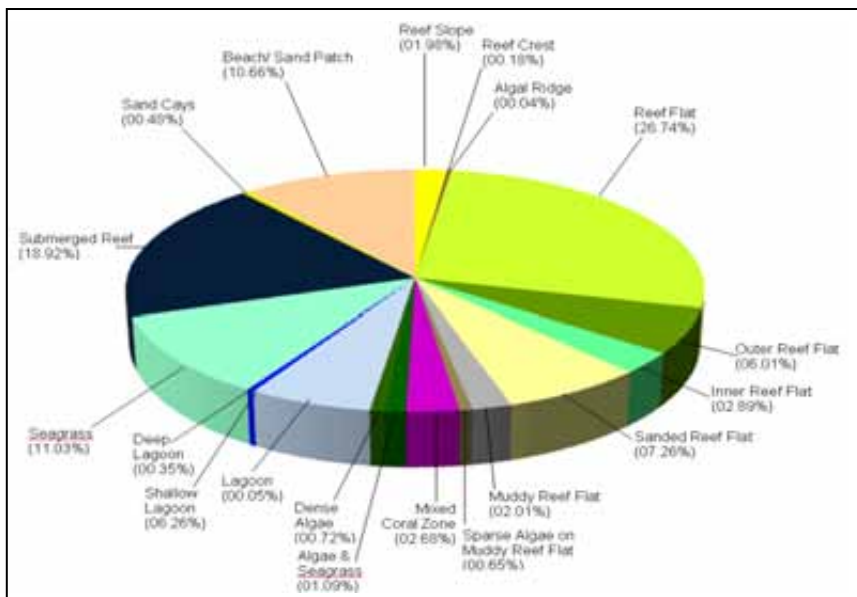


Fig. 4.1.9: Distribution of Coral Reef Categories (% Area) in Gulf of Mannar

There are total 19 classes recorded in this area. The dominant classes (Fig. 4.1.9) are Reef Flat (26.74 %) along with inner (2.89 %) and outer reef flat (6.01 %), submerged reef (18.92 %), seagrass (11.03 %), beach/sand patch (10.66 %) and sanded reef flat (7.26 %) of the total reef area.

Andaman & Nicobar Islands:

The Andaman and Nicobar Island (Figure 4.1.10 and 4.1.11) chain constitutes a string of oceanic islands. These islands separate Andaman Sea from South East Asian coast in the east, Bay of Bengal in west from Indian peninsula, and Malacca Strait in from Sumatra south.



Fig. 4.1.10: Coral Reef Areas of Andaman Group of Islands

Andaman & Nicobar group of islands is the largest Archipelago system in the Bay of Bengal associated with healthy fringing reefs full of biodiversity. The Andaman coral reefs are a treasure trove of biodiversity in India. Marine researchers have identified nearly 200 coral species in the reefs around Andaman and Nicobar. Andaman and Nicobar Islands lie within the geo-

coordinates of 10°30' to 13°40'N, 92°00' - 94°00'E and 06°30' to 09°30' N, 92°30' to 94°00'E respectively. The general orientation of the islands is north south. Andaman and Nicobar group of Islands consist of about 350 islands along with a number of exposed islets and rocks, of which, only 38 are inhabited. Andaman & Nicobar Islands are divided into two districts as Andaman Islands and Nicobar Islands. Together they constitute a Union Territory (U.T.) of India. A deep oceanic ridge along 10°N separates the Andaman Group and the Nicobar group Islands. These two island groups are separated by the Ten Degree Channel. The islands are away from the mainland coast and lack inland river discharges into the sea which result in the turbidity-free water. This favourable condition has enriched the coral environment. The Andaman Sea is one of the least explored regions of the Indian Ocean. Coral reefs stretch over an area of 11,000 sq. km in the Andaman Islands while the Nicobar Islands have 2,700 sq. km (Krishnakumar, 1997). The islands are characterized by three interconnected natural ecosystems – Tropical Rainforest, Mangroves and Marine ecosystems (Coral reefs) that are the result of typical topographical, climatological and edaphic characteristics of the area. Mahatma Gandhi Marine National Park (MGMNP), Wandoor (Photo 4.1.13 and Photo 4.1.14) on western coast and Rani Jhansi Marine National Park (on eastern coast of South Andaman) cover exclusive coral reef areas. The coral fauna is extremely diverse as compared to other parts of India.

The coral reefs of Andaman region are of fringing type (Plates: 4.1.11, 4.1.12, 4.1.13, 4.1.14 and 4.1.15). The reef area of Andaman covers total 79 SOI (1:25,000 scales) sheets. As compared to the other regions of Indian subcontinent maximum reef area is found in this region. In Andaman and Nicobar Islands beach or vegetation boundary clearly demarcates the landward boundary of the reef. Discernability of discrete seaward boundary of coral reefs is however poor in this area because of greater depth. In many places reefs end with submerged reefs towards the sea. This category of submerged reef is mostly found in Wandoor National Park mainly around Tarmugli Island, eastern part of Middle Andaman, around North Reef Island whereas submerged rocks are found near East Island. The deeper reef flat has been recorded in Boat, Jollybouis and North Sentinel Islands. Muddy and sandy muddy reef flats have been observed under some coastal turbid environments near to the Andaman mainland.

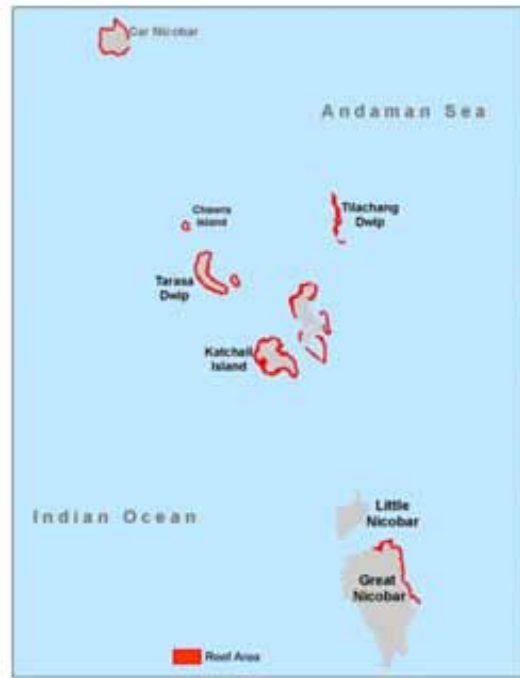


Fig. 4.1.11: Coral Reef Areas of Nicobar Group of Islands

These classes in certain places also had sparse algal cover on them. For Interview and Twins Islands' reefs, coralline shelf has been observed whereas reef slope exposure is prominent for Havelock Island. The outer most part of reef area including reef slope, reef front etc., having the highest energy zone are present and prominent around Neil Island and in many parts of North Andaman



Photo 4.1.13: Branching Corals, Interview Island



Photo 4.1.14: Plate Coral, Grub Island MGMNP, Wandoor, Andaman

It has been reported that the northwest coasts of Andaman uplifted due to the 2004 Sumatra earthquake (Mikio Tobita *et al.*, 2006). The 2004 earthquake resulted in elevation changes ranging from subsidence of 3 m at Indira Point (Great Nicobar) and uplift of 1.0 to 1.5m at Diglipur. While the South Andaman group of islands were generally submerged, subsidence as well as emergence was observed on Middle and North Andaman (Rajendran *et al.*, 2007 and Rajendran *et al.*, 2008). Lot of changes in the coral environment has been observed due to this event (Bahuguna *et al.*, 2008). The same results were observed in the present study. The Exposed Reef Flat classes were observed along the north western coasts of the Andaman, Sentinel Island and west coast of Rutland and Little Andaman Islands. Due to land uplift, shallow coral reefs are exposed and found dead due to lack of water column over them. North Reef and Interview Islands are heavily damaged and coral reefs have been exposed. Subsequently, sand deposition and the algal growth over exposed reef flats were also observed.

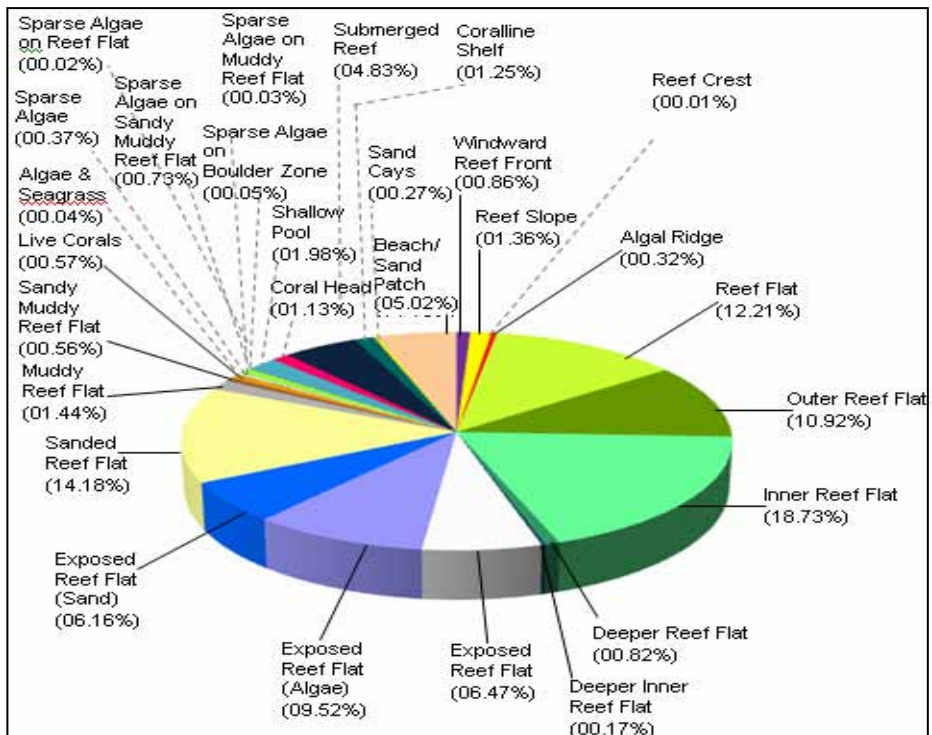


Fig. 4.1.12: Distribution of Coral Reef Categories (% Area) in Andaman

The Major categories (Fig. 4.1.12) found in the Andaman Islands are Inner Reef Flat which covers 18.73 % of the total reef area followed by Sanded Reef Flat 14.18 %. Reef Flat and Outer Reef Flat respectively cover 12.21 % and 10.92 % of the total reef area. Exposed reef classes occupy 22.15 %, out of which algae covers 9.52 %. Mud associated classes such as muddy reef flat and sandy muddy reef flat recorded 2 % of total area. It has been observed that 1.98 % area falls under shallow pool category. Submerged Reefs occupy an area of 4.83 %.

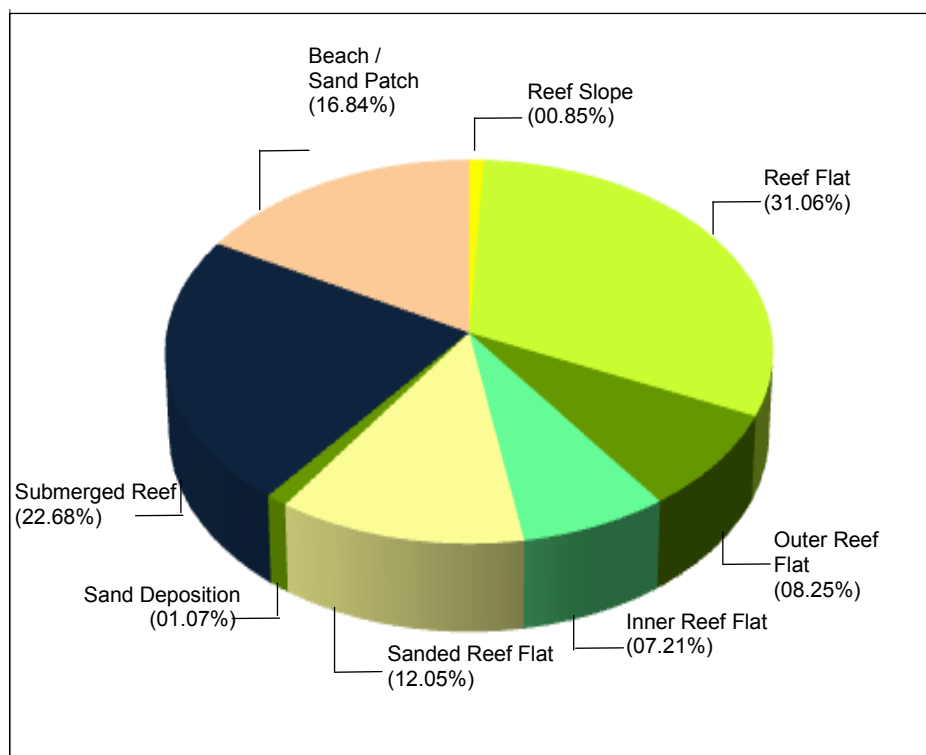


Fig. 4.1.13: Distribution of Coral Reef Categories (% Area) in Nicobar

The Nicobar Islands are covered in 41 number of SOI (1:25,000 scales) sheets, however 39 sheets were classified as cloud free data was not available for the remaining sheets. Nicobar (Plates: 4.1.16 - 4.1.18) region recorded very few reef classes unlike Andaman. The major classes are Reef flat (outer and inner), sanded reef flat, submerged reef, reef slope and beach/sand. Entire Car Nicobar Island recorded only three classes Reef Flat, Sand Deposition and Beach/Sand

Patch. The sand deposition observed here is mostly due to 2004 tsunami. The submerged reef class was observed around the islands of Nancowry, Camorta and Katchall. Reef slope areas are present and prominent around Tilanchang Dwip and Nancowry Islands. Coral reef of Tarasa Dwip recorded well marked inner and outer reef flat.

The dominant class is Reef Flat (Fig. 4.1.13) with 31.06 % area. The other classes are submerged reef 22.68 %, beach/sand patch 16.84 %, outer and inner reef flat together 19.26 % and sanded reef flat 12.05 %.

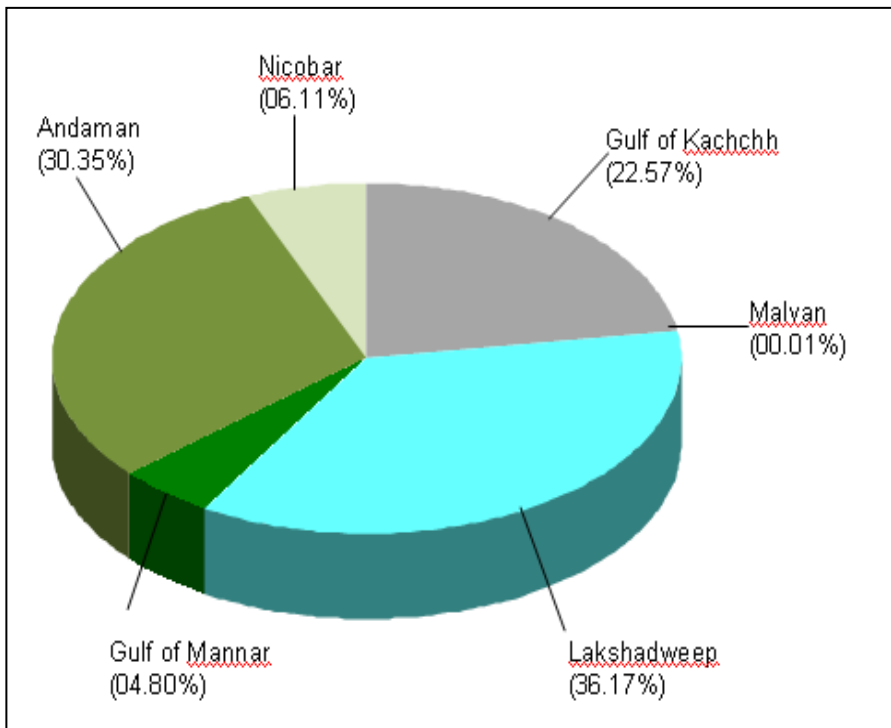


Fig. 4.1.14: Coral Reef Regions (% Area) in India

The percent areal distribution of coral reefs in the Indian coast is given in Fig. 4.1.14. Lakshadweep has the largest area under coral reefs (36.17%). Andaman has the second largest area (30.35%) under coral reefs. The Gulf of Kachchh has the third largest area under coral reefs (22.57%). It has highest diversity in reef categories based on the present data set. The dense algae and coral reef

classes associated with sand, mud etc. are more in this region compared to other areas. The coral areas attached with mainland are in degraded condition probably due to the sediment and effluent flux. Malvan recorded the smallest regional area with patchy corals which is evident from the very low diversity of the coral environment. In Gulf of Mannar the coral reefs observed along the islands are very few. This area is also under stress due to turbid waters and probably due to human activities such as dredging and the sediment flux from the mainland. The coral reefs of Andaman and Nicobar Islands show healthy and diverse reefs as compared to other part of coral reefs of India. The coral area in this region is very narrow across the coast due to the narrow, steep shelf. The coral reefs of these areas have been largely affected by the natural processes than the anthropogenic activities.

The diverse coral reef ecosystem is beyond doubt, one of the planet's greatest attractions and beautiful presentations. It requires proper conservation and management. The digital database on 1:25,000 scale on eco-morphological zones of Indian coral reefs can serve as a baseline information. This provides qualitative and quantitative details on the distribution and spatial extent. Information on eco-morphological zonation generated from the present study on Indian Coral Reefs will enable to monitor coral reef health in future.

Plate: 4.1.1

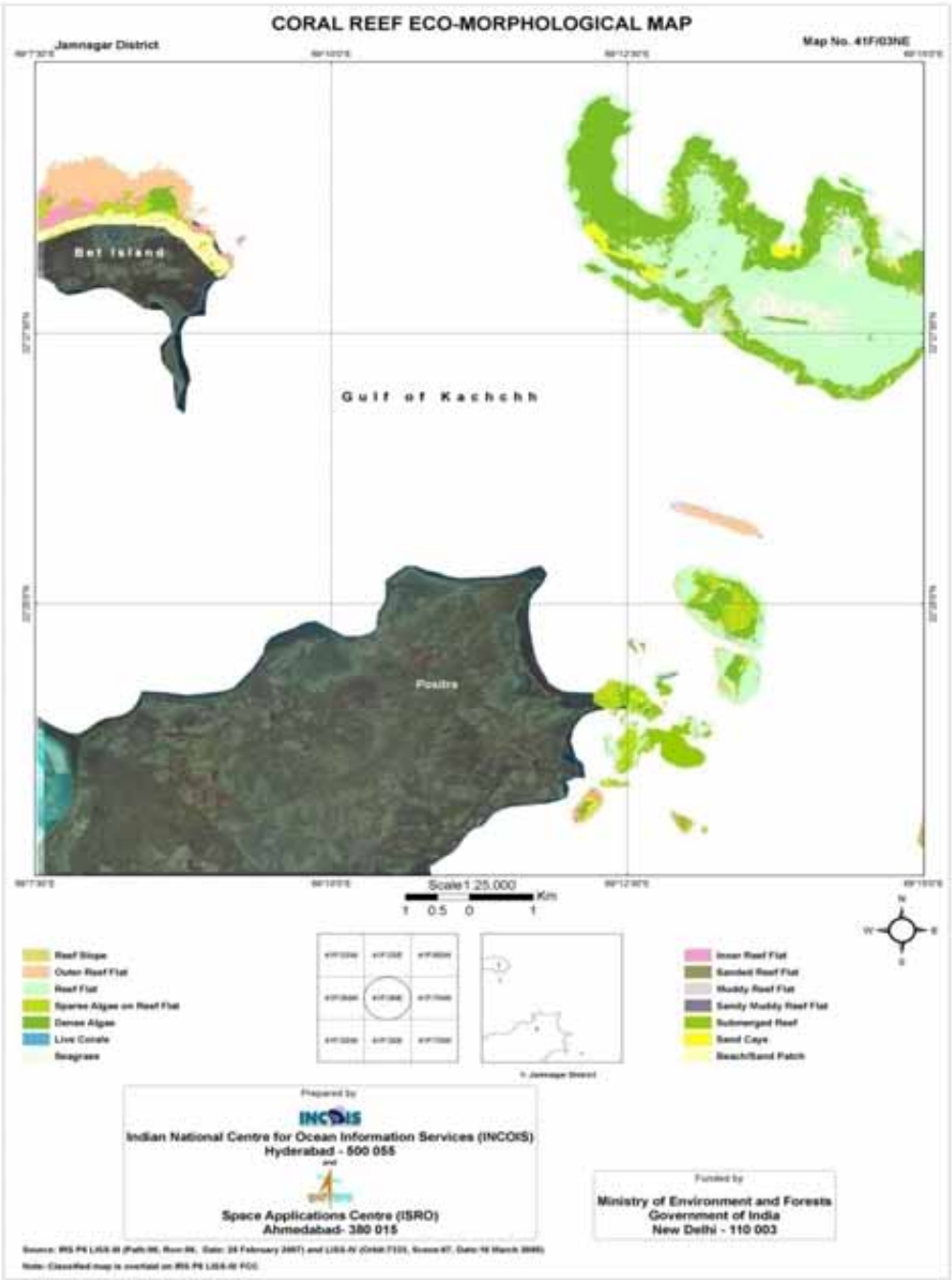


Plate: 4.1.2

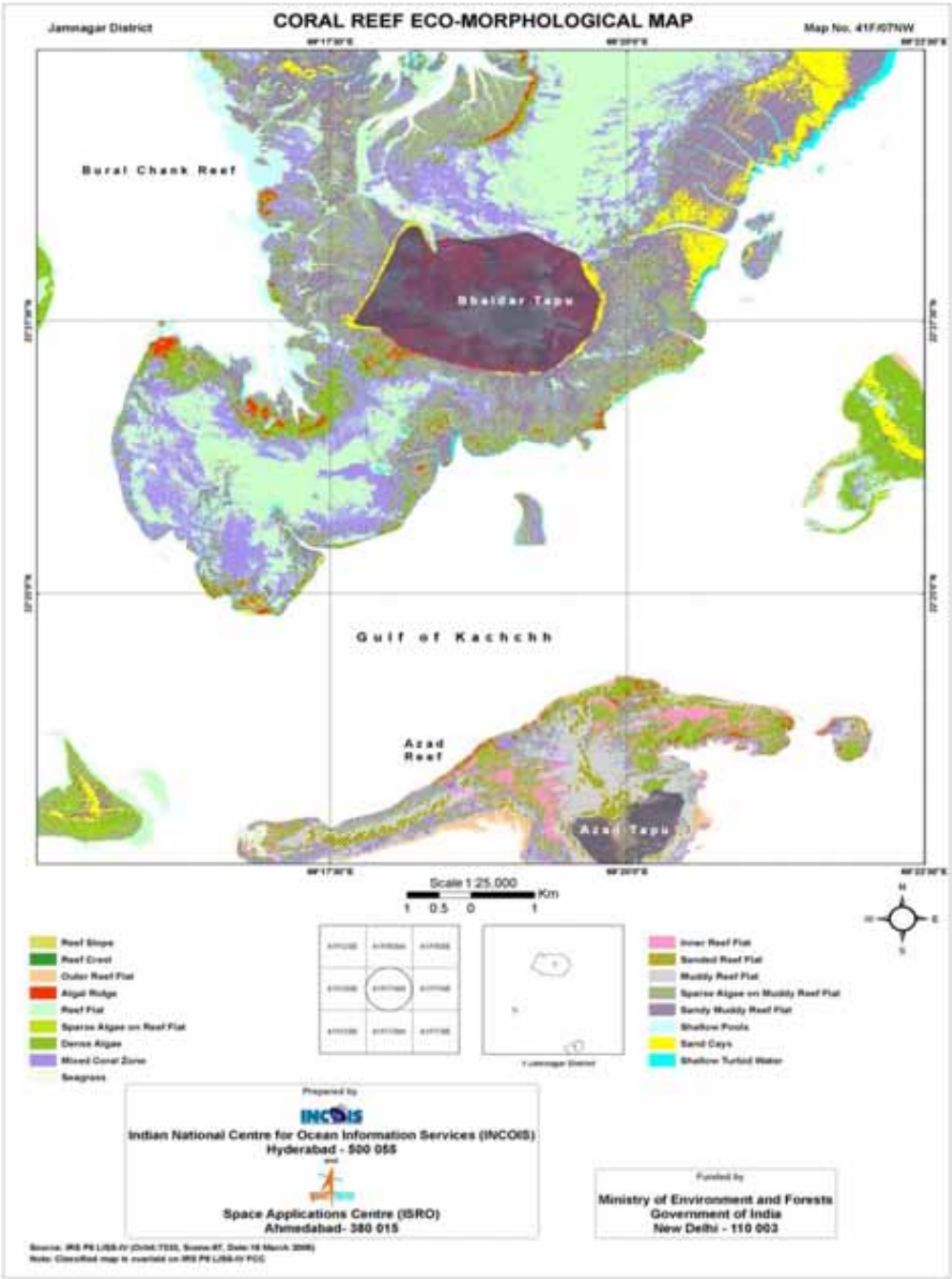


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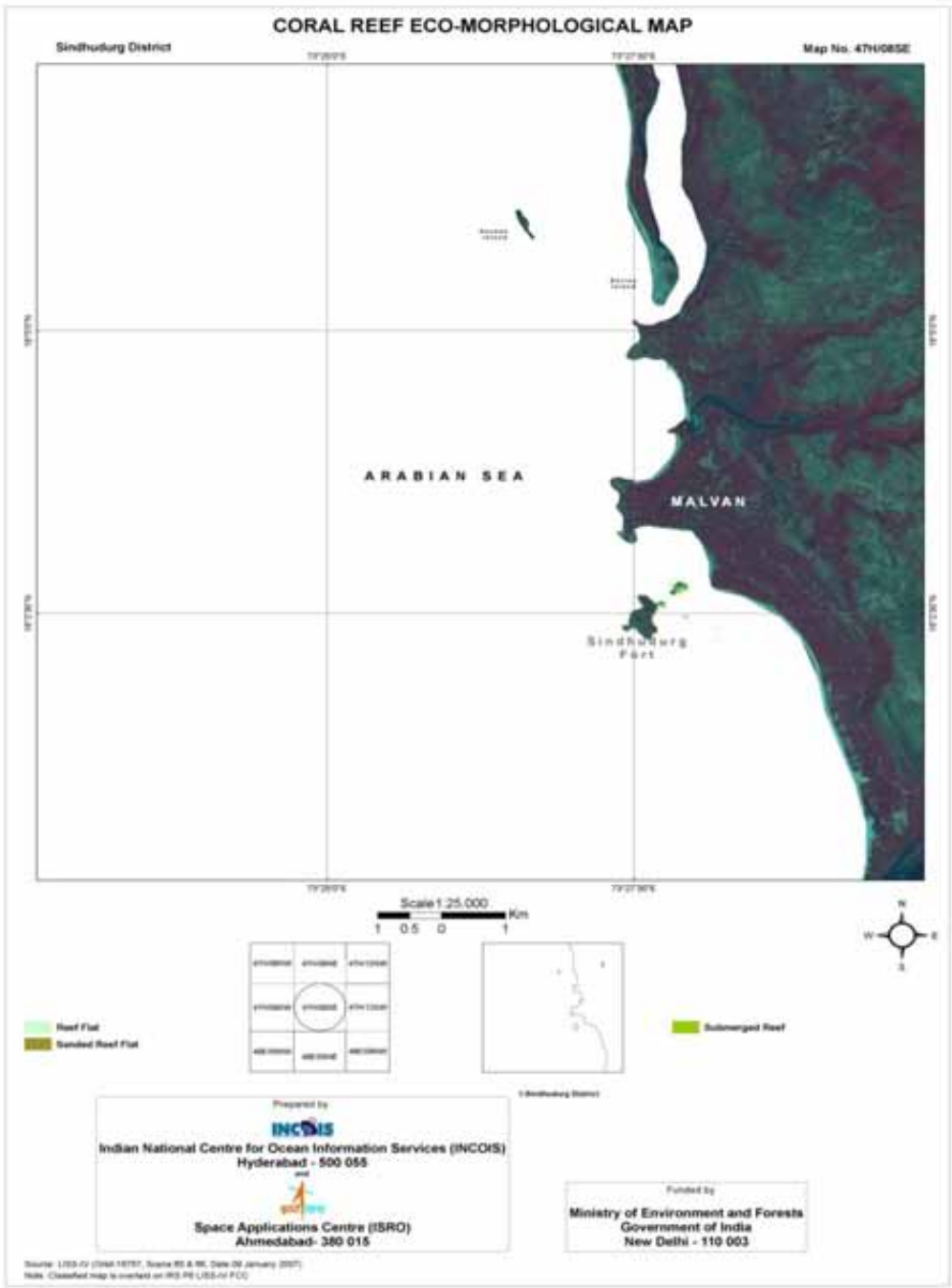


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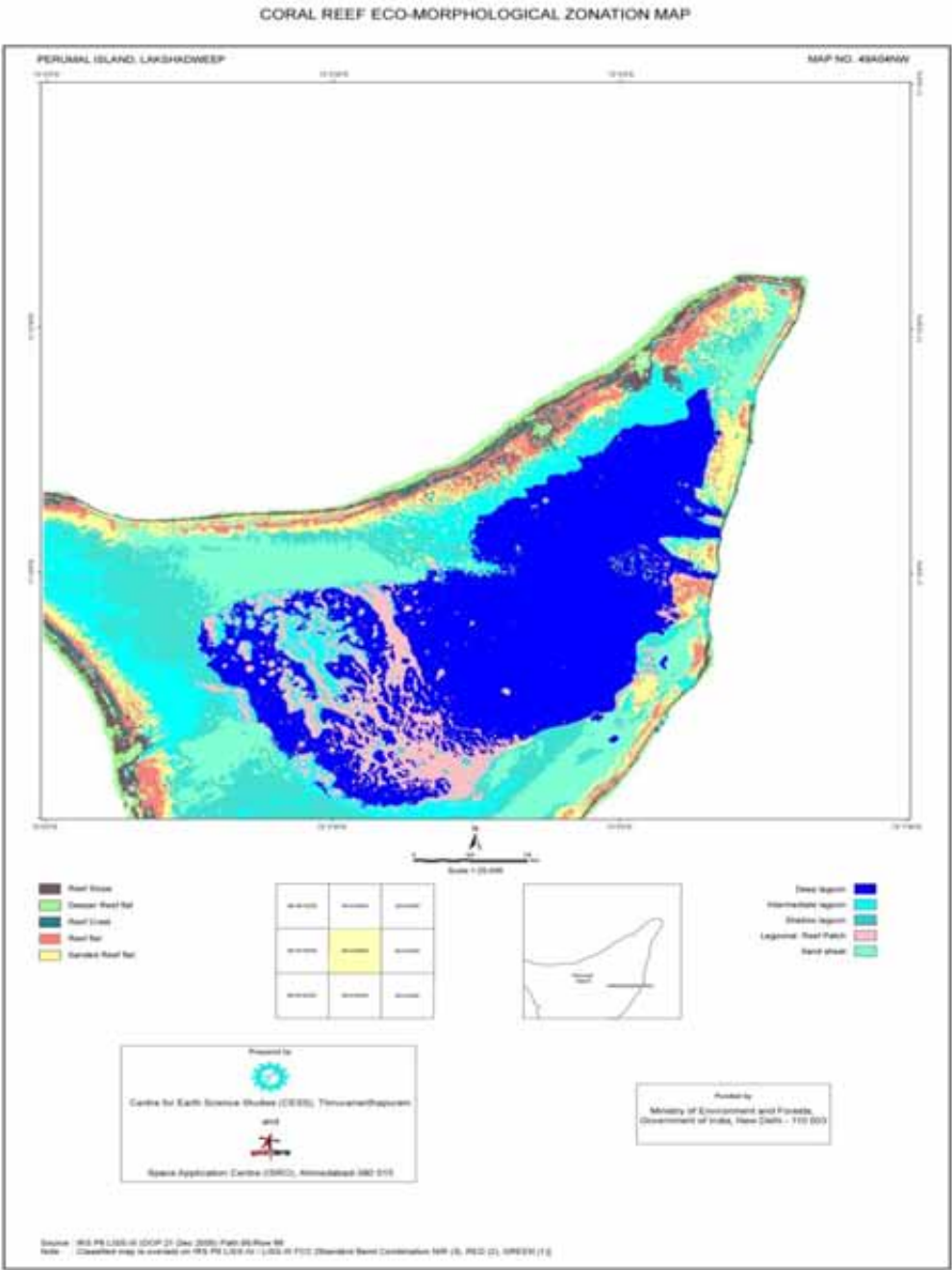


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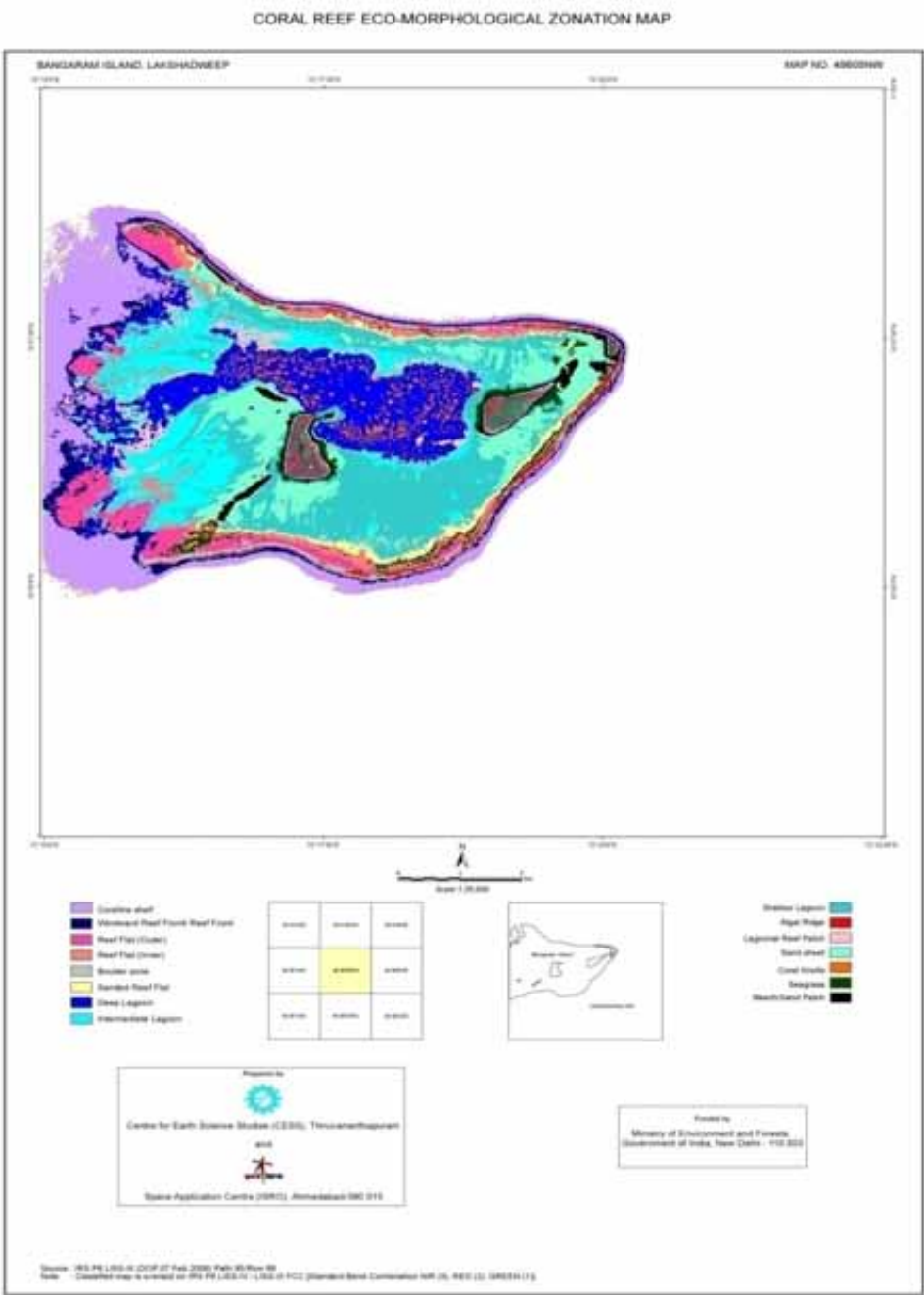


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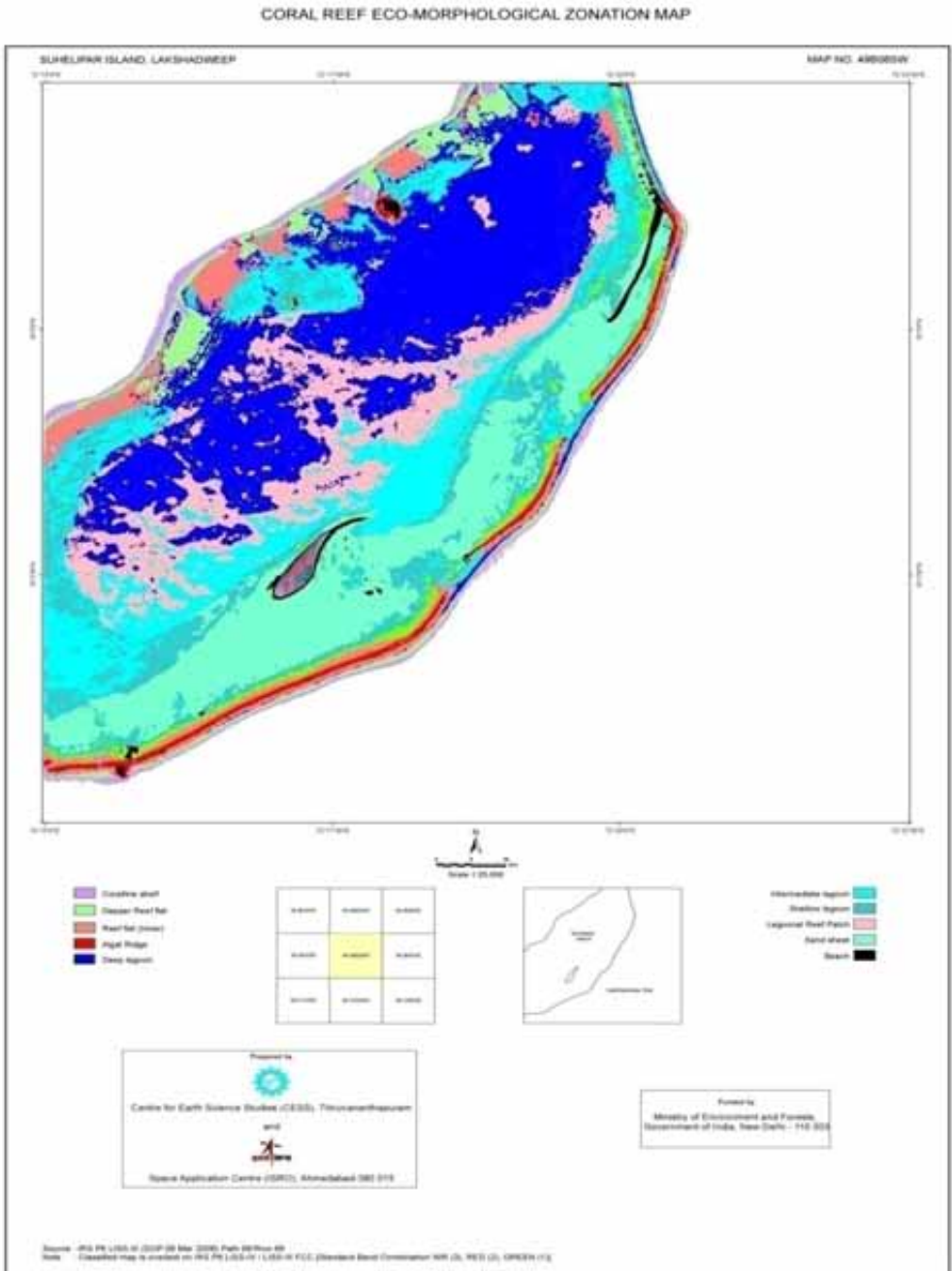


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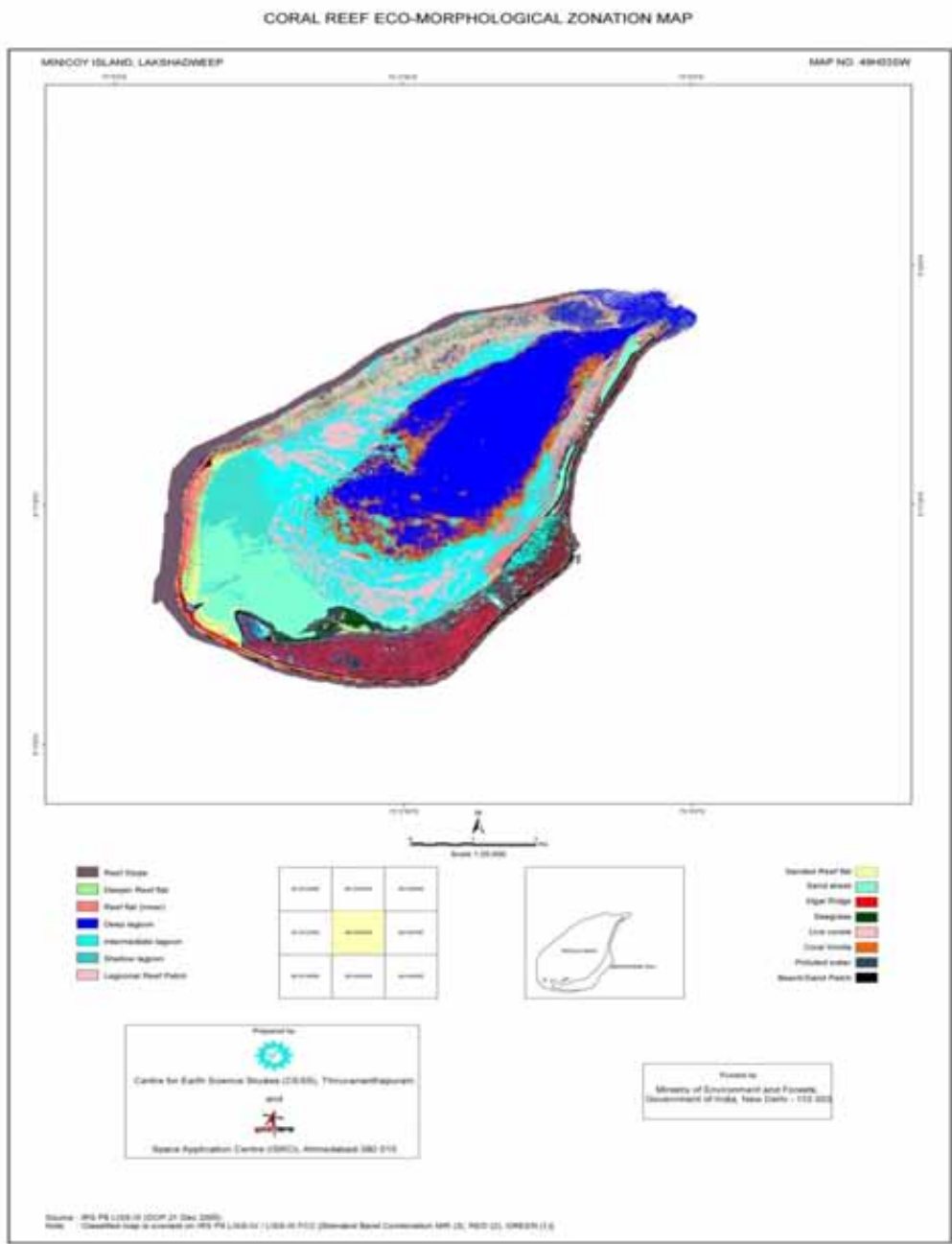


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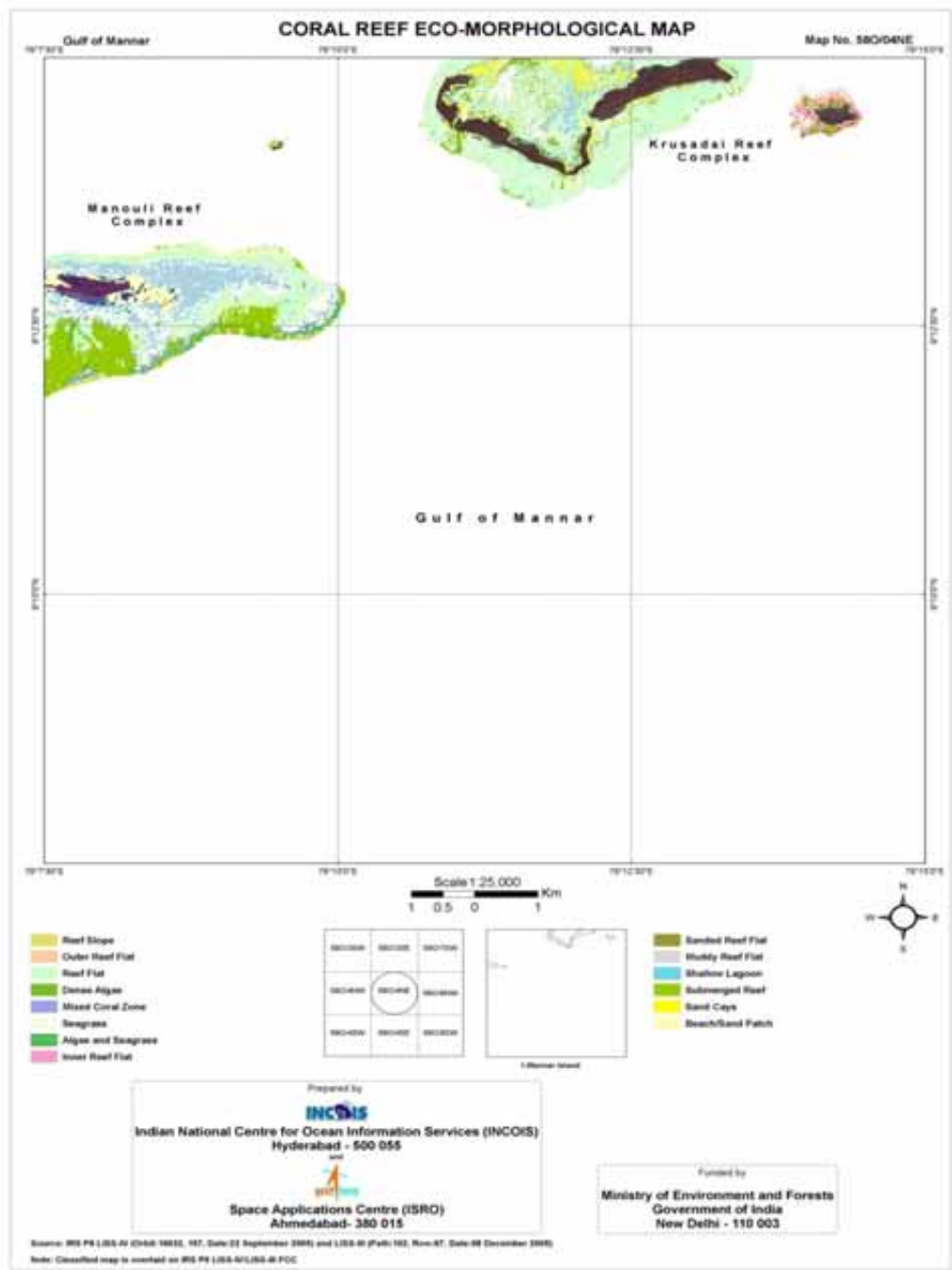


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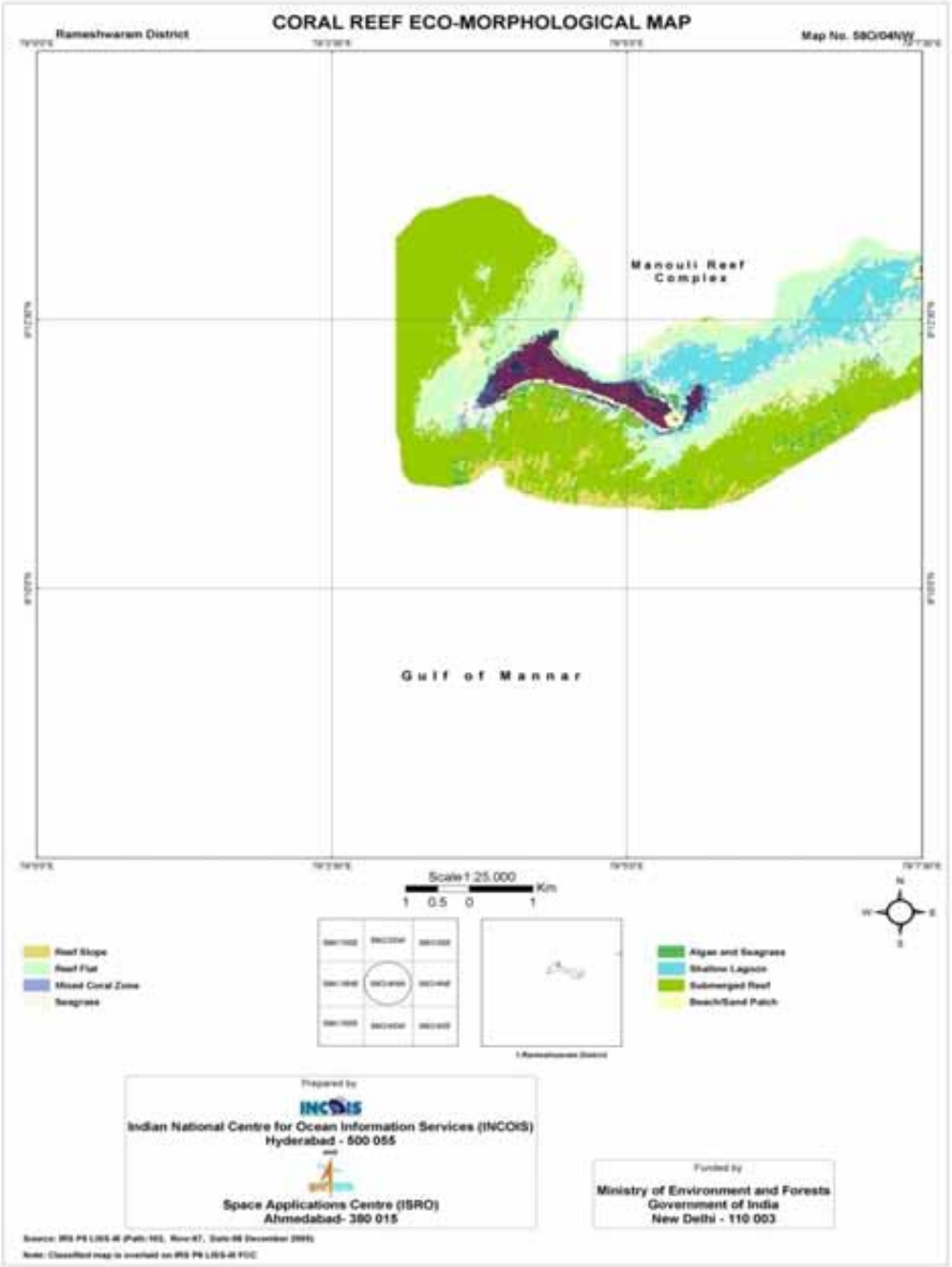


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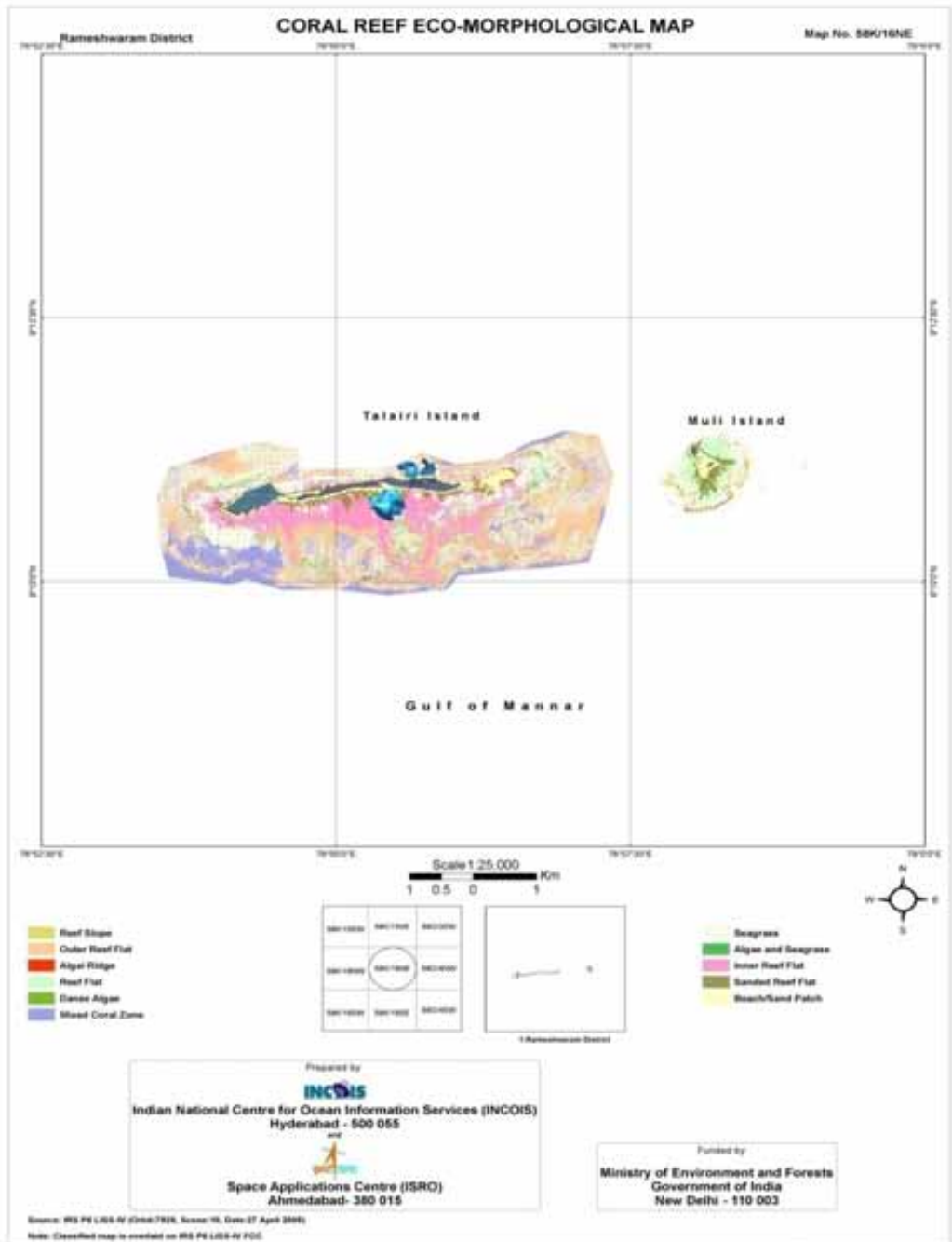


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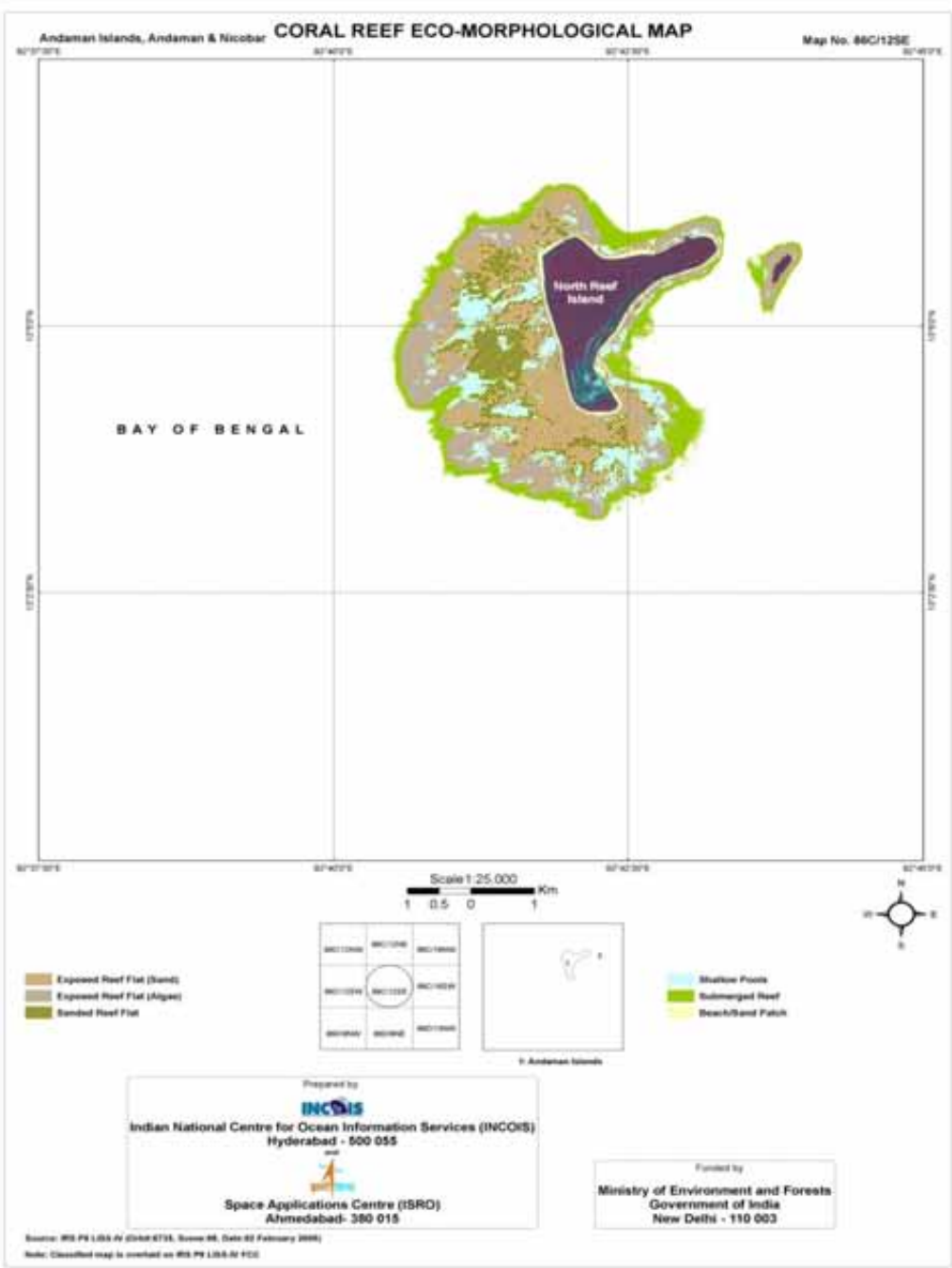


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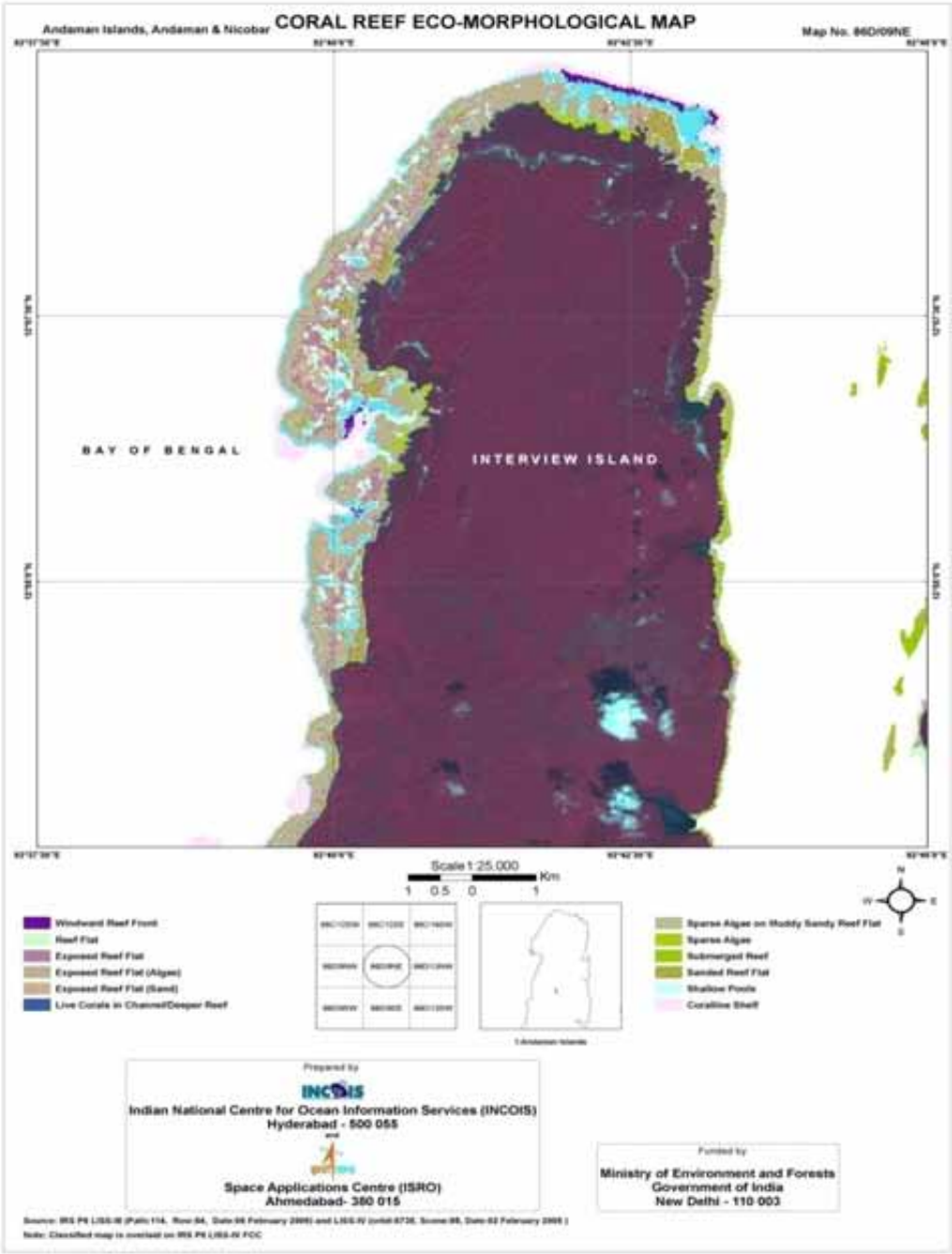


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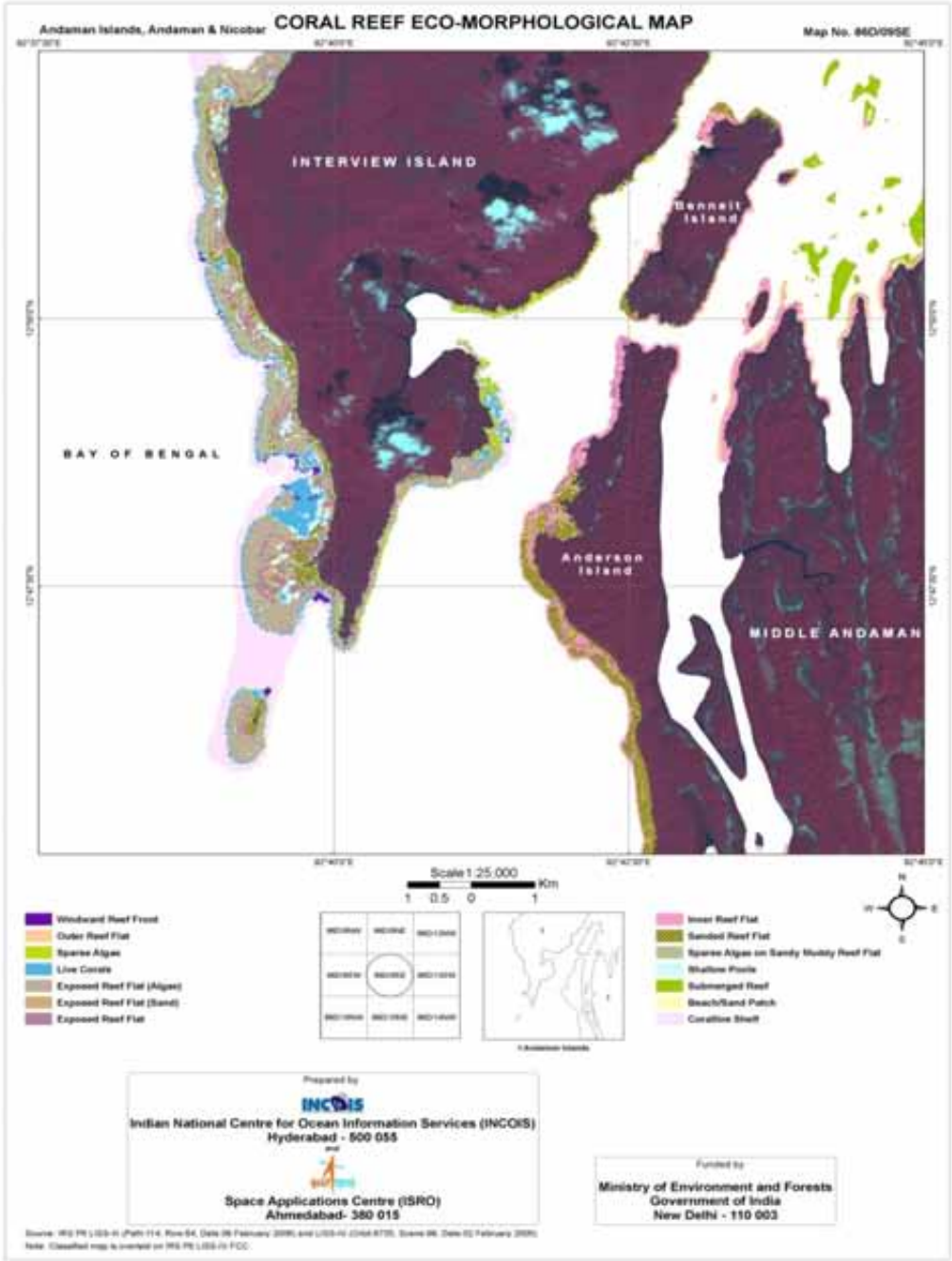


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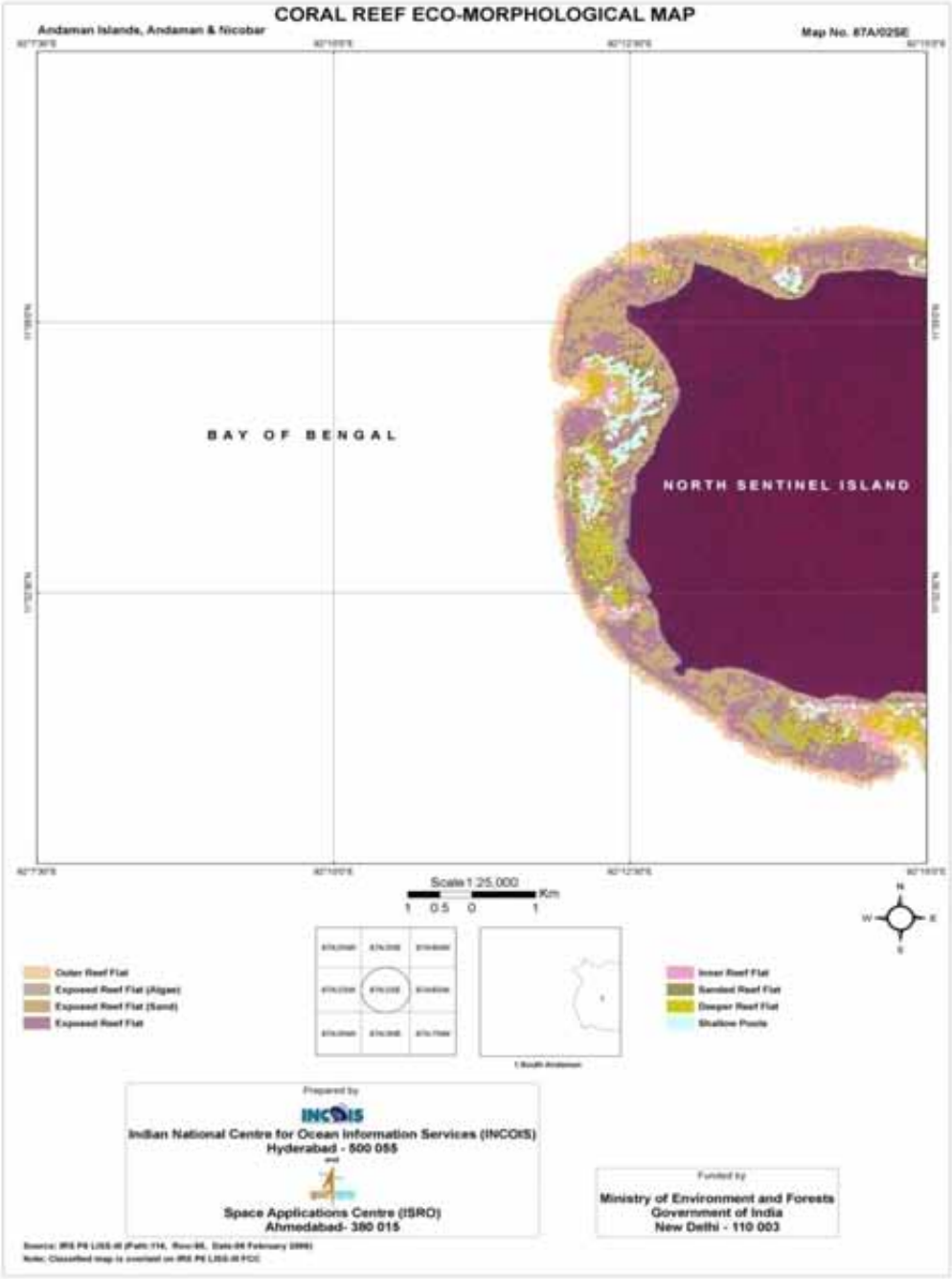


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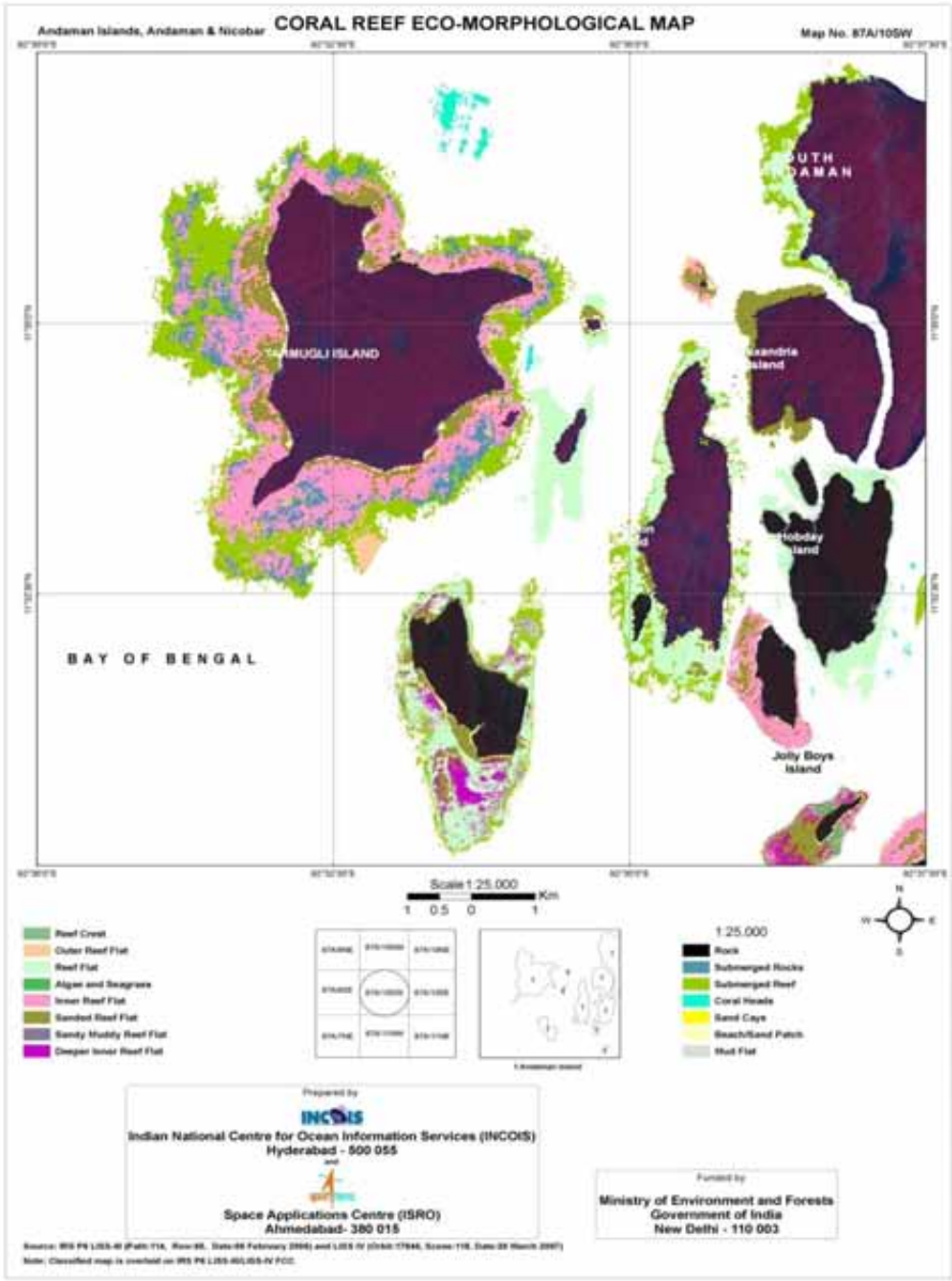


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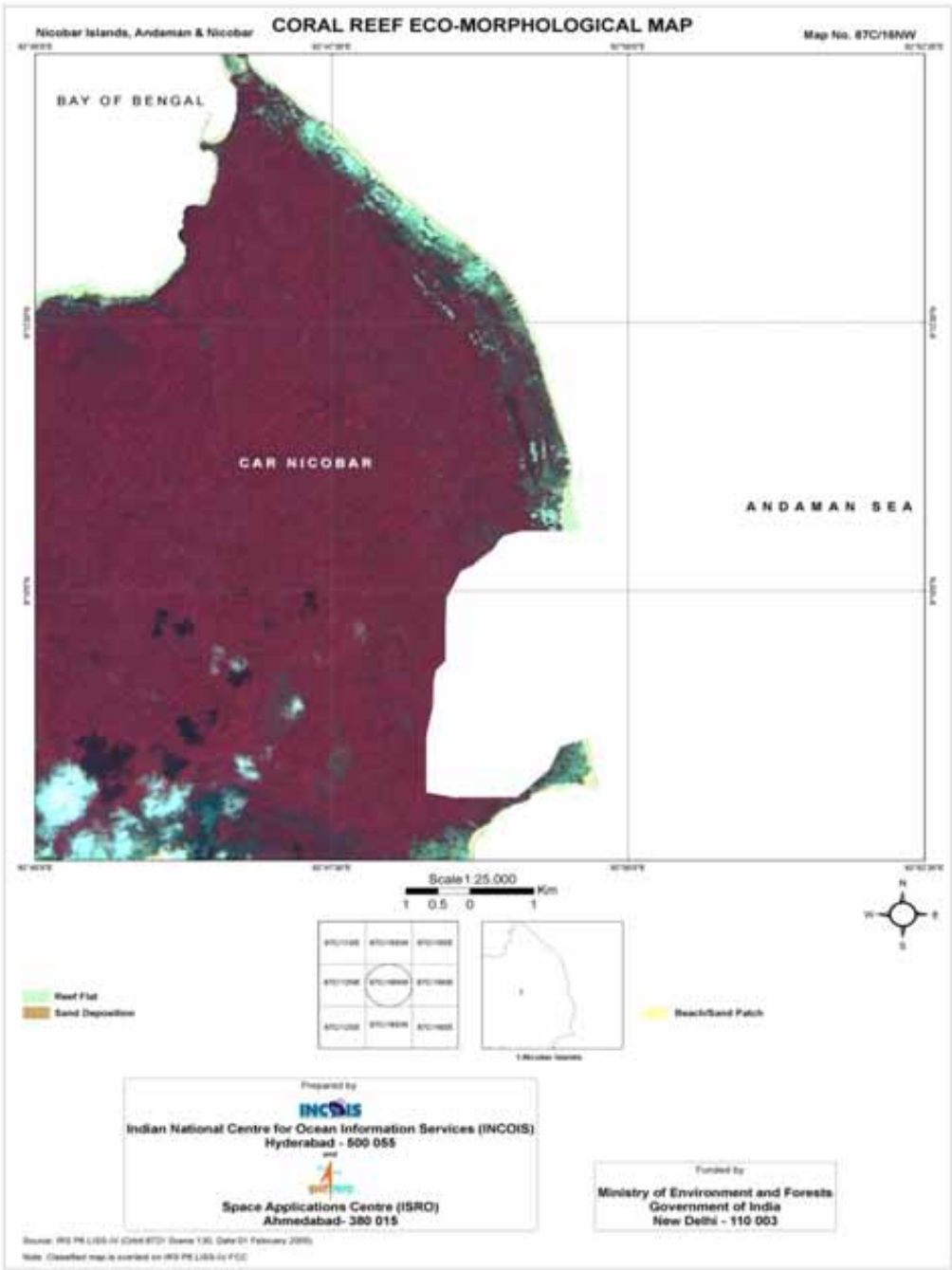


Plate: 4.1.17

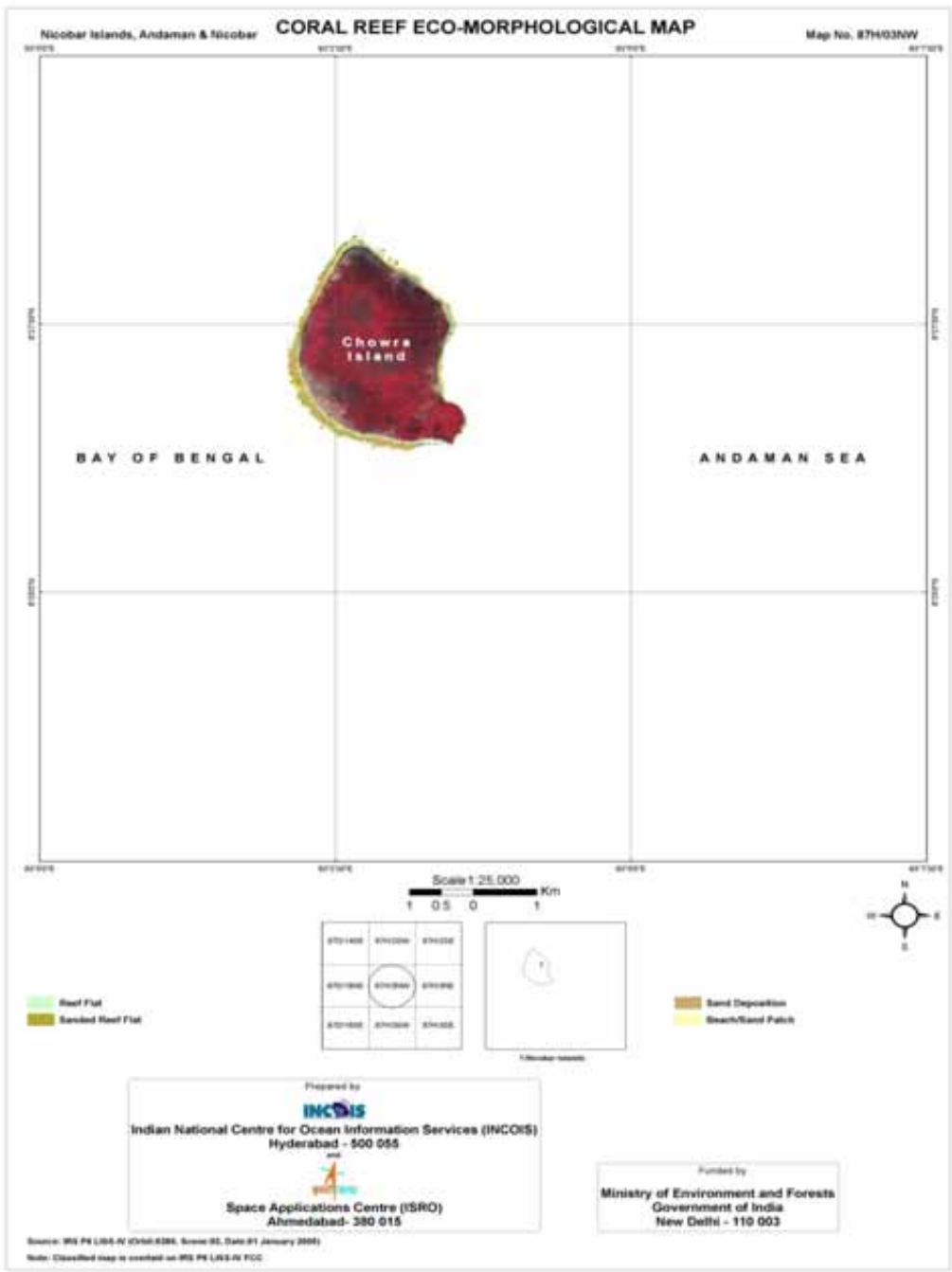
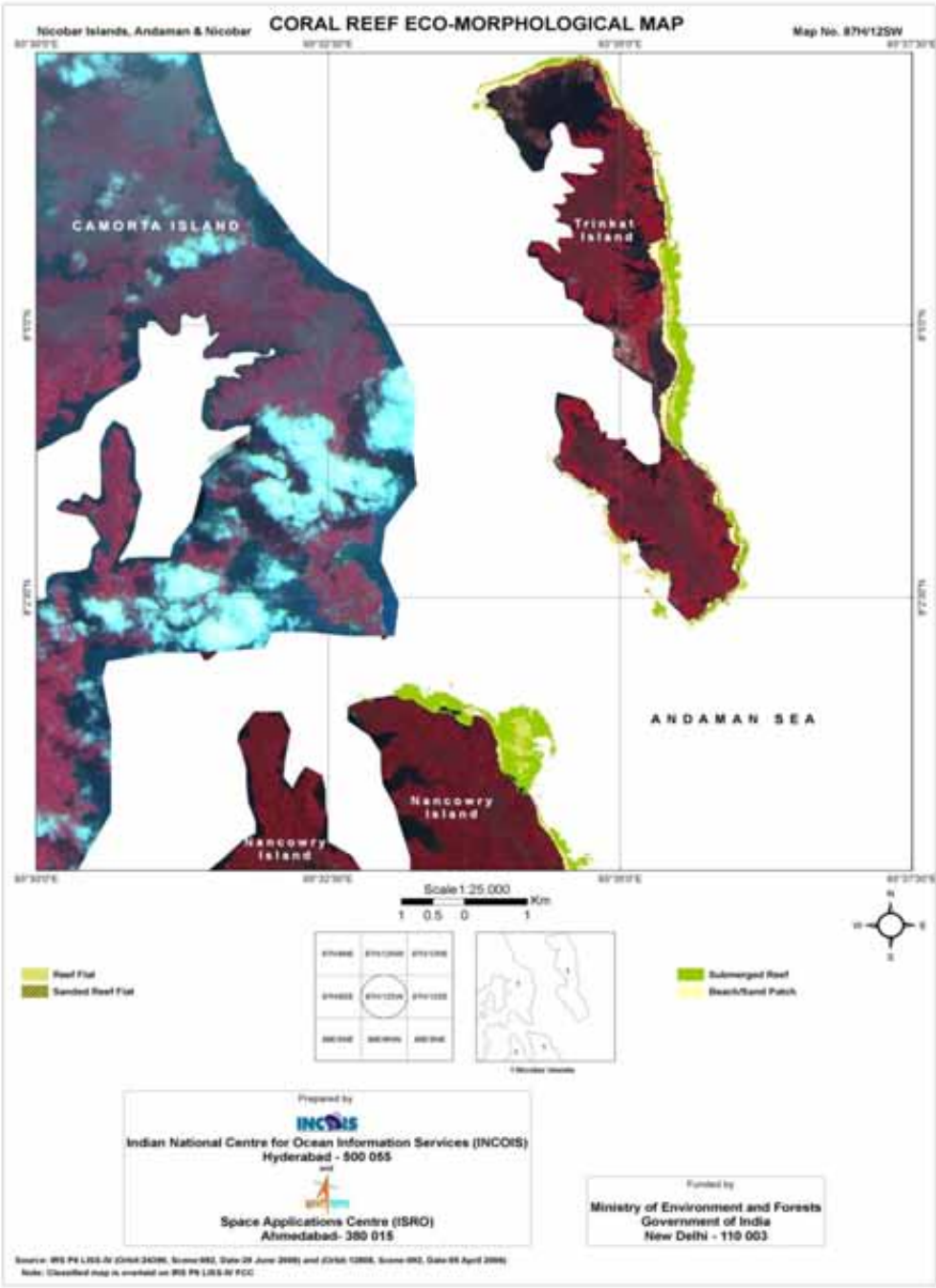


Plate: 4.1.18



4.2 Health Model

Tropical coral reefs occur in the circum-equatorial belt, often bordering the developing countries with booming populations. Much of this tropical population is located in coastal countries with surrounding fringing and offshore coral reefs. Population growth rate and increasing rates of urbanization not only bear threats to coral reefs but also make the task of coral reef management all the more difficult. Global climate change and human pressures increasingly threaten coral reefs worldwide; particularly the various utilization practices of reef-associated resources by an ever increasing number of people having access to the reefs, all the more add to the aggravated situation of reef-ecosystems. Already 58% of the global reefs are threatened by human activities out of which 27% are at high risk (Madl, 2005). The manifold varieties, the frequencies and the intensities of anthropogenic influences have soared in the recent past, triggering a process that brings about massive changes to world's coral reefs. Almost all reefs reflect the result of adverse impacts on both local as well as global scale.

Worldwide coral reef ecosystems are in a state of decline (Bryant et. al., 1998) although the causes largely remain a matter of debate Lidz Barbara et al., 2006). In the backdrop of marine pollution, deteriorating coastal environments, rising sea level (Albritton et al. 2001) and global warming, the problem remains in the inability to pinpoint the precise cause of reef degradation. Natural and anthropogenic stressors as well as their combined effects need to get clearly identified in the context of reef health and vitality.

Coral reef ecosystem exhibits a superlative sensitivity towards environmental and climate changes of varying magnitudes and frequencies, operating at different spatial and temporal scales. This unique ability of coral reef ecosystem to transpire the effects of environmental changes or stresses, affecting the reefs either at local or regional level, as well as long-term climate changes of regional or global order (e.g. sea-level rise, global warming, etc.) has credited coral reefs to be identified as a significant, ecological indicator compared to any other ecosystem or even biome counterparts of the world. Ecosystem health assessment is a prerequisite for ecosystem conservation and

management. However, comprehensive assessment of reef resilience to environmental changes and impacts calls for a fundamental and long-term study of reef-ecosystem dynamics along with identifying the natural or anthropogenic stressor(s) and their effect(s) on the reef.

Today coral reefs are among the most threatened coastal ecosystems worldwide as they react quickly to new stressors because they thrive in a narrow range of environmental conditions and are very sensitive to small changes in sea-water temperature, underwater light, water quality and hydrodynamics. Hence, coral reef systems serve as an important ecological/environmental indicator of change for diagnosing the state and status of tropical, coastal environment.

Under this project component, a two-stage *Coral Reef Health Model* has been designed to assess reef health where in ecological and environmental parameters (referred as *Operational Ecosystem Reference Points* or *OERPs*) collectively define a *Reef Health Index* (RHI). On the basis of RHI, an early *Warning Index* (WI) can be generated using the environmental parameters for the concerned reef in order to adopt proper management action. The objectives were :

- To identify Operational Ecosystem Reference Points (OERPs) that give information on health of reefs
- To retrieve OERPs from satellite data
- To integrate the information on OERPs
- Generate model for assessing reef health

The model has been developed for the following areas:

- Bural Chank(22°40' to 22°55'N; 69°26' to 69°42'E),
Kalubhar (22°23' to 22°29' N; 69°35' to 69°40E),
Munde-ka-bet (22°30'to 22°34' N; 69°50' to 69°57'E) and
Pirotan reefs (22°34'to 22°38'N; 69°55' to 69°59'E) in Gulf of Kachchh
- Kavaratti(10°32'to 10°35'N; 72°36' to 72°40'E),
Chetlat (1°141' to 11°43'N; 72°30'to 72°44'E) and

Bangaram reefs (10°54'to 10°59'N; 72°14'72°20'E) in Lakshadweep

- Krusadai (9°13'to 9°16'N; 79°10' to 79°15'E) and Manouli Reef Complex (9°11' to 9°14'N; 92°31' to 92°34'E) in Gulf of Mannar
- Tarmugli (11°33' to 11°37'N; 92°31' to 92°34'E), Jolly Bouys and Boat Island (11°30' to 11°33'N; 92°33' to 92°35'E) from Mahatma Gandhi (Wandoor) Marine National Park and Havelock Island (11°53' to 12°04'N; 92°56' to 93°04'E) in Andaman

Operational Ecosystem Reference Points (OERPs): Concept

Indicators of coral reef health or Operational Ecosystem Reference Points (OERPs) were identified based on existing literature, existing coral reef maps and extensive ground surveys. The initial study was based on pre-and post-monsoon satellite data analysis with concurrent, seasonal *in situ* or field data collection.

Archive of IRS 1C/1D LISS III satellite data pertaining to 2002-2003 period and Resourcesat-1 (IRS P6) LISS III and LISSIV MX data of 2004-2006 period were used to create seasonal *ecomorphological zonation maps* (generated using the standard methodology discussed in the previous chapter) of coral reefs while NOAA climatology SST (monthly) data of the concurrent period were archived for the summer months (March-June period) for the study of Sea Surface Temperature. Qualitative analysis of suspended sediment load or turbidity within the reef environment was carried out using IRS LISS III and LISS IV data and the same was also used for understanding the status of Mangrove in the vicinities of reef environment. In certain areas like Gulf of Kachchh and Gulf of Mannar *in situ* measurements were also done for sea surface temperature and sediment load. Water samples were also analysed in certain cases in order to assess the water quality parameters.

Line Intercept Transects (LIT) and Quadrats were employed to collect field information pertaining to reef biodiversity aspect (e.g. coral communities, coral density and diversity, percentage of live coral cover, algal diversity and

density, seagrass diversity and density, etc.). Data on fisheries, coastal development and tourism was also collected during field surveys.

Comparing recent coral reef habitat maps with existing or previous maps on extent and eco-morphological zones along with live coral cover, the changes in coral reef habitats have been estimated. Map based change-detection analysis has been carried out on GIS platform from multi-date satellite images based eco-morphological maps. Changes in land use land cover (mapped using IRS LISS-III data) also gave an idea about coastal development. Accordingly changes in land use land cover and condition of coral reefs were studied. Details of the methodology to Retrieve OERPs is given in Fig. 4.2.1

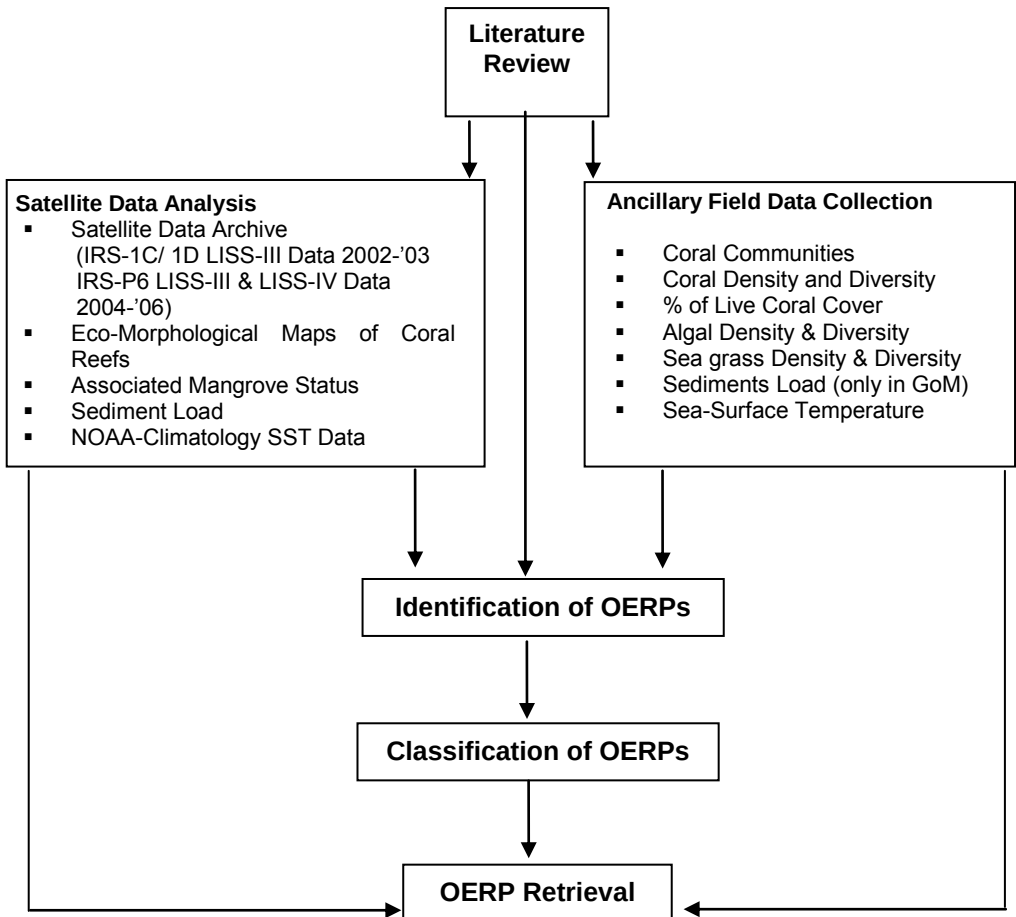


Fig. 4.2.1: Methodology to retrieve OERPs

Based on the collected data on the parameters discussed above, the OERPs were identified and retrieved from satellite data employing digital classification of the coral reefs. Ground-based OERPs like diversity and density of corals, algae and seagrasses were collected from field data. The OERPs have been classified into three categories and are described in the succeeding (Results) section.

Model: Conceptual Framework

In order to simplify the model-concept at the initial stage of development, the method of Weightage Distribution to the OERPs (Input Parameters) followed here is purely manual and subjective. It is envisaged that the total contribution of a group of OERPs to its respective index is equal to 100%. Accordingly, the selected OERPs have been assigned weightages based on their relative importance and the sum of parametric/OERP weightages is thus always 100%. Reef-impact or reef-status conditions with respect to these individual OERPs have then been ranked. Thus, three categories of OERPs lead to the generation of three separate {composite score (rank multiplied by weightage) based} indices. At the first-go, the attempt is to bring all these different parameters onto a common platform (i.e. of Composite Scores = Rank x Weightage). Moreover, there was also the need to test the response of all the four different reef-regions of India through a robust model based on common and constant weighted parameters. Significance or importance of operational parameters are no doubt region specific but introduction of user-defined, Saaty's scale based weightage distribution to the operational parameters, right at this stage of concept development may unnecessarily complicate the model and chances of each reef-region showing their characteristic highs/lows can thus be reduced/avoided. However, 'user-defined, Saaty's scale based weightage distribution' to the reef-region specific, operational parameters can be incorporated in this model as a next level improvement.

A two-stage/step Model has thus been conceptualized:

- i. Model sums the Ecological and Damage Indices and generates Reef Health Index (RHI).
- ii. Model generates Warning Index for Coral Reefs on the basis of RHI.

Model Implementation

All the four major reef regions of India (namely, Gulf of Kachchh, Lakshadweep, Gulf of Mannar and Andaman and Nicobar) are characteristically different from each other in their genetic types, physiographic settings, anthropogenic pressures, etc.

Gulf of Kachchh has reefs in its southern coast that occur in the northernmost latitudinal limits comprising mainly fringing type of reefs along with one offshore platform reef, few patch reefs and a number of coral pinnacles. The reefs are a part of the Marine National Park since 1982. These reefs occur in turbid waters with heavy load of sediments entering the Gulf in the northeast from the Indus delta. The Gulf is under severe threat of natural as well as man-made disasters. The natural threats include cyclone, drought and earthquake. Because of its strategic location it is ideal for setting up of various industries, salt works, etc. There are already petroleum industries, chemical factories, fertilizer companies, thermal power plants, 11 major and minor ports, cement factories and many salt works in the area. The impact of all the developmental activities is already visible in the health of the resources. *Acropora* sp of coral has become extinct due to dredging.

Lakshadweep reefs are in open-ocean settings consisting of 36 islands, 12 atolls, 3 reefs and 5 submerged coral banks. They are mainly atolls with only one platform reef. The coral reefs are surrounded by clear waters. Lagoons comprise patch reefs and coral knolls. Compared to other reef regions, Lakshadweep reefs are rich in diversity however the increasing population pressure is impacting these reefs.

In the Palk Bay the reefs fringe the Rameswaram Island. The Gulf of Mannar is located south of the Palk bay and is home to a number of offshore platform reefs, patch reefs and coral pinnacles, which lie from south of the Pamban Pass to north-east of Tuticorin. They form a part of the Marine Biosphere Reserve and the Marine National Park. Before the establishment of the Marine National Park, large scale quarrying of coral blocks for production of cement, to use as a building material, etc. was a common practice. The over exploitation of coral has altered the ecology of the island. Sewage and release of industrial effluents

are threatening the coral reef that has affected the recolonisation of *Acropora formosa* and also decreased the primary production.

The Andaman and Nicobar Islands have narrow, linear and extensively well developed reefs closely fringing the islands intermittently for about 350 kms. These reefs have been severely affected by December, 26th 2004 Indian Ocean tsunami and are slowly restoring back.

Gulf settings (Gulf of Kachchh and Gulf of Mannar) and open-ocean or offshore settings (Lakshadweep and Andaman and Nicobar) of the reef regions and genetic typology of reefs (i.e. fringing, atoll, platform, patch etc.) play a vital role in shaping the overall environmental conditions of the reef environments. Thus, it becomes necessary to build up a multi-parametric reef health assessment model wherein all the reef-regions can be tested. Selection of operational Environmental or Ecological parameters in such multi-metric model is indeed a crucial task, as the question of commonality as well as region-specific operability of the parameter needs to be taken due care of. Next, of course is the question of their relative impacts and effects with reference to region-specific reef systems. The indicators operational in different study areas are different and also vary in their respective ranges. Reef health assessment is being done worldwide, most often considering sea surface temperatures (SST) as the single most important parameter. In order to meet the need to evolve a multi-metric, holistic approach to test the diverse conditions of Indian coral reef regions, certain ecological as well as environmental parameters have been chosen as Operational Ecosystem Reference Points (OERPs) in the design of Coral Reef Health Model.

Categories of OERPs

From an ecosystem perspective stress can be defined as the degree of mortality (short- or long-term) to any species or species group comprising a coral-reef ecosystem caused by any process or event, either natural or anthropogenic. Brown and Howard (1985) discussed various interpretations of the term stress and settled on the definition in which stress is viewed as a “*gradient between ideal conditions and the ultimate limits of survival*”.

Among the OERPs that have been identified for Indian reefs, it is observed that, there are some *Environmental parameters* that give an early idea of the reef environment condition, whereas some OERPs give idea about the current *Ecological* state of reef and then there is the third type that indicates the *Damage* (mostly associated with *Reef Morphology*) that has already occurred. Accordingly, we have classified the OERPs as *Environmental (leading)*, *Ecological (co-incident)* and *Damage (lagging)* indicators.

Environmental OERPs (*early warning signals about adverse impact*)

- SST anomaly compared to above average summer temperatures
 - Duration of SST anomaly (week to month)
 - Water Turbidity
 - Coupled Effect of Rise in SST and Turbidity
 - Onset of Algae
- } (Combined)

Ecological OERPs (*reflecting status of reef environment with development*)

- Density and Diversity of Corals and Calcareous Algae
- Coral Bleaching
- Turf/Fleshy Algae
- Sargassum cover
- Seagrass cover
- Community Shift from Branched to Massive forms
- Unique Habitat

Damage OERP's (*reflecting damages on reef already happened*)

- Reef Erosion
- Mud Deposition
- Phase Shift from Coral dominated habitat to Macro Algae dominated habitat
- Migrating Sand

Environmental (*leading*) OERPs

SST Anomaly

Reef- building corals can thrive within 1-2°C of their upper temperature limits (of course varying geographically with water temperature). However, a temperature increase beyond 30°C for prolonged periods may trigger massive coral bleaching event. With increasing seawater temperature, a thermal stress is exerted upon the corals resulting in the expulsion of unicellular photosynthetic algae or the zooxanthellae from their host tissues. As a result coral mortality occurs without re-inoculation by healthy endosymbionts' population. Bleaching refers to the discoloration of the host coral when pigmented zooxanthellae are thus removed. Records of massive, worldwide, coral bleaching events are attributed to positive anomalies in Sea-surface temperature (SST) and in ultra-violet light (Brown, 1997) in the aftermath of El Nino Southern Oscillation (ENSO) (e.g. in 1998, 2002; Hughes et. al., 2003). As the sea-surface temperatures are likely to cross the upper thermal threshold of reef- corals, bleaching event has been perceived as a major threat to many reef systems, resulting in the collapse of entire stands of monospecific coral gardens (Hoegh-Guldberg, 1999; Wilkinson, 2000; Hughes et. al., 2003). Some reefs impacted during the 1998 ENSO event have yet not been recovered, potentially resulting in decreased fish abundance, phase and strategy-shifts in benthic community structures, diversity loss, and decreased over-all productivity (McClanahan, 2000; Chabanet, 2002; Splading and Jarvis, 2002).

In the Coral Reef Health Model, monthly NOAA SST images were obtained to register information on increase/decrease in summer months' (March-June) SST and were related to coral bleaching events observed on field.

Water Turbidity and Coupled Effect of Rise in SST and Turbidity

Turbidity, suspension and settling of fine-grained sediment in the water column are major stressors to many coral reefs especially if situated in a gulf or a bay. Fine-grained terrigenous sediment is initially transported to reefs by island stream run-off. Resuspension by waves is a subsequent and commonly

dominant process that increases the suspended-sediment concentrations in reef waters through redistribution. Frequency, intensity and duration of turbidity events on coral reefs all have implications for coral viability. The effects of turbidity and sedimentation on the reef community are multiple, ranging from blockage of light to interference with recruitment to physical smothering. The “residence time” of the fine suspended sediments is also an equally important issue as long residence time for finer sediment on reefs leads to frequent high levels of turbidity.

Turbidity plays a unique role of a *regulator* when its effect on reef health is considered in combination with the effect of SST-rise. If in a reef environment of good health, suddenly high temperature prevails along with moderate or high turbidity, then the initial impact of temperature rise will be negated and lessened in the long run. Thermal stress on reef will be less and low warning can be issued. In case of an already degrading reef, the stress-impact of SST-rise and turbidity will be dual and detrimental. However, stress response of the reef to this coupled effect will be definitely region-specific.

Onset of Algae

This parameter is exclusively considered with respect to Gulf of Kachchh scenario.

In Gulf of Kachchh, it has been observed that the onset of coral reef friendly macro-algae (*Sargassum*) normally takes place during September-October and reaches senescence during March/April. Significantly, since 2002 the onset of algae has shifted to November - December. The shift in the life cycle of algae indicates that the reef system is not in healthy condition. Therefore, deviation in the life cycle is considered to be an early indicator. The more the delay, higher is the concern.

Ecological (co-incident) OERPs

Ecological OERPs consider the Ecosystem level indicators that reflect the coral reef environment concurrent to the developmental processes/stages.

Density and Diversity of Corals and Calcareous Algae

According to Grey (1979) the best documented responses to environmental stressors are:

- i. Reduction in species richness;
- ii. Change in species composition to dominance by opportunistic and tolerant species and
- iii. Reduction in mean size of organisms.

Till date, the majority of the coral reef monitoring programs worldwide have focused essentially on two primary parameters i.e. percentage of live hard coral cover and calcareous algae and various indices of the diversity of benthic cover, either at the species or life-form level (De Vantier, 1986, Aronson et al.1994, English et al.1994). Percentage hard coral cover, coral diversity indices and coral vitality indices are now considered to be important, but have proved to be insufficient as the sole data for reef assessment. The realization that 100% live hard coral cover is not a standard even to compare coral reefs in a pristine state has led to the use of the term coral “vitality” or “mortality” indices which take into account ratios of live and dead coral cover in an estimation of reef health (Grigg and Dollar 1990; Dustan 1994, Gomez et al.1994, Ginsburg et al.1996, Steneck et al.1997).

Coral Bleaching

‘Coral bleaching’ (i.e. the expulsion of symbiotic zooxanthellae from host coral tissues) phenomenon is the most common stress-response which is both wide spread and can be measured in a quantitative fashion, Brown and Howard (1985) have suggested that bleaching can serve as an excellent bioassay for assessing environmental stress on corals. However, it is equally important to keep in mind that zooxanthellae loss is a sensitive, sublethal response of corals to a wide range of environmental stressors (like temperature and salinity fluctuations coupled with marine pollution), it is precisely this lack of a response sensitivity that limits its usefulness. Bleaching although provides an early indication of stressful conditions upon a reef however difficulty remains in identifying and attributing the specific environmental stressor. The reef

habitat areas that may undergo bleaching phenomena may become potential sites for future algae invasion and thus pose a threat for phase shift.

Turf/Fleshy Algae

Competition with macroalgae has been proposed to be a limiting factor to reef corals. On healthy, accreting reefs, the slow-growing, reef-forming corals and calcareous algae dominate much of the open substrate, while the faster growing turf algae are kept in check by the combination of grazing and low nutrient supply. Thus, a "healthy reef" can be characterized as one with high cover of live corals and short algal turfs and low cover by fleshy algae. A degraded coral reef, especially those near large centres of human population, shows a shift away from this description, towards communities dominated by diseased corals and high cover of macro algae, especially species that overgrow corals. Their spatial and temporal coverages are important to monitor the benthic diversity and status of competition at reef ecosystem level.

Sargassum Cover

Seasonal blooms of macroalgae like *Sargassum sp.* which dominates reef surfaces and do occur at specific time periods also transpire the co-incident sea as well as reef state.

Seagrass Cover

Seagrass is an important phyto-benthic substrate associated with coral reef systems. Seasonal or unprecedented spurt in seagrass populations in the reef systems signify a change in the nutrient condition in the reef environment. Accordingly seagrass populations' growth and coverage can be monitored to understand the nutrient condition of the reef environment.

Community Shift from Branched to Massive forms

Community shift from delicate branched coral (e.g. *Acropora sp.*) to hard massive (e.g. *Porites sp.*) ones indicates an environmental as well as an ecological condition where the natural coral growth parameters are under

going change. Identification of community shifts from satellite data is based on a hypothesis that a healthy reef will display relatively great spatial heterogeneity due to diverse bottom types and benthic habitats, but an unhealthy coral reef will display homogeneity if it is bleached or colonized by macroalgae (Wulder and Holden, 2000).

Unique Habitat

Presence of some unique or endemic reef communities or reef associates qualifies a particular reef to be considered as unique habitat. Source of this sort of information is however known field only.

Damage (lagging) OERPs

Natural stresses on coral reefs can range from trivial events causing insignificant mortality to intense storms, volcanic eruptions, massive sedimentation episodes, etc.

The damage OERPs reflect the status of damages that has already occurred to a reef habitat and include:

- Reef Erosion
- Mud Deposition
- Phase Shift from Coral dominated habitat to Macro Algae dominated habitat
- Migrating Sand

Other than the Phase shift, the Damage parameters conform to physical loss in terms of available coral recruit area arising out of the geomorphological processes. The processes of both reef-erosion as well as litho-substrate deposition pose damaging threat in terms of absolute loss of habitat-area. However, both these processes leave a scope for reef renewal in a long time perspective. The case of mud or sand deposition is however twined with a more serious threat in terms of its potential to partially change the reef-ecology status because of Phase Shift (live coral cover to algae or sea-grass community).

The term “phase shift” as applied to coral reef ecosystems, describes the change in reef biota from coral to macroalgae attributed to environmental degradation. Reasons cited for such phase shifts include overfishing, excessive nutrient input, predation by *Acanthaster planci*, and depletion of major functional groups like fish and echinoid grazers. Experimental manipulations have confirmed the important role that grazers play in keeping macroalgae from dominating reefs, and field observations of phase shifts from coral to algae, subsequent to catastrophic disease events in echinoids confirm this (Work. et. al., 2008).

Reef Health Indices

Each OERP is given a weightage (Wt) that adds up to 100% scaled to 1 for simplifying the computation purpose. As per the scaled condition of the parameter, each parametric condition is ranked into categories. Rank x Weightage gives Composite Scores (CS) of OERPs that go as an input to generate the respective indices.

Since the OERPs/Input Parameters for both EI and DI are to be retrieved from Change Detection Maps based on eco-morphological classification of multi-date satellite images; they will be derived in units of classified zones or area/spatial cover statistics. So percentage area cover has been considered as common ranking criteria.

Reef Health Index (RHI)

$RHI = \text{Ecological Index (EI)} + \text{Damage Index (DI)}$

Ecological Index (EI)

Ecological Criteria have been ranked as follows.

The range of Total Composite Score is from 1.0 to 3.0. Total Composite Score 1 indicates Reef having High Ecological Value, Total Composite Score 2 indicates Reef having Medium Ecological Value, Total Composite Score 3

indicates Reef having Low Ecological Value. More the index, lower is the ecological value of the reef.

Table 4.2.1: Scaling of Ecological Criteria

Distribution of Weightages to OERPs	Rank 1	Rank 2	Rank 3
Density & diversity of corals & calcareous algae [Wt = 0.4]	>80%	50-80%	<50%
Coral	1-10%	11-70%	>70%
bleaching	1-10%	11-60%	>60%
[Wt = 0.15]	10%	5-<10%	<5%
Turf/fleshy	10%	2-<10%	<1%
[Wt = 0.25]	1-10%	10.1-49%	>50%
Sargassum	Yes	Rare	No
[Wt = 0.05]			
Seagrass			
cover*			
[Wt = 0.02]	Shift		
Community			
[Wt = 0.1]			
Unique	habitat		
[Wt = 0.03]			
Total Composite Score (TCS)	1.0		3.0

Ecological Index (EI) = High to Low Ecological Value = 1.0 to 3.0 (TCS)

Damage Index (DI)

Damage indicators help in generating Damage Index. Damage criteria have been ranked as follows.

Table 4.2.2: Scaling of Damage Criteria

Distribution of Weightages to OERPs	Rank 1	Rank 2	Rank 3	Rank 4
Erosion [Wt = 0.5]	<5%	5.1-20%	20.1-50%	50.1 % & Above
Mud Deposition for more than 1 yr [Wt= 0.25]	<5%	5.1-20%	20.1-50%	50.1 % & Above
Mud Deposition for less than 1 yr	<5%	5.1-20%	20.1-50%	50.1 % & Above

[Wt= 0.15] Phase shift [Wt= 0.09] Migrating sand [Wt= 0.01]	<5%	5.1-20%	20.1-50%	50.1 % & Above
	<5%	5.1-20%	20.1-50%	50.1 % & Above
Total Composite Score (TCS)	0-1.0	2.0	3.0	4.0

Rank 1 indicates No damage to Very Less Damage, Rank 2 is for Less Damage, Rank 3 for Medium Damage and Rank 4 for High Damage.

Damage Index (DI) = Negligible to High Damage = 0.0 to 4.0 (TCS)

Details of computation and scaling of Reef Health Index (RHI) is given in Figure 4.2.2 below:

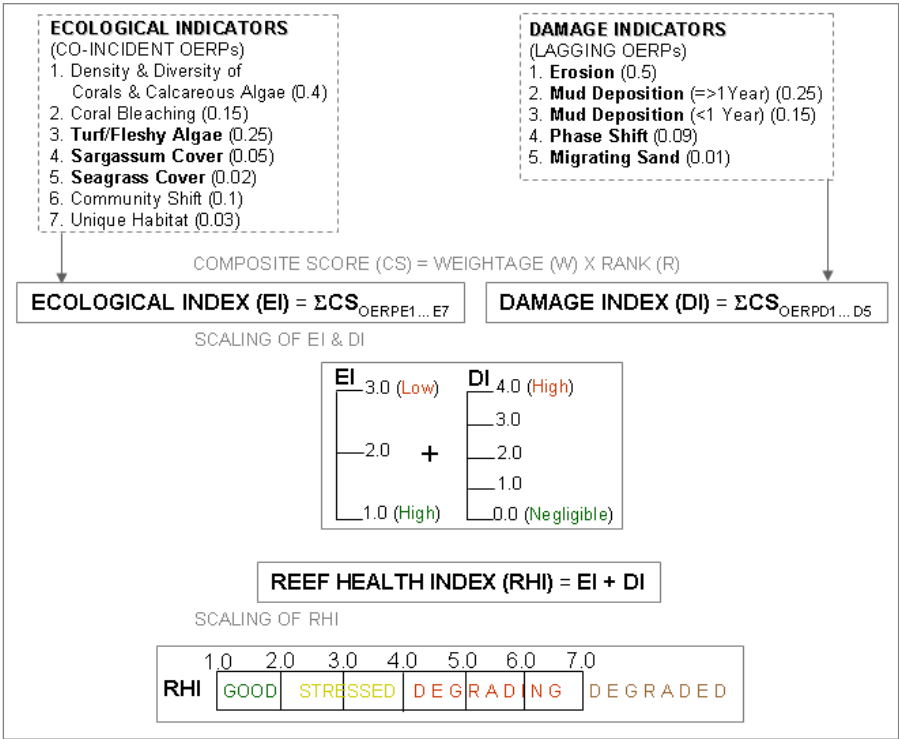


Fig. 4.2.2: Methodology for RHI

$$\text{RHI} = \text{EI} + \text{DI}$$

Scaling of RHI:

Reef in Good Health = 1.0 to 2.0

Reef in Stressed Health = 2.1 to 4.0

Reef in Degrading Condition = 4.1 to 6.9

Reef in Degraded Condition = 7.0

Warning Index (WI)

If RHI $\Rightarrow$ 2.1 then the model computes WI.

The Environmental OERPs can be used to give an early warning directly for any reef region. If any region is found to be exhibiting these OERPs, they are then marked as hotspots and given early warning signal for monitoring and taking management actions. It is also observed that the effect of these OERPs is highly dependent on their frequency and duration of occurrence along with the current state of the reef and location of the reefs.

Each OERP is given a weightage (Wt) as follows,

1. Sea-Surface Temperature or SST (Wt 50% = 0.5)
2. Water Turbidity or WT (Wt 40% = 0.4)
3. Water Turbidity coupled with High Temperature or CE (Wt 90% = 0.9)*
4. Algae onset (Wt 10% = 0.1)

(* This coupled effect is considered and computed only when data is available for both SST and WT, operational in a reef region.)

Again, based on the stress-impact induced upon a reef with reference to frequency, degree and duration of SST anomaly, water turbidity, etc., along with location of the reef, different stress levels can be visualized. Each stress level is then given ranks according to its scale of severity, viz.

No Stress (NS)	(Rank 1)
Low Stress (LS)	(Rank 2)
Moderate Stress (MS)	(Rank 3)
High Stress (HS)	(Rank 4)

Warm Spot	(Rank 5)
Hot Spot	(Rank 6)
Bleached	(Rank 7)

Sea-Surface Temperature (SST)

SST as a single parameter takes care of two aspects viz. SST-anomaly in terms of SST-rise and duration of the anomaly. SST-rise combined with its duration or persistence has a unidirectional correlation to reef warning condition i.e. higher the anomaly more is the level of thermal stress.

Table 4.2.3: Ranking of Reef Stress Conditions with respect to SST-rise, Duration of SST Anomaly

	SST-rise in °C			
Duration	< 0.5	0.5-0.9	1	> 1
1 week	NS (1)*	LS (2)	LS (2)	MS (3)
2 weeks	NS (1)	LS (2)	MS (3)	HS (4)
3 weeks	NS (1)	MS (3)	HS (4)	Warm Spot (5)
4 weeks	LS (2)	HS (4)	Warm Spot (5)	Hot Spot (6)
> 4 weeks	MS (3)	Warm Spot (5)	Hot Spot (6)	Bleached (7)

* Figures in the bracket indicate respective Rank of Reef Stress Condition.

The Hot Spot concept was developed through a combination of field observations, in-situ measurements, and analysis of regional and global satellite based SST data (Goreau and Macfarlane (1990), Goreau et al. (1991), Goreau & Hayes (1994, 2005). A Hot Spot is defined as an area where the monthly average sea- surface temperature is 1 degree C above the historical baseline average for the warmest month of the year. It is not the same as a short-term 1°C anomaly; it must remain for a month to be a Hot Spot. Thus, a Hot Spot is a time-integrated anomaly over a one-month period, NOT an instantaneous short-term fluctuation. Bleaching alerts are not issued until AFTER ONE STRAIGHT MONTH OF EXCESSIVE TEMPERATURES

(Normal Summer Monthly Maximum Mean +1°C). If the anomaly duration is less than that, then the area is termed as a Warm Spot, not a Hot Spot.

Water Turbidity (WT)

Table 4.2.4: Ranking of Reef Stress Conditions with respect to Turbidity

Turbidity	Reef Stress Condition
No Turbidity (Clear Waters)	NS (1)*
Low Turbidity (Water Clarity (WC) = > 5 m)	LS (2)
Moderate Turbidity (WC = 1-5 m)	MS (3)
High Turbidity (WC = <1m)	HS (4)

* Figures in the bracket indicate respective Rank of the Reef Stress Condition.

Coupled Effect of Sea-Surface Temperature and Water Turbidity (CE)

CE is considered/computed if and only if both SST and WT are operational and data is available for both these parameters.

Table 4.2.5: Ranking of Reef Stress Condition with respect to Coupled Effect

SST-rise in °C	No Turbidity	Low Turbidity	Moderate Turbidity	High Turbidity
<0.5	NS (1)*	NS (1)/ LW (2) (if Turbidity rises suddenly)	MS (3)	HS (4)
0.5-0.9	HS (4)	MS (3)	LS (2) (only if reef conditions are normal) else MS (3)	NS (1) (only if reef conditions are normal) else LS (2)
1	Warm Spot (5)	HS (4)	MS (3)	LS (2)
>1	Bleached (7)	Hot Spot (6)	Warm Spot (5)	HS (4)

* Figures in the bracket indicate the respective Rank of Reef Stress Condition.

Onset of Algae

Table 4.2.6: Ranking of Reef Warning Condition with respect to Delay in Algae Onset

Temporal Delay in Algae Onset	Reef Stress Condition
2 Weeks	NS (1)*
4 Weeks	LS (2)
6 Weeks	MS (3)
8 Weeks and Above	HS (4)

* Figures in the bracket indicate the respective Rank of the Reef Stress Condition.

Table 4.2.7: Ranges of Total Composite Scores for Leading OERPs (Warning Index)

Leading OERPs	Ranges of Total Composite Scores (CS) (Weightage × Rank)
Sea Surface Temperature (SST)	0.5 to 3.5
Water Turbidity (T)	0.4 to 1.6
Coupled Effect of SST & T (CE)	0.9 to 6.3
Algae- Onset (AO)	0.1 to 0.4

WI may result from different combinations of three basic input parameters i.e. SST, WT and AO. CE (of SST and WT) can only be derived if both SST and WT are operational as well as their data is available for a particular reef-region. If SST and WT data are available then model will automatically compute CE and will not consider these two parameters separately.

Higher the weightage associated with the WI combination, the more realistic it is.

Among all the parameters required to generate the Warning Index, SST is the single most important parameter and warning will be generated only if SST anomaly is present (may be along with other parameters). However, if SST anomaly is not reported then the warning will not be issued to the region.

Regions exhibiting SST anomaly only will be given warning based on the temperature rise and duration as given in Table 4.2.3.

Table 4.2.8: Scaling of Warning Index

Range of WI (ΣCS)	Level of Reef Stress	Warning Condition/Action
0-1.25	Reef under No Stress	No Warning
1.26-2.50	Reef under Low Stress	Low Warning
2.51-3.75	Reef under Moderate Stress	Medium Warning
3.76-5.00	Reef under High Stress	High Warning
>5.00	Warm Spot Condition and	Very High Warning

Early Warning is issued to Reefs having high warning index.

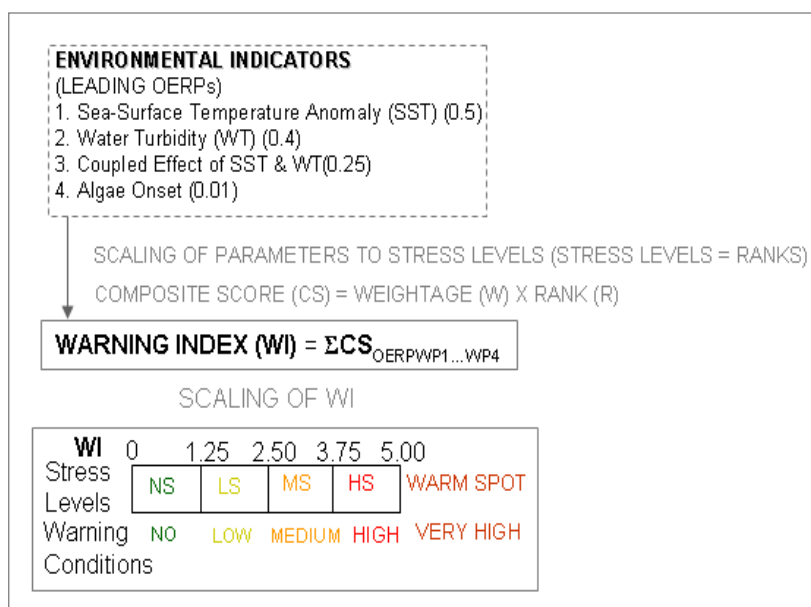


Fig. 4.2.3: Methodology for WI

Coral Reef Health Model: Software Customization

On the basis of the logic described in the preceding section the Coral Reef Health Model has been customized as an Application Module on IGIS software (version 1.0) (developed by ISRO) using the Visual Basic scripting language and Visual Basic Development Tool (version 6.4).

Coral Reef Health Model runs on the IGIS platform as a customized application package. Each of the four major coral reef regions i.e. Gulf of Kachchh, Lakshadweep, Gulf of Mannar and Andaman and Nicobar are recognized as individual projects within the software. User can select the region as per his/her choice and a View will open with a geo-referenced vector database (registered with Polyconic projection and Everest 1930 datum) of the selected region. The Menu Bar of the coral reef health model appears under the main Tool bar of the IGIS software. In order to feed the input parameters into the model it is necessary to activate a point layer (either the customized point layer: OERP_GOK or a New Theme defined by the user and registered to same projection and datum information as that of the OERP point layer). The parametric inputs for the model can thus be fed for geo-coordinate point(s) falling within the recognized boundaries of the coral reef regions. The idea of using a point layer as an interface to register the parametric inputs onto this GIS platform is basically to take care of the field based Ecological and Environmental Parameters which is tagged with GPS co-ordinates. Moreover, it is also possible to derive Point-specific information from either Raster or Vector data (viz. satellite data or thematic maps). Hence, the point layer has the advantage of combining/integrating parametric feeds for multiple points arising from both spatial databases as well as field (non-spatial) data.

The user needs to prepare and customize his/her data (involving image processing and preparation of multi-temporal Eco-morphological zonation maps following the standard methodology, collection of field data on the Ecological OERPs as per the Ranking criteria discussed under Ecological Index; the Damage parameters can follow from multi-temporal change detection of eco-morphological maps of the concerned reef; whereas SST and Water Turbidity can follow from either satellite retrieved input or real-time buoy/*in situ* measurements; Delay in Algal onset can be computed either using multi-temporal data or field information) in order to match the required format of the input feeds.

The user can run and provide inputs to the model and generate Report on Reef Health Index (RHI) and subsequently on Warning Index (WI) for that particular location of the concerned reef. The report has the provision of hard copy printing as well as e-mail attachment.

Model Demonstration:

Coral Reef Health Assessment for Pirotan Reef, Gulf of Kachchh

Pirotan Reef (location: 22°34'41" - 22°37'06" N and 69°55'54" - 69°58'57" E), identified as the core area of Jamnagar Marine National Park (Jamnagar district, Gujarat, India), is situated on the Jamnagar-Okha coastal segment of the Saurashtra peninsula, in the interior of southern part of Gulf of Kachchh – a macro-tidal and highly turbid environment in the west coast of India. Pirotan is a fringing type of reef with an island (namely, Pirotan Island) in its core and lies to the north of Jindra bet (island) and to the north-west of Munde-Ka-Bet reef. (Fig. 4.2.1) Semi-arid, low rainfall climate, sluggish terrestrial streams with low detritus load, hyposaline and turbid waters with moderate to high tidal (3-5m) range, presence of shoreline currents compared to long shore currents, low wave but fairly high tidal energy conditions with mostly calcareous mud with occasional sand and clay as the principal littoral zone material, a fairly wide and a low gradient of the littoral zone (Merh, S.S. 1995): all these characteristics of this coastal segment offer an ideal situation to study reef (occurring in the northern most limits of its existence as far as Indian coral reefs are concerned) response to sedimentation processes on habitat as well as species level. Location of Pirotan reef among all the coral reefs occurring in this coastal segment is all the more unique as it is separated from the main coastline of Saurashtra Peninsula by the presence of Jindra bet (island) to its south, away from the localized tidal circulation of any micro-bays curved out of the coastline crenulations otherwise common in this coastal segment and it remains as a projected headland just on the southern margin of abruptly narrowing of the width of the east-west oriented, Gulf of Kachchh at 70°20'E (Wagle, B. G. 1979).

Archived IRS satellite data of Pirotan reef (2004-2006 period), concurrent NOAA SST data and field data of the same period has been used for initial data preparation e.g. Eco-morphological Maps (Fig. 4.2.4) Turbidity image (Fig. 4.2.5) for assessing the reef health using the Coral Reef Health Model Application Module on the IGIS software.

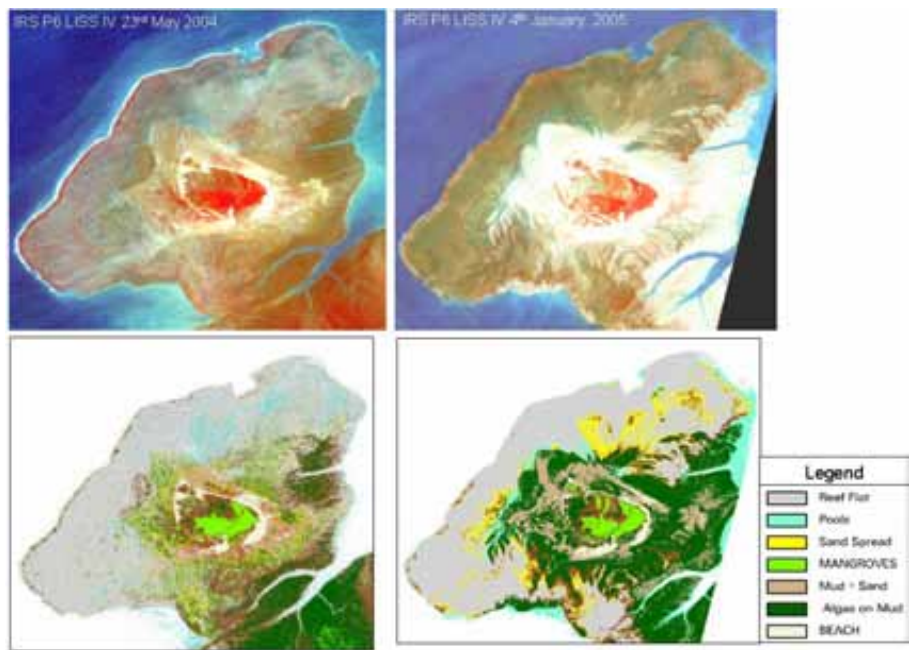


Fig. 4.2.4: Eco-morphological Maps of Pirotan Reef

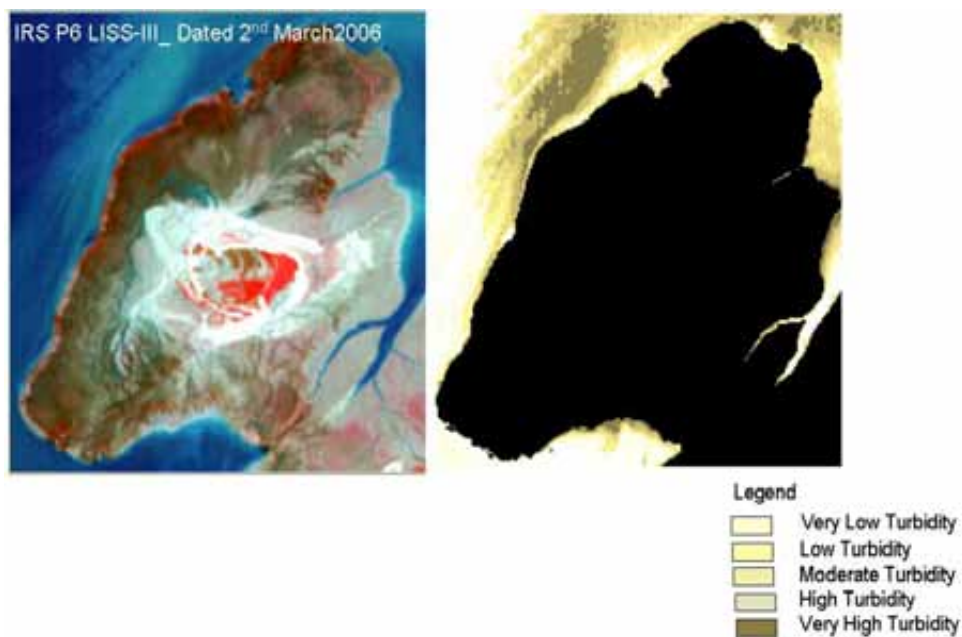
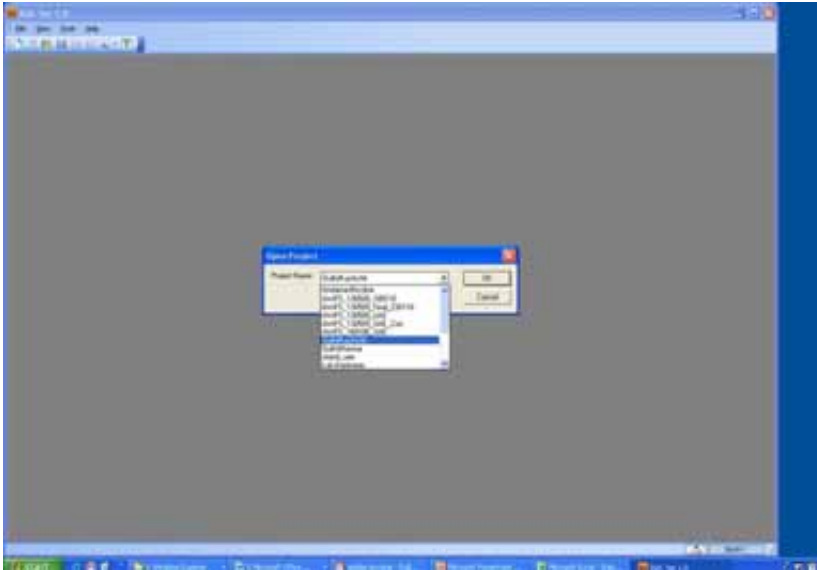


Fig. 4.2.5: Turbidity Image of Pirotan Reef Environment

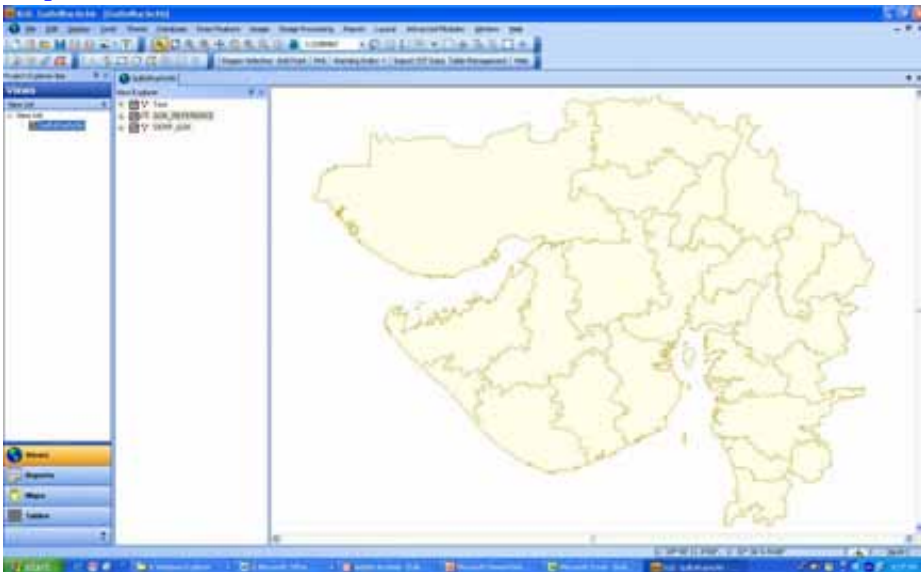
Model Run: Screen shots

Step 1:



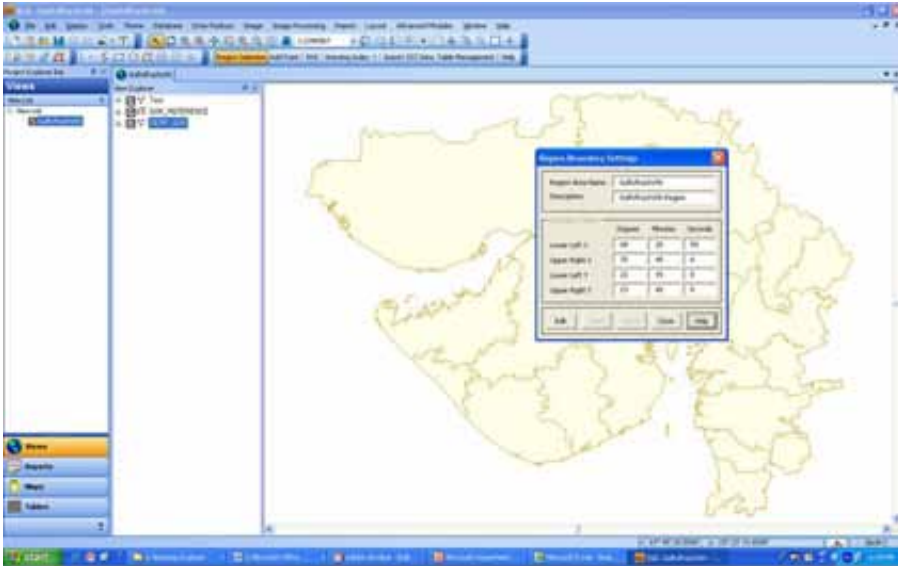
Gulf of Kachchh project was selected from the File menu of IGIS software.

Step 2:



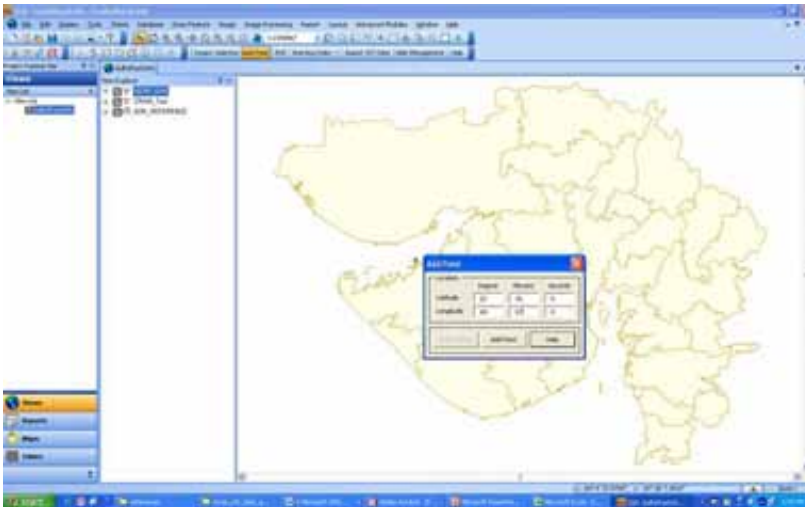
The View opens with the geo-referenced vector database of the Gulf of Kachchh region.

Step 3:



The user can select the Region Selection menu from the application menu bar in order to define/modify the coral reef region boundary to ensure that all the data in the point layer is falling within the reef region.

Step 4:



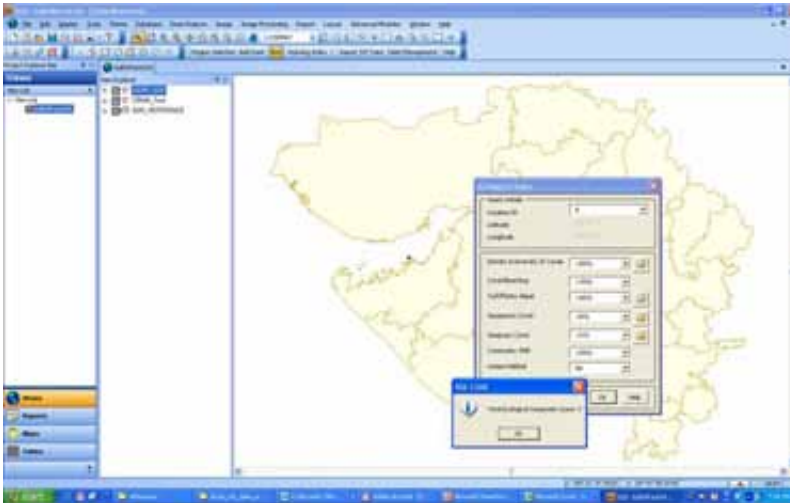
The Add Point menu is selected after activating the existing (OERP_GOK) or a New Theme (Point_ layer) in order to add the test point (indicated by green circle; Location_ID:8) on the reef (22° 36'N, 69° 57'E on Pirotan reef). All the input parameters are fed for this particular point.

Step 5:



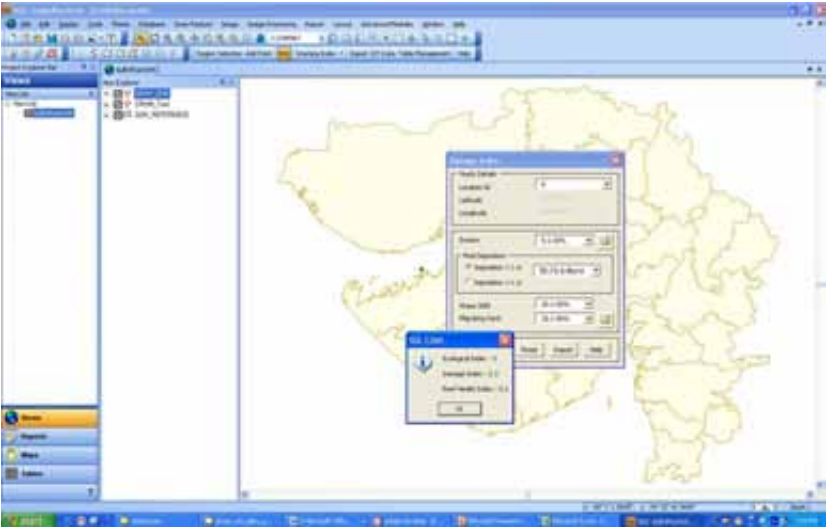
Next the RHI menu is clicked which invokes the Ecological Index dialog box for feeding the inputs for Ecological parameters. The interactive GUI will accept the inputs in the designed format for the particular point location (Location ID: 8) on the reef. User can enter the inputs just by selecting the pop down menus (criteria).

Step 6:



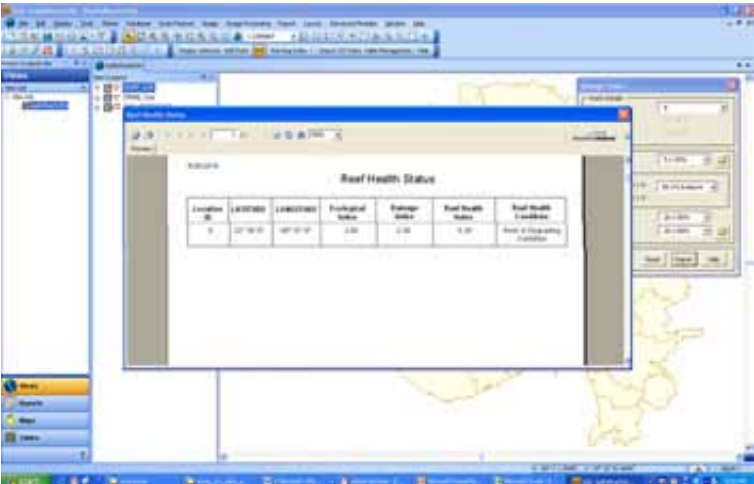
With completion of all inputs the user clicks on OK button and the software computes the Total Ecological Composite Score and displays the score on a message box.

Step 7:



Next the Damage Index dialog box opens where the user has to feed the inputs for the damage parameters selecting the appropriate criterion for each parameter using the respective pop down menus. Once this step is complete, the software displays the scores of Ecological Index, Damage Index (DI) and Reef Health Index (RHI). The DI and RHI get computed at this level.

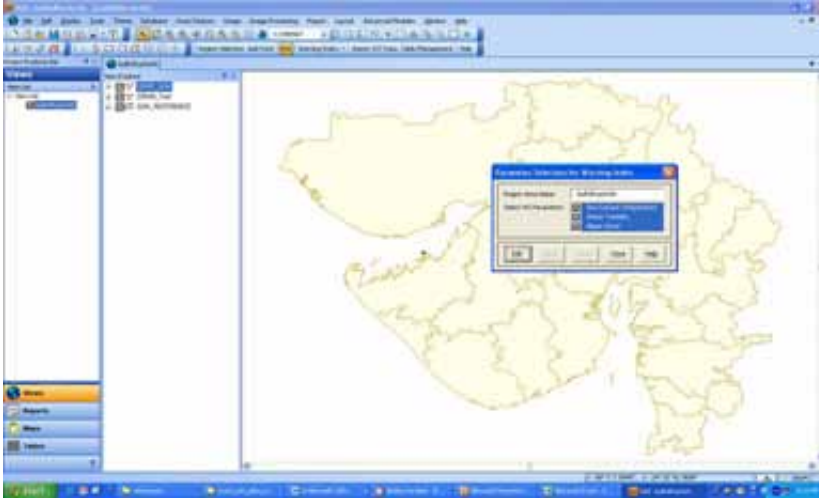
Step 8:



RHI report can also be generated by clicking on the Report button on Damage Index dialog box. The report will display the point specific information in a tabular fashion under the column heads: Location ID, Latitude, Longitude, EI,

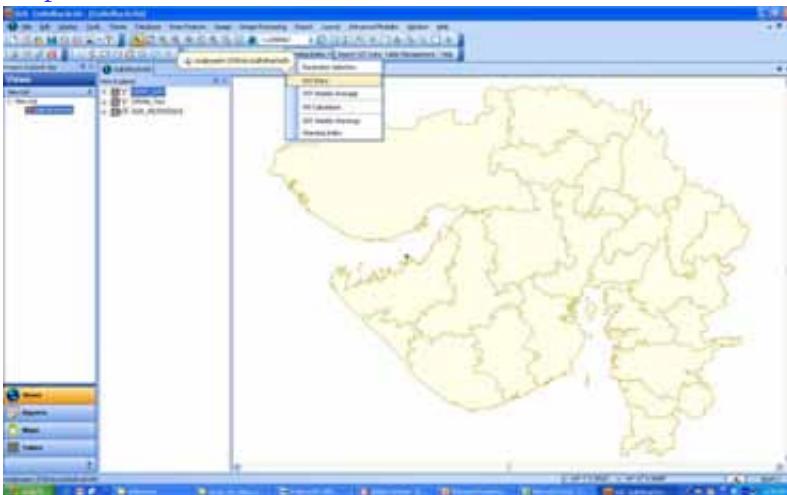
DI, RHI and the Reef Health Condition. *In this case the Pirotan reef is under Degrading Condition.*

Step 9:



If the RHI $\Rightarrow$ 2.1 then the software will ask the user whether to calculate Warning Index (WI)? If yes, then the user is supposed to select the Warning Index menu from the menu bar. User can select/edit the operational parameters from the pop down menu of Parameter Selection for Warning Index.

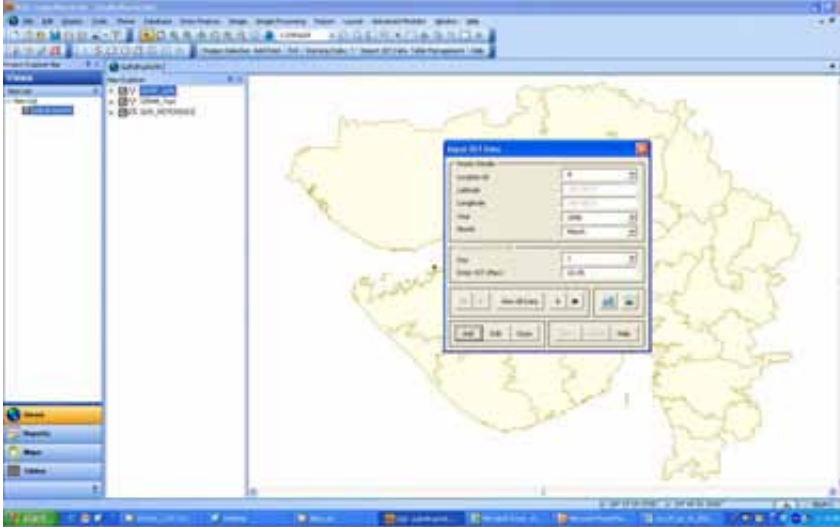
Step 10:



User needs to enter daily Max. SST data for the summer months' period (March-June 1st week) for a year in order to compare with a regional threshold

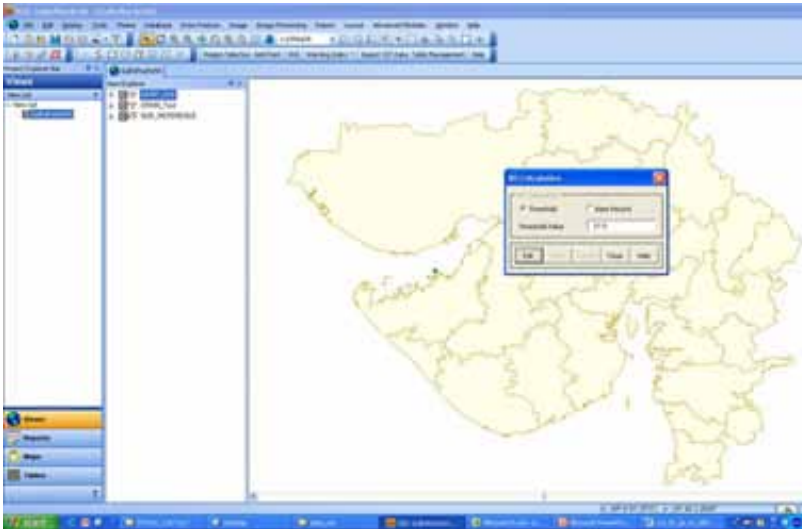
value to derive the SST anomaly condition. Provision has also been kept to upload SST data from database files (.dbf format) or even from ASCII data format. Deriving point-specific SST data (for a pixel) from SST image has been idealized as a future improvement for the model.

Step 11:



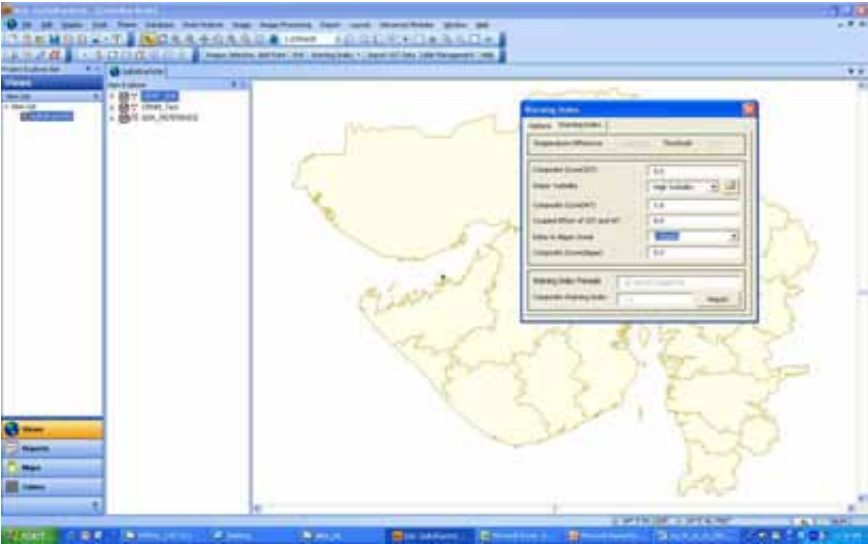
User can enter daily Max. SST data using the Input SST Data dialog box for the available/required data period (March- June 1st week).

Step 12:



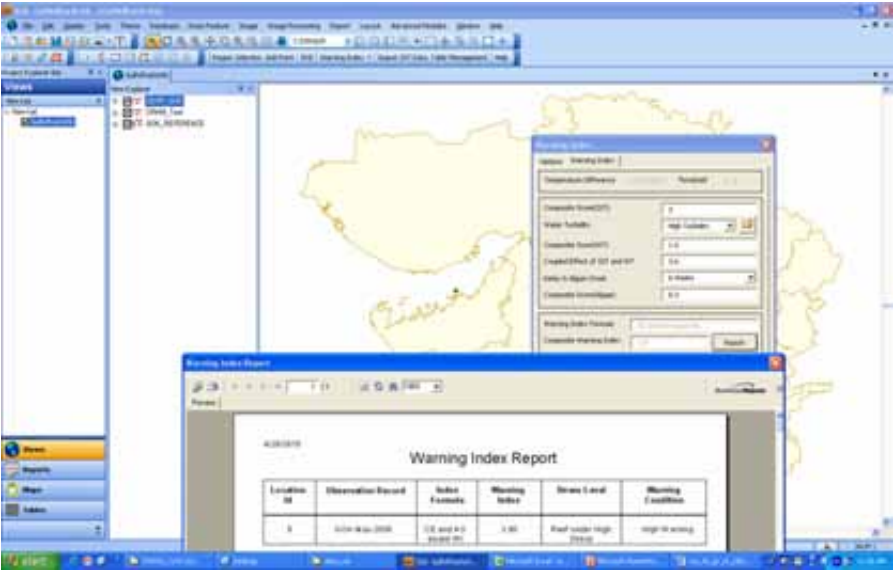
User can define the standard reference (either a regional threshold value or a year's record considered as the base record) for comparing the SST condition.

Step 13:



Next the Warning Index can be calculated for the point location on the reef by additionally entering the inputs for Water turbidity and Delay in Algae onset by selecting the appropriate criteria from the available pop down menus.

Step 14:



Once the composite Warning Index is calculated the Warning Index Report can be generated to display the Location_ID, Observation record period, Index Formula (operational parameters considered), Warning Index, Stress Level and Warning Condition for that particular reef location. *Pirotan reef location received a High Warning condition for being a “Reef under High Stress”.*

The Coral Reef Health Model conceptualized and customized thus can generate Reef Health Status Reports and Warning Index Reports for a point location on a reef. The advantage of using a point layer in this case lies in the fact that if a single point non-spatial data pertaining to the reef is available that can be used as a representative point while a complete reef-scale (micro-zonation) health map can also be obtained with increasing the point density on the reef. The data preparation part (through standard methods) needs attention as the inputs to the model depend on them. IGIS being enabled with image processing as well as GIS capabilities the data preparation can also be done easily using the same software. The software also possesses the flexibility to edit/modify regional as well as parameter settings and thus can evolve with time to meet conceptual demands to improve in the design and efficacy.

Conceptually the model involves the critical reef health parameters and can assess the reef health considering both reef habitat and environmental conditions. Reef health assessment and generation of warning conditions through this kind of model is first of its kind as mostly the reef health assessment models take care of either SST or any other dominating stressor as the single important parameter.

The model concept can be improved and restructured in future by considering certain critical environmental parameters (like salinity) which has not been considered at this stage. The major scope of improvisation in the model lies in deriving point-specific information from existing raster data or thematic maps and incorporating that information (value) into the model. Inclusion of polygon layer based reef information is also an issue for future development. Retrieval of as many parameters as possible from satellite data also needs to be attempted in order to provide faster and near- real time health assessment reports. The aspect of multi-temporal data analysis also demands a serious thinking as it is an essential pre-requisite but at the same time consumes time

for data processing and change detection analysis. The model can also have an improvement in the feature data (raster as well as vector) links and display in the near future.

Taking due care of the scopes and feasibilities of the improvement aspects, it can be said that the model has operational capability supported by a network of trained users. The model can be of interest and use to reef managers as well as to the reef researchers and students. Following this attempt, the model can be strengthened conceptually as well as from customization point, a system of routine reef monitoring and issue of regional/national reef health bulletins can be established in the long run.

5. Marine Protected Areas (MPAs)

There are a total of 128 marine Protected Areas in India .Out of these, there are four Marine National Parks, sixty-seven Marine Sancturries, National Parks and Wild Life Sancturries, three Marine Biosphere Reserves, three Ramsar Coastal Wetlands, one Tiger Reserve (Sunderbans), one National Mangrove Genetic Resource Centre and Gene Centre and the Coral Reefs of Lakshadweep (seventeen), thirty two Mangrove Notifies Forests.

Four national parks (having area130 km²) and 16 wild life sanctuaries (185 km²) have been identified for conservation measures. Apart from this, 17 parks and 28 wild life sanctuaries have been proposed/ existing on the island territories of India.

It is necessary to monitor these areas to assess impact of conservation measures, status of habitats within the protected areas, impact of development on the quality and quantity of the resources, etc. No such database exists for the Indian Marine Protected Areas (MPA's). The repetitive nature of satellite data helps in monitoring vital ecosystem areas as well as in assessing the impact of conservation measures. These include the marine Biosphere Reserves, Ramsar Coastal Wetland Sites, etc.The Objectives have been to Map and monitor the selected Marine Protected Areas and create the database indicating previous and current condition and assessing the their ecological status.

Selected MPAs on the entire Indian coast have been taken up for monitoring their ecological status. Digital geo-coded IRS P6 LISS III/LISS IV pertaining to two time frames have been used for the preparation of spatial inventory of the coastal habitats at 1:25,000 scale and monitoring their status. WGS-84 datum and UTM projection have been used in mapping.The details of the Marine Protected Areas in terms of their locations, extent and coverage are given in the subsequent table.

Marine Protected Areas (MPAs)	SOI Map No. 1:25,000 scale	Total no of maps
Gulf of Kachchh Marine National Park (MNP), Jamnagar, Gujarat	41 B15 NE, SE F03 NW, NE, SW, SE F04 NW, NE F06 SW, SE F07 NW, NE, SW, SE F08 NW F11 NW, NE, SW, SE F14 SW, SE F15 NW, NE, SW F11 NW, NE, SW, SE J02 SW, SE J03 NW	31
Gulf of Kachchh Marine Sanctuary (MS), Jamnagar, Gujarat	41F09 SW, SE F13 NW, NE, SW, SE I04 NE, SE I08 NW, NE, SW, SE I12 NW, NE, SW, SE I16 NW, SW J01 NW, NE, SW J05 NW, NE, SE	24
Malvan Marine Sanctuary, Sindhudurg, Maharashtra	47H08 SE	1
Gulf of Mannar MNP, Biosphere Reserve (BR), Tamil Nadu	58K08 SE K12 NE, SW K16 NW, NE L01 NE, SE L05 NW O03 SW, SE O04 NW, NE O07 NW, SW O08 NE	15
Bhitarkanika National Park (NP), Cuttack, Orissa	73L13 NE, SE L14 NW, NE, SW, SE P01 SW P02 NW	8
Sunderbans NP-Tiger Reserve	79B4 SW, SE, NW, NE B12 NW, NE, SW, SE, B16 NW, NE, SW, SE, C1 NW, NE, SW, SE, C2 NW, NE, SW, SE, C5 NW, NE, SW, SE, C6 NW, NE, SW, SE, C9 NW, NE, SW, SE, C10 NW, NE, SW, SE,	58

	C13 NW, NE, SW, SE, C14 NW, NE, SW, SE, F4 NW, SW, G1 NW, SW, NE, SE, G2 NW, SW, NE, SE, 73O10 NW, NE, SW, O6 SE		
North Andaman and North Nicobar	86C12 SE C14 NW, SW, SE C15 NW, NE, SW, SE C16 NW, NE, SW, SE D09 NE, SE D10 NE, SE D11 NE, SE D12 NE, SW, SE D13 NW, NE, SW, SE H01 NW D14 NW, NE, SW, SE D15 NW, NE, SW, SE D16 NW, NE, SW, SE G02 NW, SW G03 NW, SW G04 NW, SW H03 SW H04 NW, SW K03 NE K07 NW 87A02 SE A06 SW A09 NW, NE, SW, SE A10 NW, NE, SW, SE A11 NW, NE, SW, SE A12 NE A13 NW, NE, SW A14 NW, SW B01 NE B05 NE, SE B06 NE, SE B09 NW, NE, SW B10 NW, SW C12 NE C15 SW C16 NW D13 SW E01 NW, SW H03 NW, SW, SE H04 NE, NW H08 NW, NE, SW		117

	H10 SW, SE H11 NE, NW H12 NW, SW 88E05 NW, NE E09 NW E10 SW E11 NE, SW, SE E12 NE, SE E16 NW, SW, SE F09 NE F13 NW, NE, SW, SE E15 NW		

Spatial data for the above Marine Protected Areas (MPAs) for the periods 1988-1989 and 2004-2007 have been used to study the change in the status of major habitats. Earlier data/existing land use/ land cover maps (1989-1991) have been used to get the status/condition of the protected areas at that time (wherever possible). The existing spatial data have been used from the Coastal Zone Information System (CZIS) developed at SAC. The spatial data on mangroves and coral reefs (vital/critical habitat), organized in the CZIS for these study areas, has been used for monitoring the selected MPAs. The current conditions of the MPAs have been obtained from the coastal land use maps prepared on 1:25000 scale from IRS P6 LISS III/LISS IV data of 2004 - 07 time frame.

Environmental (existing and freshly collected collateral data) and socio-economic parameters, issues concerning each of the protected areas, etc. collected from ground surveys have been used for the present work.

Wherever the condition of the habitats has been observed to be changing frequently with an adverse impact on the protected area, the region has been mapped and monitored depending upon the severity of the changes. The details on the ecological status of the above mentioned MPAs are discussed below:

North Andaman and North Nicobar

The Andaman and Nicobar groups of islands located in the southeast of the Bay of Bengal between 6°45' and 13°14'N latitudes and 92°12' and 93°57'E longitudes consist of 350 islands. The deeply indented coastline of the

Andaman and Nicobar islands results in innumerable creeks, bays and estuaries and facilitates the development of mangroves. There are 60 species of mangroves in the Andaman and Nicobar islands making it the second most diversely rich area in the Indian sub-continent (Nayak et al, 1992). Coral reefs are the important habitats housing diverse marine fauna, particularly in the western side of the Andaman islands.

Comparison of the earlier and the current data on the coastal habitat (Table 5.1) reveals that there has been decrease in agricultural land and area under habitation. It shows notable increase in forest covers (non-tidal/plantation), area under other vegetations and more exposed mud/tidal flat. In 1988-89, area of mangrove vegetation was 0.04 sq. km (categorized into dense and sparse classes), while in 2004-05 the area has decreased to 0.01 sq. km and can be categorized into three classes – dense, sparse and degraded.

Table 5.1: Major coastal habitats of North Andaman and North Nicobar

Coastal Habitat	Area in sq km	
	1988-89	2004-05
Agricultural-land	0.02556	0.02307
Barren-land	0.00551	0.00505
Coral-reef	0.02565	0.06032
Forest (non-tidal/plantation)	0.07576	0.39782
Habitation	0.00057	0.00009
Mangrove (dense)	0.03902	0.00173
Mangrove (sparse)	0.00257	0.00836
Mangrove (degraded)		0.00184
Mud/tidal-flat	0.01367	0.03033
Other-vegetation	0.00043	0.00123
Rocky-coast	0.01219	0.00008
Sandy-beach	0.00967	0.00252

The Gulf of Kachchh

The Gulf of Kachchh has an assemblage of ecologically sensitive ecosystems, viz. Coral reefs, mangroves, sea grasses, algae/seaweeds, etc. it is the largest inlet (approx. 7350 sq. km) of the Arabian sea, about 60 km wide at its widest and 170 km long (69°46' - 69°65'E longitude and 22°30' - 22°40'N latitude).

Comparison of the earlier and the current data on the coastal habitat (Table 5.2) reveals that there has been significant decrease in area under forests (non-tidal/man-made) and habitation. Data shows notable increase in marsh vegetation and area under salt pans. In 1988-89, area of mangrove vegetation was 124.31 sq. km, while in 2004-05 the area has radically increased to 349.74 sq. km and can be categorized into four classes – very dense, dense, sparse and degraded. Satellite imagery studies together with ground truth collection shows that there has been small increase in the number of ports/harbour/jetty (total area, 0.14 sq. km), reservoirs/tanks (0.47 sq. km) and industrial area (13.87 sq. km).

Table 5.2: Major coastal habitats of Gulf of Kachchh Marine Sanctuary (MS), Jamnagar, Gujarat

Coastal Habitat	Area in sq km	
	1988-89	2004-05
Agricultural-land	25.28	18.37
Beach/patch	7.21	1.92
Mangrove (degraded)	0.10	1.84
Mangrove (dense)	39.24	45.06
Forest (non-tidal/plantation)	81.31	41.29
Habitation	8.44	1.51
Marsh-vegetation	3.58	23.97
Mud/tidal-flat	1037.45	825.21
Salt-pans	107.37	367.46
Sandy-area	3.52	0.10
Mangrove (sparse)	84.97	291.54
Mangrove (very dense)		11.29
Industrial-area		13.87

Gulf of Kachchh Marine National Park (MNP), Jamnagar, Gujarat

Comparison of the earlier and the current data on the coastal habitat (Table 5.3) reveals that there has been decrease in area under agriculture and salt pans, but increase in habitation and area under coral reefs. Data shows notable

increase in marsh vegetation and area under other vegetations, particularly scrubs. In 1988-89, area under mangrove vegetation was 122.44 sq. km, while in 2004-05 the area has increased to 160.02 sq. km and can be categorized into four classes – very dense, dense, sparse and degraded. Satellite imagery studies together with ground truth collection shows that there has been increase in the number of ports/harbour/jetty (total area, 0.36 sq. km), airport (0.37 sq. km), aquaculture ponds (0.38 sq. km), reservoirs/tanks (4.58 sq. km) and industrial area (7.64 sq. km).

Table 5.3: Major coastal habitats of Gulf of Kachchh Marine National Park (MNP), Jamnagar, Gujarat

Coastal Habitat	Area in sq km	
	1988-89	2004-05
Agricultural-land	516.76	405.59
Barren-land	117.91	3.12
Beach/patch	33.78	7.98
Coral-reef	190.97	200.97
Mangrove (degraded)	1.50	18.34
Mangrove (dense)	30.53	51.42
Forest (non-tidal/plantation)	40.63	20.94
Habitation	10.85	14.90
Mud/tidal-flat	414.41	420.36
Open/vacant-land	0.14	0.15
Other-vegetation	60.45	222.48
Rocky-coast	0.69	3.45
Salt-pans	163.98	148.62
Sandy-area	4.39	0.71
Mangrove (sparse)	90.41	28.93
Mangrove (very dense)		61.33
Salt-marsh/marsh vegetation	3.77	15.93
Industrial-area		7.64

Malvan Marine Sanctuary, Sindhudurg, Maharashtra

The Malvan coast, which forms a part of the Western Ghats where the Sahyadri mountain ranges gradually meet the Arabian Sea, is considered as one of the biologically rich regions along the Maharashtra coast. From

Vengurla point, the coast extends towards north for about 22 km. A chain of submerged and exposed rocky outcrops extends southwards up to 15°33'N and 73°27'E. Sindhudurg is a low fortified island on the coastal reef, which is joined to the mainland by a reef. At Ratnagiri and Malvan, sandy beaches are interspersed with rock formation extending over a considerable distance into the sea and forming small bays. During low tide, the exposed area of the bay has large rock pools with rocks partially exposed and the corals are generally seen attached to the rocks. These corals are legally protected under the Malvan Marine Sanctuary. This Sanctuary, together with some adjoining areas also harbours mangrove vegetation.

Table 5.4: Major coastal habitats of Malvan Marine Sanctuary, Sindhudurg, Maharashtra

Coastal Habitat	Area in sq km	
	1988-89	2004-05
Agricultural-land	5.95	6.97
Barren-land/sandy-area	0.40	0.71
Beach/patch/sand	1.58	1.79
Mangrove (degraded)		0.03
Mangrove (dense)		0.33
Forest	1.83	1.85
Habitation	7.63	9.53
Mud/tidal-flat	1.51	1.14
Rocky-coast/exposure	0.52	0.40
Rock-outcrops	3.31	1.20
Mangrove (sparse)	0.08	0.17
Mangrove (very dense)		0.11

Comparison of the earlier and the current data on the coastal habitat (Table 5.4) reveals that there has been a little increase in area under agriculture and habitation. In 1988-89, area of mangrove vegetation was 0.08 sq. km, while in 2004-05 the area has significantly increased to 0.62 sq. km and can be categorized into four classes – very dense, dense, and sparse and degraded. Satellite imagery studies together with ground truth collection shows that there has been a very small increase in the number of aquaculture ponds (total area, 0.02 sq. km) and seawalls/enbankments (0.10 sq. km).

Gulf of Mannar MNP, Biosphere Reserve (BR), Tamil Nadu

The Gulf of Mannar lying in the south of the Palk bay is geographically distributed between 8°47'N - 9°15'N latitudes and 78°12'E - 79°14'E longitudes and harbours 21 islands. The Gulf has a number of offshore platform reefs, patch reefs and coral pinnacles, which lie from south of the Pamban Pass to north-east of Tuticorin. The region is significant both ecologically and economically. Coral reefs comprise of 94 coral species under 37 genera, 10 species of seagrasses and high density of macro-algal species. Ninety species of sponges, 119 species of annelid fauna, 450 species of molluscs, 22 species of bivalves have been reported from this region by earlier workers. This region harbours mangrove ecosystems. The region was declared as Marine National Park in 1980 comprising an area of 6.23 sq. km and was given the status of Biosphere Reserve in 1989 covering an area of 10,500 sq. km.

Table 5.5: Major coastal habitats of Gulf of Mannar MNP, Biosphere Reserve (BR), Tamil Nadu

Coastal Habitat	Area in sq km	
	1988-89	2004-05
Agricultural-land	13.78	20.88
Aquaculture-pond	0.15	0.73
Barren-land	5.65	0.87
Coral-reef	11.93	52.20
Mangrove (degraded)	1.07	
Mangrove (dense)		0.18
Forest	70.99	
Habitation	4.51	25.12
Mud/tidal-flat	2.87	3.15
Salt-marsh/marsh-vegetation	2.30	0.20
Salt-pans	32.48	37.93
Sand (with/without vegetation)	13.39	14.65
Sandy-area/dunes	4.49	8.37
Mangrove(sparse)		0.40
Forest/other vegetation	87.96	79.90
Industrial-area		5.72

Comparison of the earlier and the current data on the coastal habitat (Table 5.5) reveals that there has been increase in area under agriculture and habitation. The data also depicts an increase in aquaculture practices. In 1988-89, area of mangrove vegetation was 1.07 sq. km, while in 2004-05 the area has decreased to 0.58 sq. km and can be categorized into two classes - dense and sparse. Satellite imagery studies together with ground truth collection shows that there has been increase in the number of cooling-ponds (total area, 0.07 sq. km), ports/harbour/jetty (0.58 sq. km) and industries (industrial area, 5.72 sq. km)

Bhitarkanika National Park (NP), Orissa

Bhitarkanika (located between longitude 86°45'E - 87°50'E and latitude 20°04'N - 20°08'N) is a unique habitat of mangrove forests located in Kendrapara district of Orissa. In 1975, Bhitarkanika was declared a Sanctuary under the Wildlife Protection Act, 1972 and was declared the National Park in 1988. It comprises of Bhitarkanika, Kalibhanjadian and Gahirmatha mangrove areas and is fed by the Dharma river, the Maipura river and the Bhitarkanika river. It is the home to diverse flora and fauna intricately linked with each other. The floral diversity includes a total of more than 300 plant species (Banerjee, 1984) with both mangrove and non-mangrove species belonging to 80 families.

The diverse habitat ranging from mangrove forests to agricultural fields, rivers, streams, fresh water ponds, tidal rivers, creeks, estuaries, mudflats, fresh water and brackish water wetlands, riverine islands, off-shore islands, muddy and sandy coastlines etc. provides home to a varied and large number of animal species including the longest estuarine crocodile of the world, partial albino reptilian species, salt water crocodiles, three species of Indian monitor lizards, the python and various migratory birds.

Comparison of the earlier and the current data on the coastal habitat (Table 5.6) reveals that there has been significant increase in area under agriculture and habitation. The data also depicts marked increase in aquaculture practices. In 1988-89, area of mangrove vegetation was 180.59 sq.km, while in 2004-05 the area has enlarged to 213.20 sq. km and can be categorized into four classes

– very dense, dense, sparse and degraded. Satellite imagery studies together with ground truth collection shows that there has been increase in the number of seawalls/enbankments, port/harbour/jetty, roads and reservoirs/tanks.

Table 5.6: Major coastal habitats of Bhitarkanika National Park (NP), Cuttack, Orissa

Coastal Habitats	Area in sq km	
	1988-89	2004-05
Agricultural-land	332.09	754.57
Aquaculture-pond	0.51	26.86
Rock-outcrops/barren-land	227.59	0.77
Beach/patch/sand	11.27	3.52
Mangrove (very dense)		7.46
Mangrove (dense)	145.07	164.29
Mangrove (sparse)	35.52	24.84
Mangrove (degraded)		16.61
Forest	4.88	6.10
Habitation	13.52	34.04
Mud/tidal-flat	94.68	66.46
Salt-marsh/marsh-vegetation	0.07	3.57
Other-vegetation	9.38	8.96

Table 5.7: Major coastal habitats of Sundrbans, West Bengal

Category	Area (sq km)	
	1988- 89	2004-06
Agriculture	107.69	215.43
Mudflat/Tidal flat	39.22	10.94
sand	5.48	1.41
Salt marsh/Marsh vegetation	1.53	0.21
Mud with vegetation		2.10
Saline area		13.86
Open /vacant land	19.91	0.61

Aquaculture pond	6.47	5.74
Inter tidal mudflat		15.63
Beach/Patch		0.51
Mangrove forest Dense	1528.13	405.06
Mangrove forest Sparse	82.55	956.54
Mangrove forest Degraded	227.32	181.02
Pond/ Lake	0.11	1.04
Ox -Bow lake/ meander		0.01
waterlogged		0.52
Reservoir \Tank		0.008
Habitation		0.23
Habitation with vegetation	40.35	72.45

Sunderbans, West Bengal

Comparison of the earlier and the current data on the coastal habitat (Table 5.7) reveals that agriculture activities in the area have increased to 215.43 sq km in 2004-07 from 107.69 sq km in 1988-89. Mangrove areas have increased from 1838.00 sq km to 2032.91 sq km. This table also shows the increase in habitation with vegetation from 40.35 sq km to 72.45 sq km.

6. Coastal Zone Information System

A principal concern of coastal zone management is to ensure a rational development of area and judicious use of its resources, which is consistent with the surrounding natural systems and environment. Thus, environmentally effective system management depends upon accurate and comprehensive scientific data on which policy decisions can be based. A basic problem confronting our country is limited availability of data on natural resources, land use topography and demography for coastal areas of the country. Moreover, all these data is in either spatial or non-spatial form and thus difficult to integrate conventionally. It is, therefore necessary to develop a computer based information system composed of comprehensive and integrated set of data designed for decision making.

Available landuse, wetland, shoreline and coral reef maps prepared by Space Applications Centre, Ahmedabad using satellite images from IRS LISS-II, Landsat MSS/TM, SPOT of 1988-1994 have been digitized and put in CZIS (Coastal Zone Information System). This baseline data in GIS environment can be used for the following purpose and also for preparation of coastal zone management plan for entire Indian coast:

- i) As a set of benchmark or reference conditions in the coastal area and to monitor long-term trend of dynamic coastal system.
- ii) Preservation, conservation and monitoring of vital coastal habitats viz. corals and mangroves.
- iii) Selection of appropriate locations for aquaculture, industries, recreational activities and construction of set-back lines using specific criteria.
- iv) Assessment of the impact of reclamation of land from sea, sand mining, dredging and recreational activities.

Accordingly a Coastal Zone Information System (CZIS) has been developed and operationalized at SAC. It involved:

- i) Organization of a digital database comprising of various themes at different scales in Geographical Information System (GIS) environment.
- ii) Development of a 'Query Shell'/Customized Information System package to retrieve and use the database in user friendly and efficient manner.

The outputs of such a system can be useful for assessing environmental impacts, preparing regional plans, development of coastal zone, development of tourism and in general creating a data base of collective layers for use by planners/ decision makers.

The entire country's coastline, around 7500 km including that of island territories is covered in CZIS. This consists of nine maritime states viz. Gujarat, Maharashtra, Goa, Karnataka, Kerala, Tamil Nadu, Andhra Pradesh, Orissa, West Bengal and two union territories i.e. Andaman & Nicobar Group of Islands and Lakshadweep Islands.

The framework for development of CZIS is given in Fig.6.1. It involves the following tasks:

- i) Available maps on various themes and scales (prepared using remote sensing satellite data over a period of 1988 – 1994 to cover entire India's coastline) have been digitized and used in the information system.
- ii) Collection of non-spatial (statistical) data such as population and name of settlements from different sources.
- iii) Creation and organisation of data base envisaging
 - a) Creation of reference frames (master files) for all nine maritime states (cited earlier) and Andaman & Nicobar and Lakshadweep separately.

- b) Generation of different thematic layers using reference frames.
- c) Linking non-spatial data to spatial data base.
- iv) Development of a 'Query Shell' for creating data base and retrieving the data base information in a user friendly manner as well as generating different output maps.

The entire Indian coastal area including union territories was mapped by using satellite data (IRS, SPOT, LANDSAT TM and MSS) over a period of 1988-1994. The following thematic maps have been used:

1. Landuse maps on 1:25,000 scale
2. Landuse maps on 1:50,000 scale
3. Wetland maps on 1:50,000 scale
4. Wetland maps on 1:250,000 scale
5. Shoreline maps on 1:50,000 scale
6. Shoreline maps on 1:250,000 scale
7. Coral reef maps on 1:50,000 scale.

A brief on the maps prepared using satellite data and used in CZIS is given below:

Coastal Land Use Maps

Coastal land use is one of the most important components of coastal environment. Information on land use/ land cover in the form of maps and statistical data is very vital for planning, management, and utilization of land for various purposes such as agriculture, forestry, urban development, economic production, tourism, environmental studies and so on. Thus, it provides basic input for any coastal zone management. To provide benchmark or reference conditions for management, base line data is to be generated. The Landuse maps for Coastal Regulation Zone (CRZ) showing wetland features between HTL and LTL and land use features up to 500 m from HTL on 1:25,000 scale for the entire Indian coast have been prepared using satellite data of the year around 1991 (Year of MoEF notification for CRZ to protect

and conserve the coastal environment). These maps were generated using visual interpretation techniques & employing False Colour Composites (FCCs) of LISS-II, Landsat TM and SPOT data by Space Applications Centre (SAC), Ahmedabad and different collaborating agencies of different maritime states. The main emphasis was on tidal wetlands, built-up area, mining areas, etc. About 1000 maps for the entire country's coastline have been prepared. These maps have about 85 per cent classification accuracy at 90 per cent confidence level. The planimetric accuracy is about 60-75 m. Land use maps on 1:50,000 scales were also prepared for entire Indian coast.

Number of maps prepared for Landuse on 25K and 50K are as follows:

State	Landuse 1:25K	Period of Data Used	Landuse 1:50K	Period of Data Used
Gujarat	244	1988 - 1989	89	1988 - 1989
Maharashtra	81	1987 - 1994	35	1987 - 1994
Goa	21	1988 - 1993	5	1987 - 1994
Karnataka	33	1987 - 1991	17	1987 - 1991
Kerala	64	1988 - 1990	27	1988 - 1991
Tamil Nadu	33	1987 - 1991	17	1987 - 1991
Andhra Pradesh	117	1989 - 1993	43	1988 - 1989
Orissa	87	1988 - 1989	26	1988 - 1989
West Bengal	66	1988 - 1991	24	1988 - 1989
A & Nicobar	116	1987 - 1994	50	1987 - 1991

A standard classification scheme was designed to generate information on various environmental units on a regional or a national level on 1:25,000 scale. Major land use categories delineated were agricultural land, forest (natural and man-made), coral reef, mangroves, mudflats, sandy areas, sandy beach, built-up land etc.

Linear features delineated were high water line, low water line, road, rail, administrative boundaries viz. district boundaries, state boundaries. Village locations (settlements) were also marked along with village/town/city names.

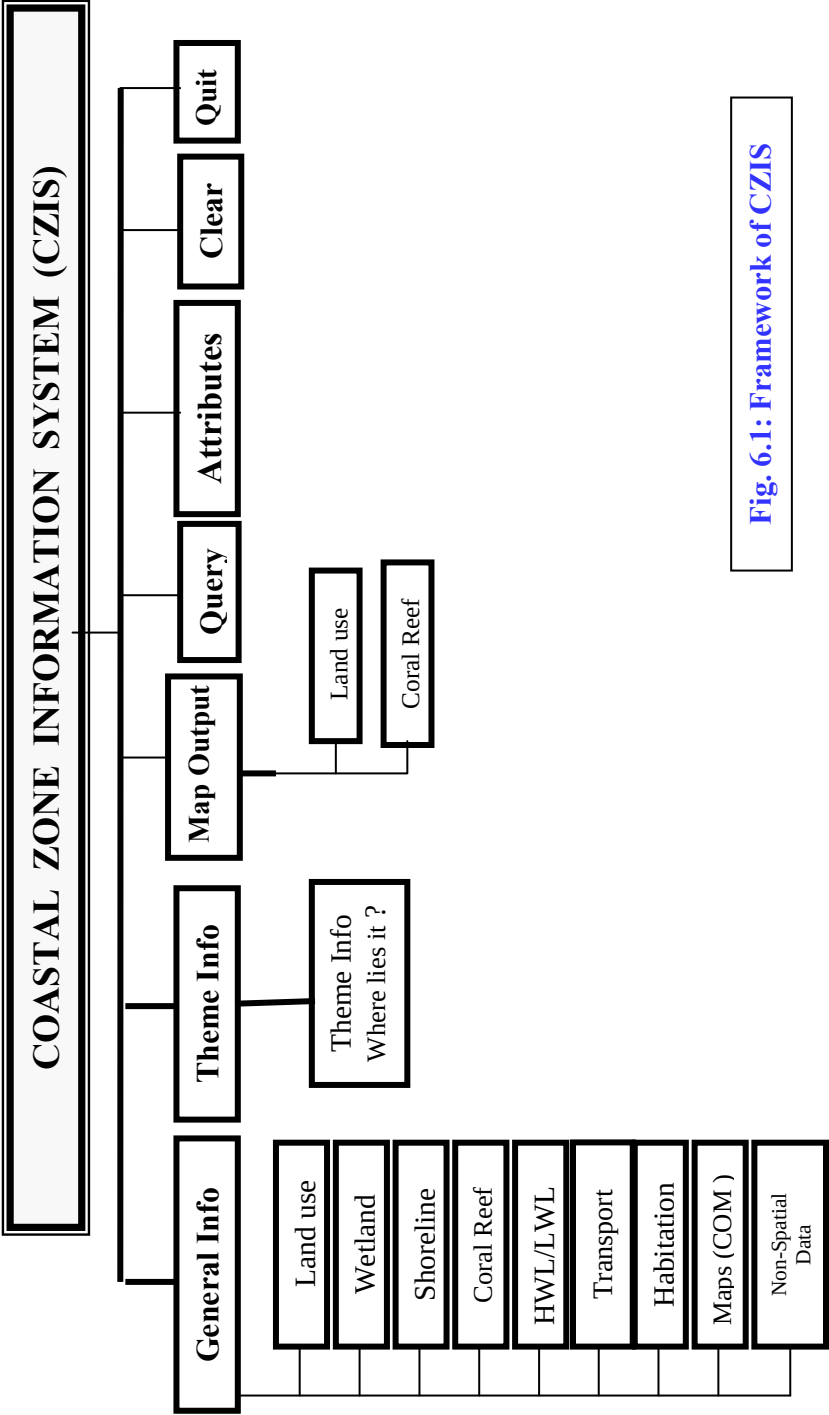


Fig. 6.1: Framework of CZIS

Wetland Maps

Coastal habitats viz. wetland, mangroves, salt marshes, sea grasses are vital component of coastal environment. Wetlands are areas which are transitional between terrestrial and marine system where tidal water periodically inundates and water table is usually at or near surface or land is covered by water (Cowardin et al. 1979). These are being cleared for urban, industrial and recreational growth as well as for aquaculture development. Information of loss of tidal wetlands is important as they provide a vital link in the marine energy flow through transfer of solar energy into forms which are readily usable by a wide variety of estuarine organisms. The knowledge about aerial extent, condition and destructive uses of wetlands is vital for coastal zone management programmes. Monitoring of changes in coastal wetlands can help in preservation, conservation of habitats, marine life, construction of ports and jetties and so on. Wetland maps are prepared on 1:50,000 and 1:250,000 scales for entire Indian coast using visual interpretation techniques & employing False Colour Composites (FCCs) of LISS-II, Landsat TM and SPOT data by Space Applications Centre (SAC), Ahmedabad and different collaborating agencies of different maritime states.

Number of maps prepared for Wetland on 50K and 250K are as follows:

State	Wetland 1: 50K	Period of Data Used	Wetland 1: 250K	Period of Data Used
Gujarat	64	1988 - 1989	4	1986
Maharashtra	29	1993	4	1986
Goa	6	1992 - 1993	--	--
Karnataka	12	1988 - 1991	2	1986
Kerala	28	1988 - 1993	8	1986
Tamil Nadu	38	1989 - 1990	9	1987 - 1991
Andhra Pradesh	38	1992 - 1993	10	1985 - 1987
Orissa	26	1993	5	1986
West Bengal	25	1988 - 1991	5	1985 - 1989
A & Nicobar	47	1987 - 1994	7	1986 - 1989
Lakshadweep	--	--	5	1986

Classification accuracy of these maps was about 85 per cent at 90% confidence level.

Coral Reef Maps

In India, coral reefs are mostly found in the Gulf of Kachchh in Gujarat State, Gulf of Mannar in Tamil Nadu, in the Lakshadweep Islands and Andaman & Nicobar Group of Islands. There are mostly fringing reefs in the Gulf of Kachchh, Gulf of Mannar and A & Nicobar Islands, with a few a few platforms, patch and atoll reefs and coral pinnacles. Lakshadweep islands are mostly atolls with few coral heads, a platform reef and sandy cays. Coral reefs of Andaman & Nicobar Islands are among the richest in the Indian Sub-continent, which not only protects the coastline against the sea erosion but also, harbor host of animal communities. As cited above, coral reefs are highly specific in their requirement of water quality, temperature, and salinity for their growth. These are being destroyed by siltation, mining and pollution. Sedimentation of reef reduces live coral and species diversity. The knowledge about extent and condition of coral reef will help to plan preventive and conservative measures to protect this fragile ecosystem. Indian Remote Sensing satellite data have been successfully used for preparing coral reef maps showing extent of coral reefs and their associated features. Coral reef maps of the Indian coastal areas cited above have been prepared by Space Applications Centre., Ahmedabad. These are already reported (Gupta M.C et. al., Technical Note, 2003 and 2006) for Andaman & Nicobar and Lakshadweep. There are 6 and 7 maps prepared for coral reefs on 1:50,000 scale using FCCs of IRS LISS-II and SPOT data of 1988-1989 for the Gulf of Kachchh and the Gulf of Mannar respectively.

Shoreline Maps

Shoreline maps are another important component of coastal environment. In India, many areas are eroded and threaten the life and property of the local population. One of the major requirements of coastal zone management is to understand the coastal processes of erosion, deposition, sediment transport, flooding and sea level changes. These processes continuously modify the shoreline. Thus maps delineating multi-date shorelines /shoreline change will

be most useful to locate erosion prone areas, areas susceptible to flooding during monsoon and so on. This will help in number of applications such as construction of jetties/ ports, development near the shore etc. Shoreline change mapping has been carried out for the entire Indian coast using IRS and Landsat MSS/TM data on 1:50,000 and 1:250,000 scale.

Survey of India (SOI) topographical framework was used for organizing and creating the data base. Name of the villages and associated population were also stored in the database.

Number of maps prepared for Shoreline on 50K and 250K are as follows:

State	Shoreline 1: 50K	Period of Data Used	Shoreline 1: 250K	Period of Data Used
Gujarat	--	--	12	1975 - 1986
Maharashtra	29	1988 - 1993	5	1985 - 1989
Goa	6	1992 - 1993	--	--
Karnataka	10	1998	--	--
Kerala	26	1985 - 1993	8	1969 - 1987
Tamil Nadu	33	1989 - 1990	--	1987 - 1991
Andhra Pradesh	32	1985 - 1993	10	1973 - 1988
Orissa	25	1973 - 1993	7	1973 - 1987

Customized Query Shell

A Query Shell (Customized Package) “CZIS-INDIA” for entire Indian coast including union territories is designed and developed around ARC/INFO GIS to facilitate preparation of an effective coastal zone management plan. The Query Shell is aimed at to provide systematic retrieval as well as integration of wide range of data, both spatial and non-spatial for decision making as well as for automatic generation of map outputs.

The GIS facilities of MACRO language such as Arc Macro language (AML) in Arc/INFO GIS, are used for the realization of customized query shell as per the user's needs. The query shell is menu-based, easy to use as per the user profile. User friendly ‘Software Modules’ are developed to facilitate automatic retrieval of general information, theme wise information, zone-wise

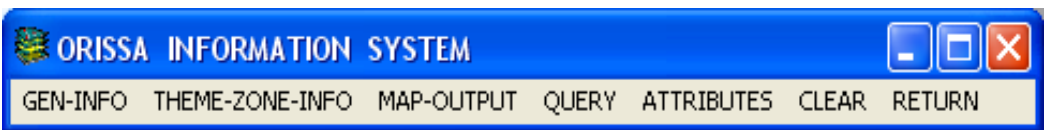
information, map compositions and generation of output maps on 1:250,000, 1:50,000 as well as on 1:25,000 scales.

Capabilities of Query Shell

The query shell ‘CZIS-India’ can be invoked in arc of ARC/INFO GIS by a simple command.

Arc: &r czis-india

It display the front menu (Fig. 6.2) to interact with the coastal zone information system (CZIS) of different states and union territories, as per user’s selection by clicking the mouse. The user can access all the states / Union Territories CZIS one by one, optionally, by selecting Yes or No. After selecting the desired state/ union, it displays the following menu bar (example – Gujarat) to interact and access the total Information of the respective state / union territory.



CZIS has three main capabilities:

Query System (General Info)

It provides retrieval of all the information existing in the data base prepared for the entire country such as land use information on 1:25,000/1:50,000 scales including transport network, habitation, HTL, LTL & CRZ boundaries, wetland information on 1:50,000/250,000 scale, shoreline information on 1:50,000/250,000 scale and coral reef information on 1:50,000 scale. Information of non-spatial data can be provided either in the tabular form or is linked with spatial data such as population and names of villages.

Thematic Information

A user can extract information for specific land use categories viz. agriculture, natural forest, man-made forest, dense mangroves, sparse mangrove, coral

reefs etc. in any order, or similarly for wetlands categories and coral reefs categories on different scales for entire states/ union territories or SOI as per toposheets. The area of different categories is calculated automatically and is displayed along with legend. The user can optionally generate map composition to obtain the hard copy maps.

Output Map Generation

Automatic Generation of different maps using either SOI toposheet numbers as input or a desired area of interest (A.O.I) to cover the desired area or complete island(s) in case of Lakshadweep that has more than one SOI toposheets.

These Sub-shells are described in Sections A, B and C respectively. The complete Flow Chart of CZIS is given in Fig 6.1. The database design specifications are as per National Resources Database (NRDB) standards.

A. Query System

Query System can be used to retrieve all the information created in the data base in a user friendly manner. This is the first menu of CZIS named as “General Info”. This has the following Sub-menus.

General Info

- Land use on 25,000 scale
- Land use on 50,000 scale
- Wetland on 50,000 scale
- Wetland on 250,000 scale
- Coral Reef on 50,000 scale
- Coral Reef on 250,000 scale
- Shoreline on 50,000 scale
- Shoreline on 250,000 scale
- Existing Map Compositions (COM)

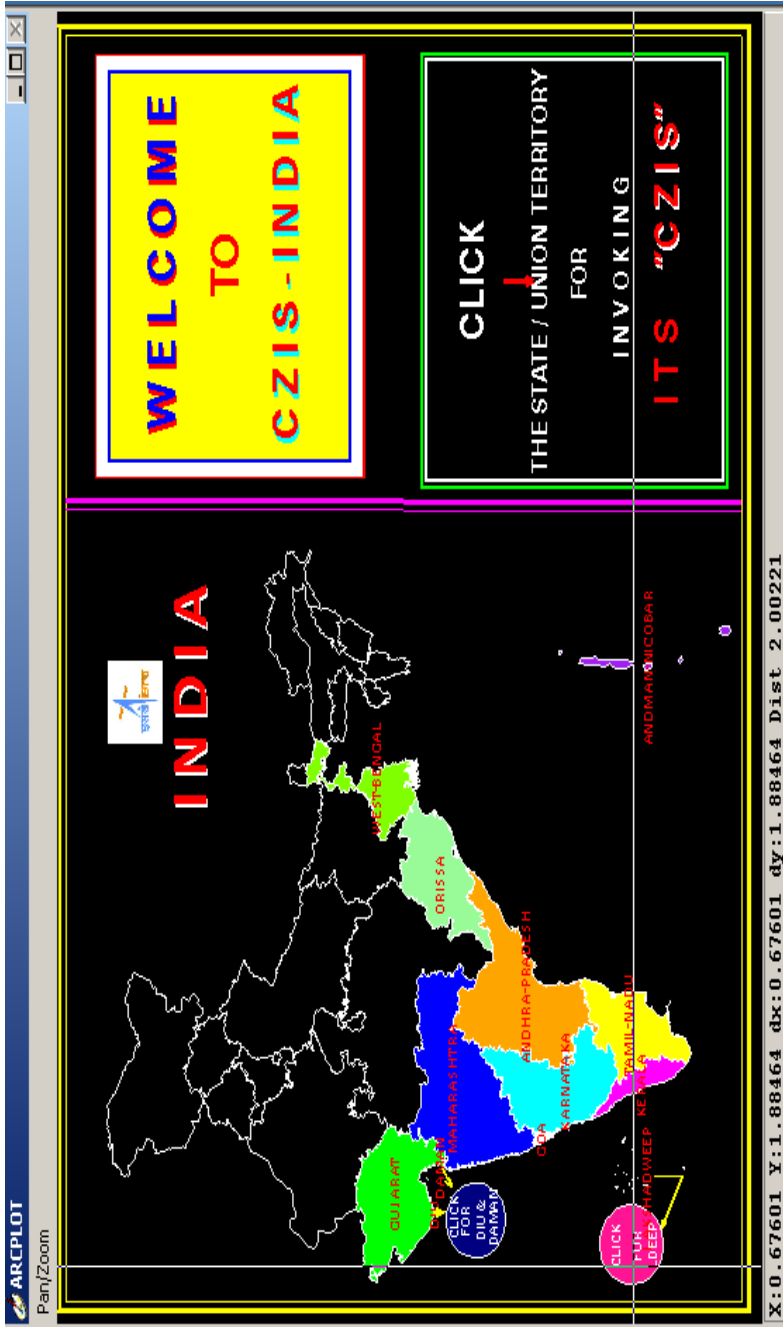


Fig. 6.2: Front Main Menu, CZIS

The first sub-menu provides land use information on 1:25,000 scale. By clicking this sub-menu, the land use data of the entire state or union territory is displayed on the terminal. Optionally, the other information viz. legend, linear features namely rail, road, high water line, low water line, settlements, SOI map numbers can also be superimposed. The scale of the display is calculated automatically and is shown at the bottom. The information of other themes cited in the above sub-menu i.e. land use on 1:50,000 scale, wetland and coral reefs on 1:50,000 and 1:250,000 can be obtained in the similar fashion by clicking the desired theme. The sub-menu of shoreline on 1:50,000 and 1:250,000 scales provide shorelines of different years with different line patterns. The information about different polygons of land use, wetlands, coral reefs (in sq. meters) and the linear features such as transport, boundaries (in meters) can be obtained interactively using 'Query' menu of CZIS.

The desired area can be selected and enlarged using either cursor or by providing longitudes and latitudes of two opposite corners. The total area of states / union territories or the desired enlarged area can be displayed on the screen again and again. The scale and full legend is displayed automatically after enlargement.

'Existing Map Compositions' sub-menu allows to select any map composition (.com) existing in the data base from a popup menu and display it with a desired page size. Non-spatial information existing in the tabular form can be obtained on the screen by clicking the desired title menu if any in the General Info menus. The non-spatial socio-economic data such as village names, population etc. linked with spatial data can be obtained interactively using 'Query Menu' of the Island Ecosystem. Fig. 6.3 shows the Flow Chart of Information Retrieval using 'Query System'.

B. Thematic Info

Query System can provide thematic information for selected categories by a user on a popup menu. Any theme viz. landuse, wetlands and coral reefs on different scales can be taken up by clicking its corresponding item in the sub-menu under 'Theme Info' as given below:

This sub-shell provides land use, wetlands and coral reefs information and has the following sub-menus

- ❖ Land use entire state / Union Territory (scale-1: 25k)
- ❖ Land use Toposheet-wise (1: 25k scale)
- ❖ Land use entire state / Union Territory (scale-1: 50k)
- ❖ Land use Toposheet-wise (1: 50k scale)
- ❖ Wetlands entire state / Union Territory (scale-1: 50k)
- ❖ Wetlands Toposheet-wise (1: 50k scale)
- ❖ Wetlands entire state / Union Territory (scale-1: 250k)
- ❖ Wetlands Toposheet-wise (1: 250k scale)
- ❖ Coral Reefs entire area / Union Territory (scale-1: 50k)
- ❖ Coral Reefs Toposheet-wise (1: 50k scale)
- ❖ Coral Reefs entire area / Union Territory (scale-1: 250k)
- ❖ Coral Reefs Toposheet-wise (1: 250k scale)

All the above sub-menus have the following facilities

- i) Any number of land use/wetlands/coral reef categories can be selected on the popup menu in any order one by one.
- ii) The thematic map will be displayed on the screen using the selected shades with legend.
- iii) The area of each category will be calculated automatically in sq.kms.
- iv) The scale will be generated.
- v) The map composition can be created optionally to get the print or hard copy.

Thus, this sub-shell facilitates to get area of any category for the entire state or union territory such as mangroves, coral reefs, forest etc. automatically from the database.

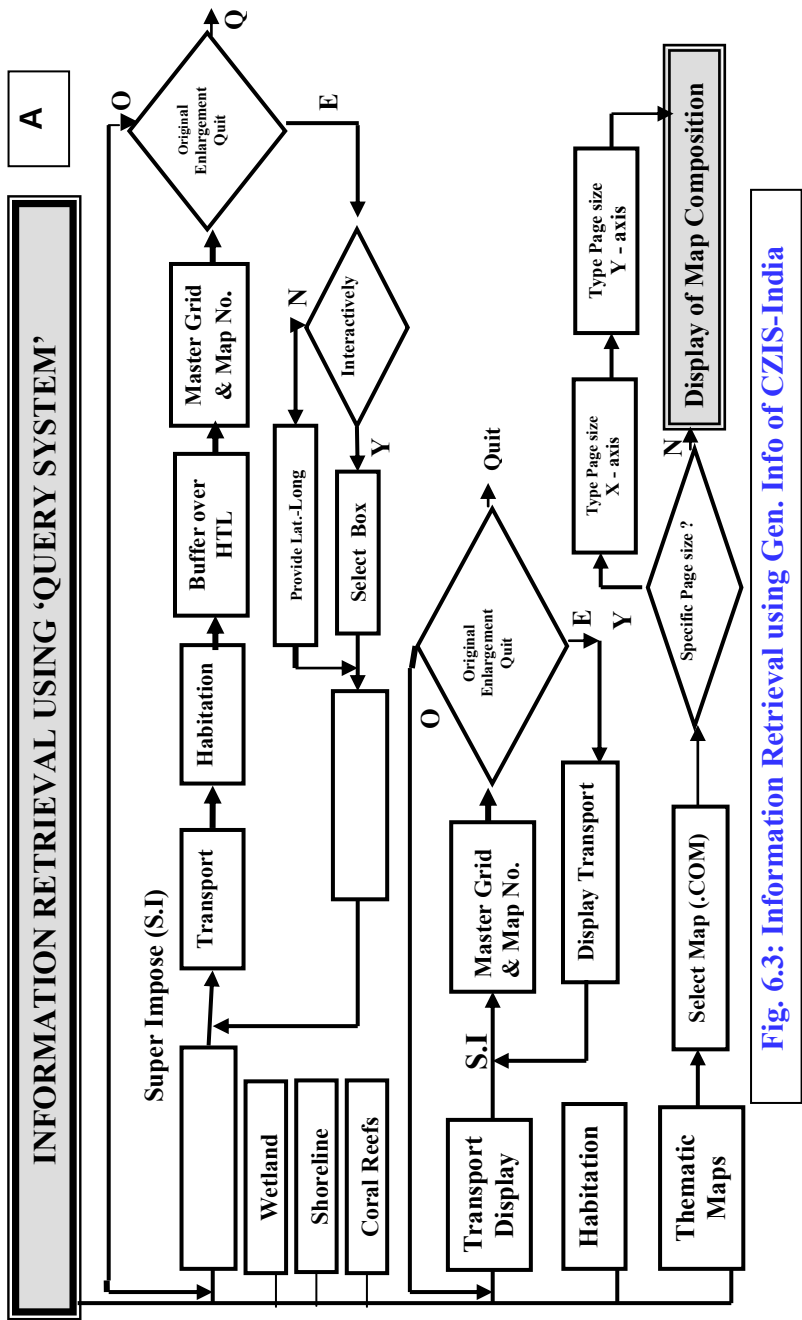


Fig. 6.3: Information Retrieval using Gen. Info of CZIS-India

Optionally, any number of categories can be selected and the map composition with selected shades (Legend) can be generated. Similarly, any SOI map area from a thematic coverage can be clipped from the corresponding database and its selected categories with area and legend can be mapped in a user friendly manner.

C. Output Map Generation

As an Output Map Generation System, CZIS can be used for generating land use, wetlands, coral reefs and shoreline changes maps of any user selected area or as per SOI toposheets on different scales. Thus, it is one of the most important shells to produce map compositions and hard copy thematic maps. This sub-shell has the following menu:

Map Outputs

- ❖ LANDUSE-MAPAS PER SOI TOPOSHEET ON 25000-Scale
- ❖ LANDUSE-MAP-OF-ANY-SPECIFIC-AREA-FROM-25 K Scale
- ❖ LANDUSE-MAP AS PER SOI TOPOSHEET ON 50K Scale
- ❖ LANDUSE-MAP-OF-ANY-SPECIFIC-AREA- FROM-50 K Scale
- ❖ WETLAND-MAP AS PER SOI TOPOSHEET ON 50K-Scale
- ❖ WETLAND-MAP-OF-ANY-SPECIFIC-AREA- FROM-50 K Scale
- ❖ WETLAND-MAP AS PER SOI TOPOSHEET ON 250K-Scale
- ❖ WETLAND-MAP-OF-ANY-SPECIFIC-AREA- FROM-250 K Scale
- ❖ SHORELINE-MAP AS PER SOI TOPOSHEET ON 50K-Scale
- ❖ SHORELINE-MAP-OF-ANY-SPECIFIC-AREA- FROM- 50 K Scale
- ❖ SHORELINE-MAP AS PER SOI TOPOSHEET ON 250 K-Scale
- ❖ SHORELINE250K-MAP-ANY-SPECIFIC-AREA- FROM-250 K Scale

Map generation as per SOI toposheet numbers requires toposheet Number as the only input. While map generation for any specific area prompts for selecting the rectangular box using two opposite corner points. The later facilitates to cover the user selected area or island (for Lakshadweep/ A & Nicobar) for map generation. The selected area is displayed on the screen to verify it and can be changed if required. Zooming option is provided to enlarge any area for accurate selection of the area of interest (A.O.I). The standard map

format and the illustrations are given in the next chapter. This sub-shell has three distinct capabilities as follows:

i) Map Specific Legend Generation :

Thematic coverage for the entire state/Union Territory may consist large number of categories on different scales. However, an individual SOI map or specific area map may consist of only a few of these categories/ features. Thus it is necessary to generate the legend of only those categories which exist on the individual map to avoid confusion. This menu has an in built facility to generate only these categories/ features existing on the individual maps.

ii) Map Index Generation :

This menu has also the capability to generate the map index that is the SOI map numbers of the output map and its surrounding maps automatically. For the maps of any specific area, it lists all the SOI maps covering the area automatically.

iii) Map Scale Generation :

For any map output, the map scale is generated automatically.

For all the maps, a standard output map format is taken up. However, it can be modified if required. A Flow Chart of Automatic Output Map Generation System is shown in Figure 6.4.

Coastal area / zone of a country assumes great importance because of high productivity of its ecosystems, concentration of population, exploitation of renewable and non-renewable natural resources, discharge of waste effluent and municipal sewage, development of various industries and spurt in recreational activities. India has a long coastline of about 7500 km distributed among nine coastal states and its islands territories of Andaman & Nicobar and Lakshadweep. Its coast is divided into two parts, West coast and East coast. The West coast is fronted by the Arabian sea and the east coast is fronted by the Bay of Bengal. It has richly diverse coastal ecosystems like coral reefs and

mangroves which contribute to its high productivity along with wide expanse of mudflats, lagoons, estuaries, beaches, dunes etc. However, exploitation of its natural coastal resources has been increased due to pressure of population along with an increase in the load on harbours due to expanding import-export trades, developments of various chemical, petrochemical fertilizer and allied industries and above all petroleum exploration. Thus, there is a need to protect the coastal environment using scientific methods, ensuring continuing production and development. This requires an “Integrated Coastal Zone Management System”.

Coastal Zone Information System (CZIS) has been developed at SAC to facilitate the preparation of Coastal Zone Management of entire country i.e. all maritime states including Union Territories. The front menu of CZIS is shown in Fig. 6.2. For invoking CZIS of any of the state / union territory, the user has to click in the respective state on the entire country’s map. This will take the user in the corresponding CZIS with State Shell directly in the ARCPLOT to display all the database information in a user friendly manner.

Implementation of CZIS

CZIS has been implemented for the coastal areas of all the maritime states and union territories. The details are discussed below.

Gujarat Coast

Gujarat is a major maritime State of India. It has about 1600 km long Coastline. There are number of activities going on and coming up all along the coast such as salt industries, cement industries, oil & natural gas exploration, brackish water aquaculture, load on harbours due to expanding import-export trade and so on, besides the pressure of growing population. This puts a tremendous pressure on the coastal zone and hence necessitates a proper scientific method for developmental planning to sustain the environment. Initially, a Coastal Zone Information System (CZIS), Gujarat was developed in the year 2000 in collaboration with Department of Forests & Environment, Government of Gujarat, and Gandhinagar. It was having 244 land use maps

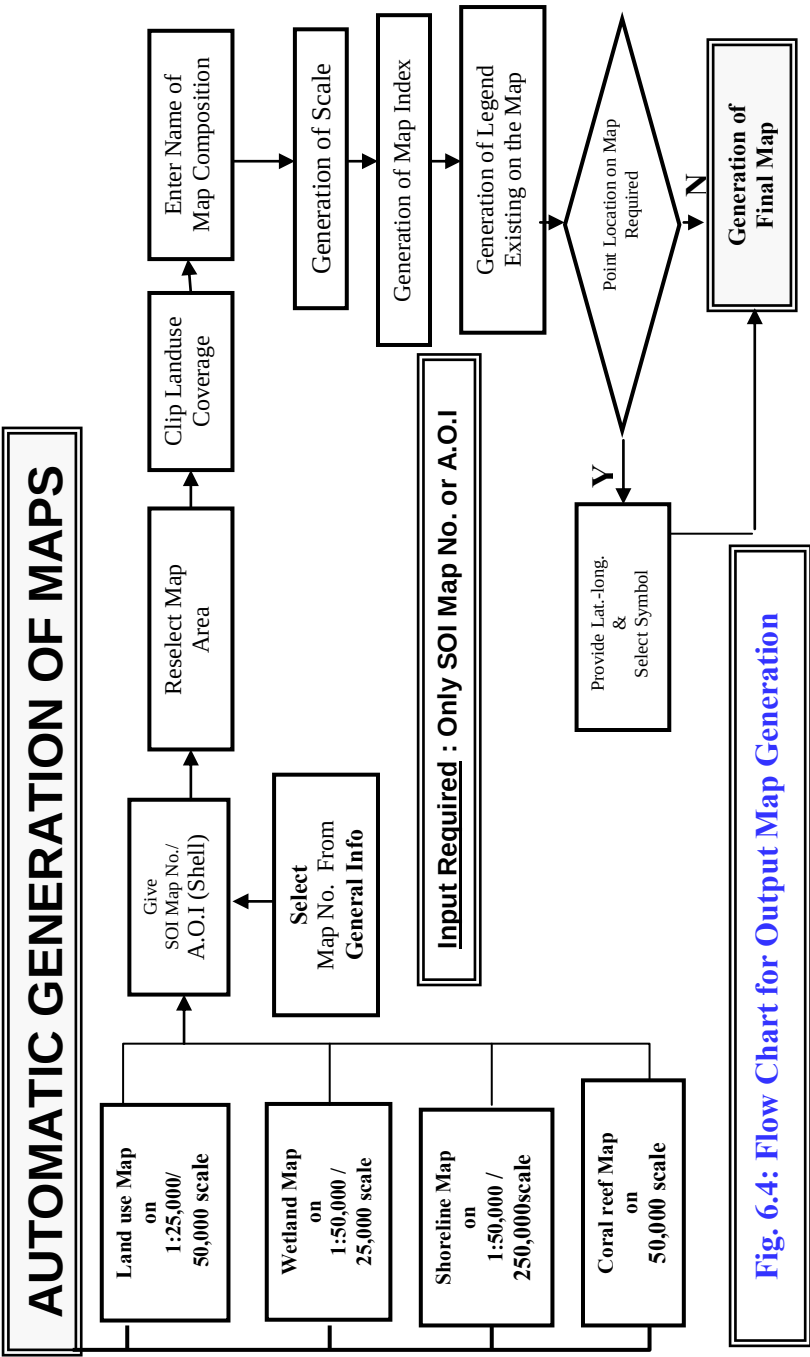


Fig. 6.4: Flow Chart for Output Map Generation

prepared for CRZ using IRS LISS-II and SPOT data of 1988-1989, along with administrative boundaries, transport, high water line, low water line etc., on 1:25,000 scale to cover the entire Gujarat coast. The database for other themes landuse (1:50,000 scale), wetland (1:50,000 and 1:250,000 Scale), shoreline (1:50,000 scale) and coral reefs (1:50,000 scale) are also created as per standard in the CZIS-India funded. Plate 6.1 shows landuse map for CRZ prepared on 1:25,000 scale for the entire Gujarat State. Taking only selected maps, example of wetland map prepared for SOI toposheet 46C (from 1:250,000 scale database) is shown as Plate 6.2. Plate 6.3 shows shoreline map of selected A.O.I using 1:250,000 database.

Orissa Coast

The coastal track of Orissa extends over 480 km. It is mainly depositional in nature, formed by the Mahanadi and the Brahmani-Baitarani deltas. The coast houses some of the excellent mangroves. The coast is endowed with six major estuaries, rich mangrove forests, Asia's largest brackish water lagoon (Chilka lake), extensive mudflats, sandy beaches etc. The Chilka lake supports many commercial and recreational activities. The tidal mark as per the SOI (Survey of India) goes to a maximum of 53 km in the distributaries for olive ridley sea turtle. Two rare species of hoarse-shoe crabs also occur in abundance in the northern Orissa coast. The area between Chilka mouth to Paradeep is characterized by Casurina plantations and agricultural area. The picturesque sandy beach of Puri is a tourist attraction. The Chilka lake has a long (~ 65 km) spit. The lake is bordered by agricultural fields, swams and rocky area. The lake houses a bird sanctuary named 'Nalabana'. The Chilka mouth is a spawning and nursery ground for many fish and prawn species. CZIS of Orissa consists database of landuse on 1:25,000 & 1:50,000 scale, wetland on 1:50,000 & 1:250,000 and shoreline on 1:50,000 & 250,000 scale. Plate 6.4 shows entire Orissa coastal area comprising 87 CRZ maps for landuse on 1:25,000 scale. An enlarged view of an A.O.I (Area of Interest selected in Plate 6.4) with a composite of SOI toposheet grid, map numbers, transport and administrative boundaries is shown in Plate 6.5. This shows the integration of different associated themes built in 'Gen Info' menu of CZIS. Plate 6.6 shows exact aerial extent of different selected landuse categories of entire Orissa in sq. kms

built in 'Theme Info' menu of CZIS. Plate 6.7 shows the wetland map of SOI toposheet 73L prepared from 1:25,000 database.

Maharashtra Coast

The Maharashtra coast is characterized by pocket beaches flanked by rocky cliffs of Deccan basalt, many estuaries and patches of mangroves. Large areas have been reclaimed from mudflats for agriculture, industrial, residential and aquaculture use mainly in Bombay and Thane region. The agricultural activity dominates in the coastal zone of Maharashtra that mainly consists of coconut, mango and jack-fruits. There are many small islands mainly in estuaries (muddy) and off the coast (rocky). CZIS of Maharashtra consists database of landuse on 1:25,000 & 1:50,000 scale, wetland on 1:50,000 & 1:250,000 and shoreline on 1:50,000 & 250,000 scale. As an example wetland map prepared from 1:50,000 scale database for SOI selected A.O.I is shown as Plate 6.8.

Goa Coast

The Goa coast is about 120 km long. It has long, linear and wide beaches and rocky cliffs. It is indented by estuaries and narrow creeks. Mangroves occur in the sheltered areas of the inter tidal zone of the estuaries. The coastal strip represents a gently rolling type of topography. CZIS of Goa consists database of landuse on 1:25,000 & 1:50,000 scale, wetland on 1:50,000 & 1:250,000 and shoreline on 1:50,000 & 250,000 scale. Taking only selected maps, example of coastal landuse map prepared from 1:50,000 scale database for SOI toposheet 48E14 is shown as Plate 6.9. Plate 6.10 shows the shoreline map of selected A.O.I prepared using database of 1:50,000 scale.

Karnataka Coast

The Karnataka coast is about 300 km long. The coastal zone is narrow and straight except around estuaries. It has long, narrow and straight beaches as well as small crescent shaped pocket beaches intercepted by rocky headlands, spectacular spits, estuaries, shallow lagoons, mudflats and few patches of mangroves. The northern coast is rocky while the southern coast has long linear beaches. Mangroves (*Rhizophora* and *Avicennia*) are found in tidal

waters, near estuaries and along the confluence of estuaries in coastal areas. Rocky coast is present in the Uttara Kannada district. The major part of the Coastal Regulation Zone area comes under agricultural land which mainly includes paddy and vegetables. CZIS of Karnataka consists database of landuse on 1:25,000 & 1:50,000 scale, wetland on 1:50,000 & 1:250,000 and shoreline on 1:50,000 scale. As an example coastal landuse map prepared from 1:25,000 scale database for SOI toposheet 48J01SE is shown as Plate 6.11.

Kerala Coast

The Kerala coast is about 590 km long. It is famous for its beautiful beaches, estuaries and lagoon. The coastline is more or less linear, at places it is offsetted by the presence of promontories. The coastal zone has high population density that makes an adverse impact on the areal distribution of different wetlands. This also creates problems such as erosion, sand mining and effluent disposal. The mangrove vegetation has become sparse. Land reclamation has taken up for urbanization and agriculture. CZIS of Kerala consists database of landuse on 1:25,000 & 1:50,000 scale, wetland on 1:50,000 & 1:250,000 and shoreline on 1:50,000 & 250,000 scale. As an example landuse map prepared from 1:50,000 scale database for selected A.O.I is shown as Plate 6.12.

Tamil Nadu Coast

The coastline of Tamil Nadu is about 900 km long. Increase in population exert pressure on the coastal zone by way of commercial and industrial exploitation. The pressures on urban areas have increased a lateral migration of population, concentrating more towards coastal zone. Pulicat is the large lagoon which supports variety of plants and animals. Fringing reef and patch reefs are present near Rameswaram (Palk bay) and in the Gulf of Mannar. Well developed mangroves forest occurs at Pichavaram. Mudflats are present along lagoons and used at some places for salt harvesting. CZIS of Tamil Nadu consists database of landuse on 1:25,000 & 1:50,000 scale, wetland on 1:50,000 & 1:250,000, shoreline on 1:50,000 and coral reef on 1:50,000 scale. Taking only selected maps, example of landuse map prepared from 1:25,000

scale database for SOI toposheet 58N14SW is shown as Plate 6.13. Plate 6.14 shows wetland map for selected A.O.I using 1:50,000 database.

Andhra Pradesh Coast

The Andhra Pradesh coast is about 1035 km long. It extends from Srikakulam district in the north to Nellore district in the south. It is marked by spits, wide beaches, mangroves and tidal flats. The coastal zone is potentially a rich terrain in agriculture, fisheries, commerce and communication. There are a number of intermediate and small ports including a natural harbour at Vishakhapatnam. The prominent rivers viz. the Krishna and the Godavari form large deltaic regions. Both these deltas have large mangrove forests. CZIS of Andhra Pradesh consists database of landuse on 1:25,000 & 1:50,000 scale, wetland on 1:50,000 & 1:250,000 and shoreline on 1:50,000 & 250,000 scale. As an example, landuse map prepared from 1:250,000 scale database for selected A.O.I is shown as Plate 6.15.

West Bengal Coast

The West Bengal coast is famous for its mangroves. The mangroves mainly exist in the Sunderbans area which is largest single block of halophytic mangroves of the world. These are in the form of dense forest along the east and the south east part of the coast. Mudflats are found all along the coast of West Bengal. Aquaculture ponds are found near Digba, Junput, Manasdwip, Pathankhali etc. The salt pans are found in the western parts of the coast near Phulbari, Kalindi, north of Dadanpatra etc. Beaches are present in the western parts of the coast. Agricultural areas are distributed all along the coast. The main crop is paddy. Plantations are mainly present along south east coast. They are mainly Casurina over dunes. The Hooghly and its distributaries form the most conspicuous drainage system and forms an estuarine delta. CZIS of West Bengal consists database of landuse on 1:25,000 & 1:50,000 scale, wetland on 1:50,000 and shoreline on 1:50,000 scale. As an example, landuse map prepared from 1:25,000 scale database for SOI toposheet 79C05SW is shown as Plate 6.16.

Andaman & Nicobar Islands

The Andaman and Nicobar Islands is a group of islands (approximately 572) in the Bay of Bengal which include islets, rock outcrops and coral reefs. These islands are endowed with a great deal of natural beauty. Their flora and fauna are of a special type, having very high degree of bio-diversity and endemism. The coral reefs of these islands are among the richest in the Indian Sub-continent, which not only protects the coastline against the sea erosion but also harbour host of animal communities. However, there have been significant changes in the islands during the last few decades. The natural resources of the islands have been increasingly exploited. Increased forest extraction, development of tourism, setting up of colonies for settlers are some of the activities which have lead to a great deal of apprehensions that these unique and fragile island ecosystems would be irreversibly degraded. CZIS of Andaman & Nicobar consists database of landuse on 1:25,000 & 1:50,000 scale, wetland on 1:50,000 & 1:250,000 and coral reef on 1:50,000 scale. CZIS for landuse on 1:25,000 & 1:50,000 scale and coral reef on 1:50,000 scale have been already created (Gupta M.C et. al, Scientific Notes 2003). Coastal wetland map of Andaman prepared from 1:50,000 scale database for SOI toposheet 87A10 is shown as Plate 6.17. Plate 6.18 shows wetland map of Nicobar prepared from 1:250,000 scale database for a selected A.O.I.

Lakshadweep Islands

The Lakshadweep, the Union Territory of India, in the Arabian sea have in all 36 islands. Of these, the ten islands are inhabited viz. Agatti, Amini, Andrott, Bitra, Chetlat, Kadmatta, Kalpeni, Kavaratti, Kilton and Minicoy. It consists 3 coral reefs, 12 atolls and 6 submerged sand banks. The total geographical land area is about 32 sq. km with around 26 sq. km as usable land area. Kavaratti is the headquarter of the Administration since 1964. The Lakshadweep islands are made up of coral boulders weather into fine white sand. They are flat and only a few meters above the high tide mark. The islands have lagoons (about 4000 sq. km area) and atoll reefs. The beauty of the so called coral islands and their biological diversity needs to be preserved. Developmental activities like tourism, construction of houses to meet pressure of increasing population etc. may lead to irreversible degradation of these unique and fragile islands. To

preserve these islands, there is a need to have an Information System which can help in providing necessary and timely information for their monitoring and effective management. CZIS of Lakshadweep consists database of wetland on 1:250,000 and coral reef on 1:50,000. CZIS for coral reef on 1:50,000 scale has been already created (Gupta M.C et. al, Scientific Notes 2006). Wetland map prepared from 1:250,000 scale database for SOI selected A.O.I is shown as Plate 6.19.

Coastal Zone Information System for entire India (ZIS-India) has been developed to include and update all the coastal information viz. landuse, wetland, shoreline, coral reef etc. for all maritime states including Union Territories in GIS environment. It is a powerful system which is fully capable of

- a) To retrieve all the information of database of all Indian maritime states in a user friendly manner,
- b) To generate category wise land use, wetland, shoreline and coral reef maps / information for an area of entire state or Union Territory or a SOI toposheet on 1:25,000, 1:50,000 and 1:250,000 scale and
- d) To create final map outputs by providing only SOI toposheet number (obtained from General Info) as an input.

The criteria provided by MoEF (CRZ notification 2011) can be used for generating CRZ information which in turn can provide zoning of coastal area into different zones (CRZ-I, II, III and IV). The information can be used for taking decision to allow permitted activities and / or to impose certain restrictions on setting up and expansions of industries, operations and processes into the coastal zone. Thus CZIS-India can provide an effective Coastal Zone Management Planning System for sustainable development in the coastal area due to its wide information retrieval capability along with generation of varied information and automatic map outputs. This will not only guide for development of various activities such as industries, tourism, setting up of harbour or jetties all along the coast but also in proper utilization of

coastal resources to avoid any adverse effect or damage to the coastal ecosystem. Being developed around ARC/INFO, it has the capability of timely updating the data as well as creating multi-temporal and multi-thematic data so as to monitor various activities in the coastal areas e.g. status of critical habitats (such as mangroves, corals etc.), wetlands, national parks, sanctuaries, progress of developmental projects, identifying and checking violations etc.

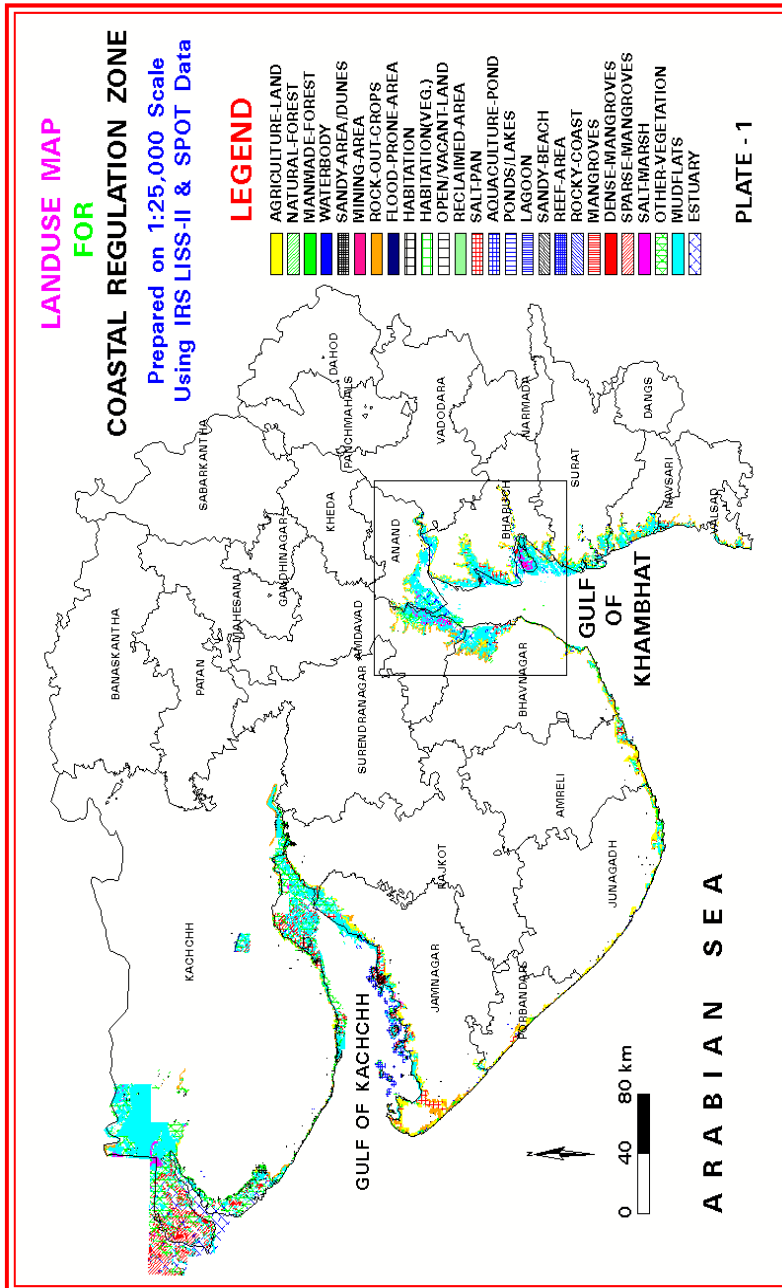


Plate 6.1: Coastal land use map, Gujarat

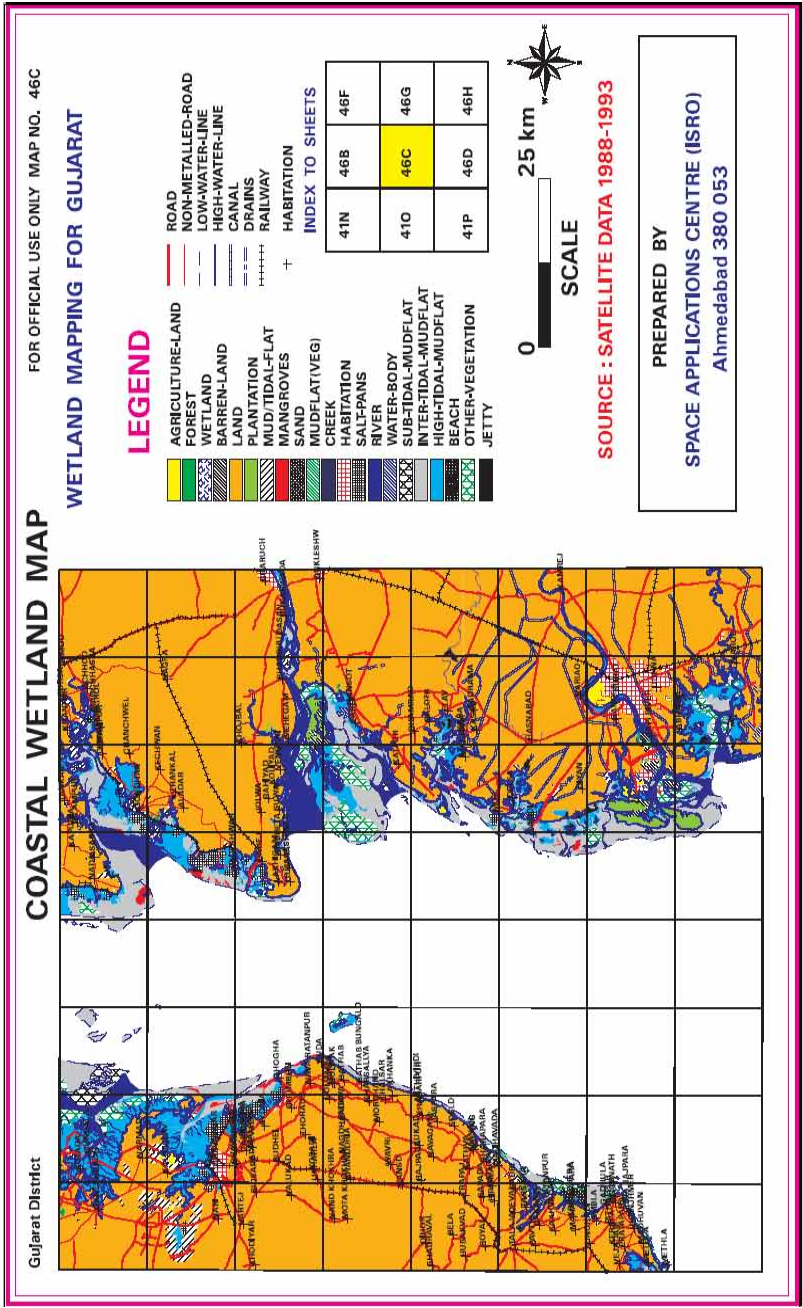


Plate 6.2: Wetland map (46 C), Gujarat

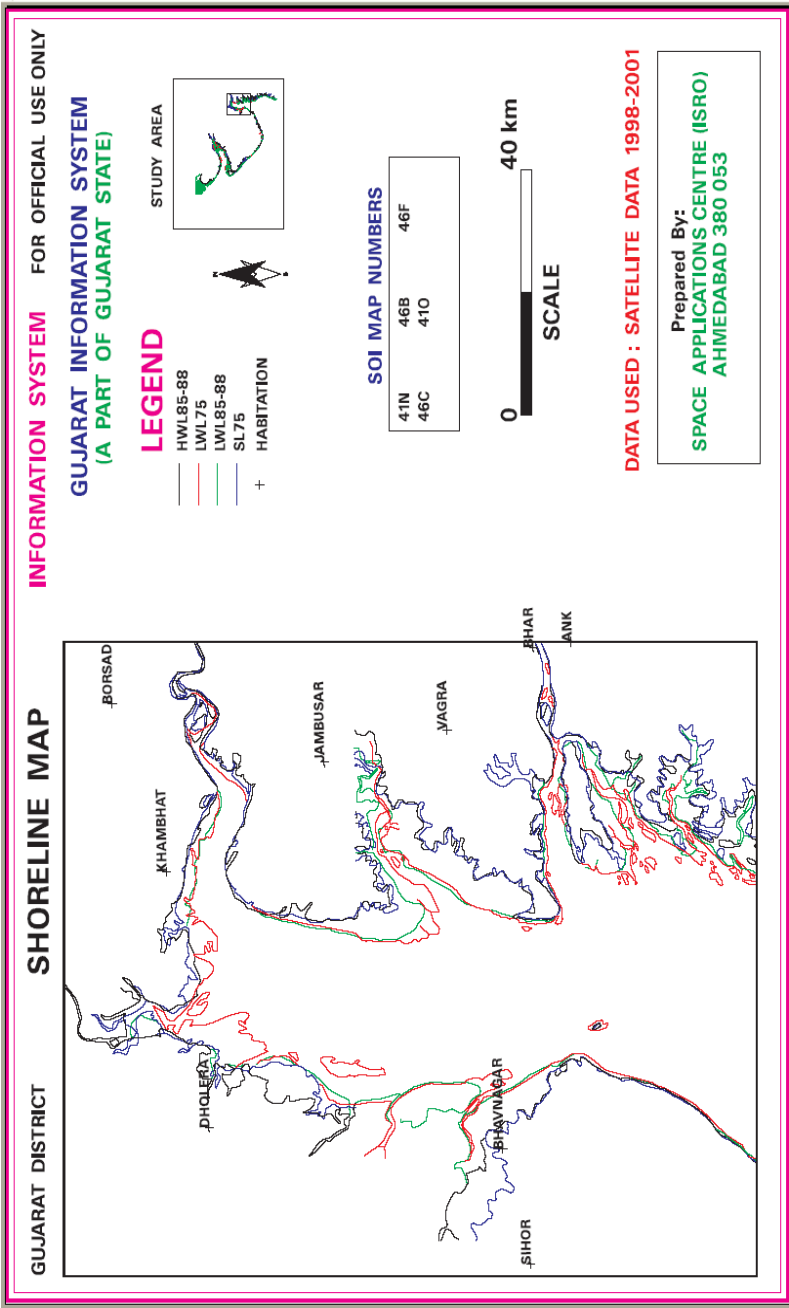


Plate 6.3: Shore line map, Gujarat

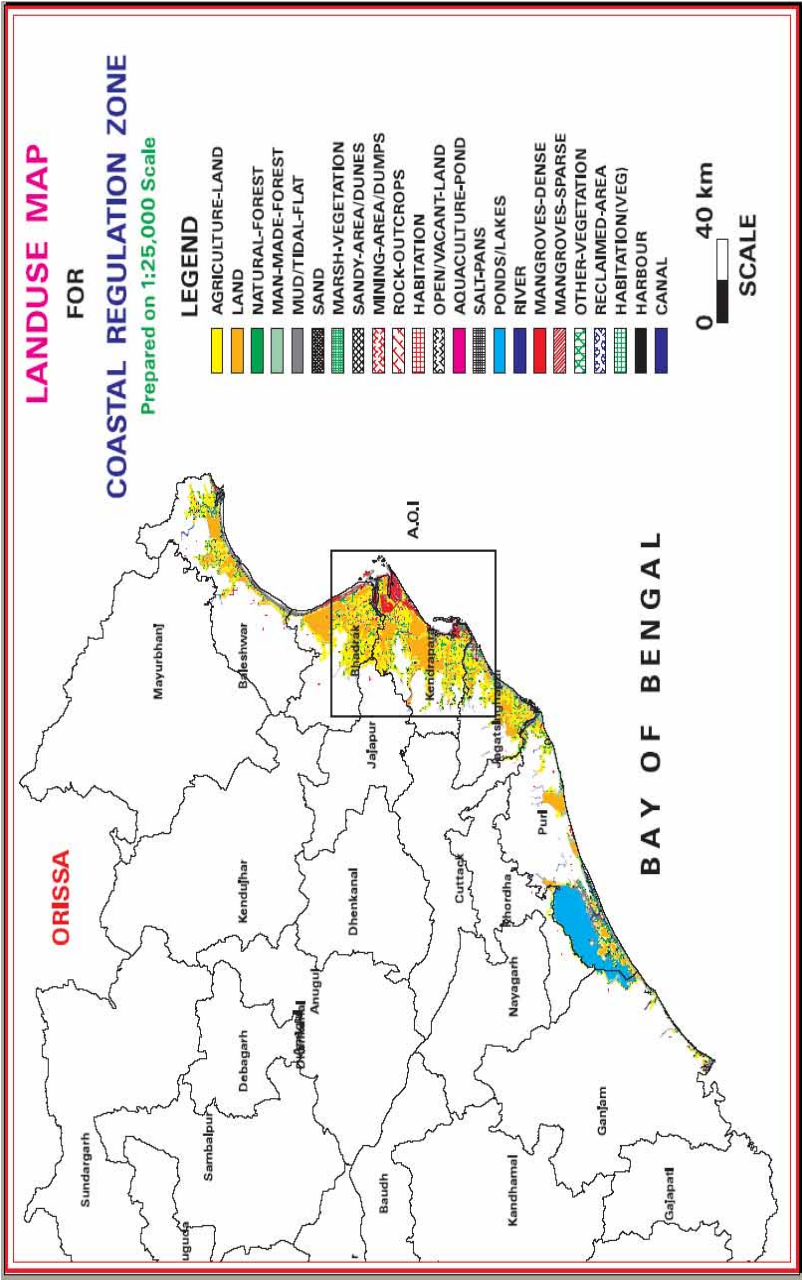


Plate 6.4: Coastal land use map, Orissa

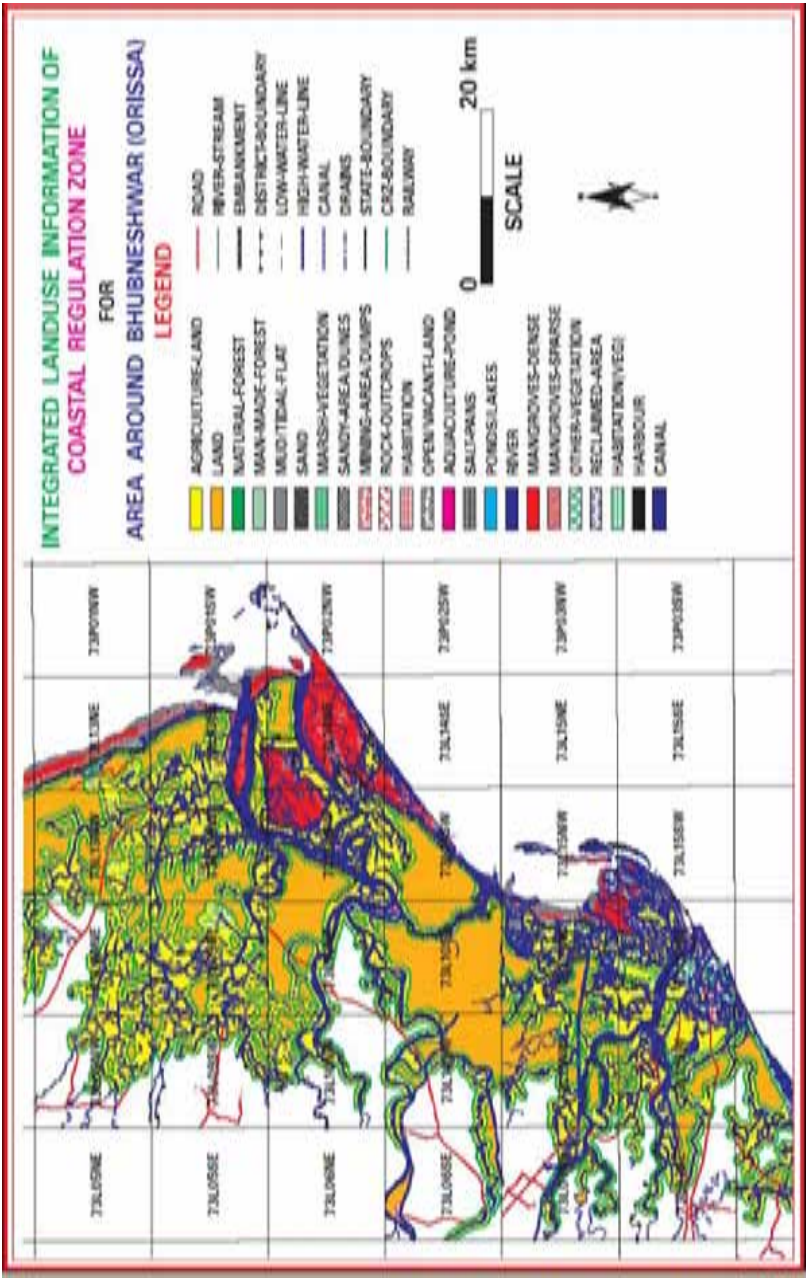


Plate 6.5: Coastal land use map, part of Orissa

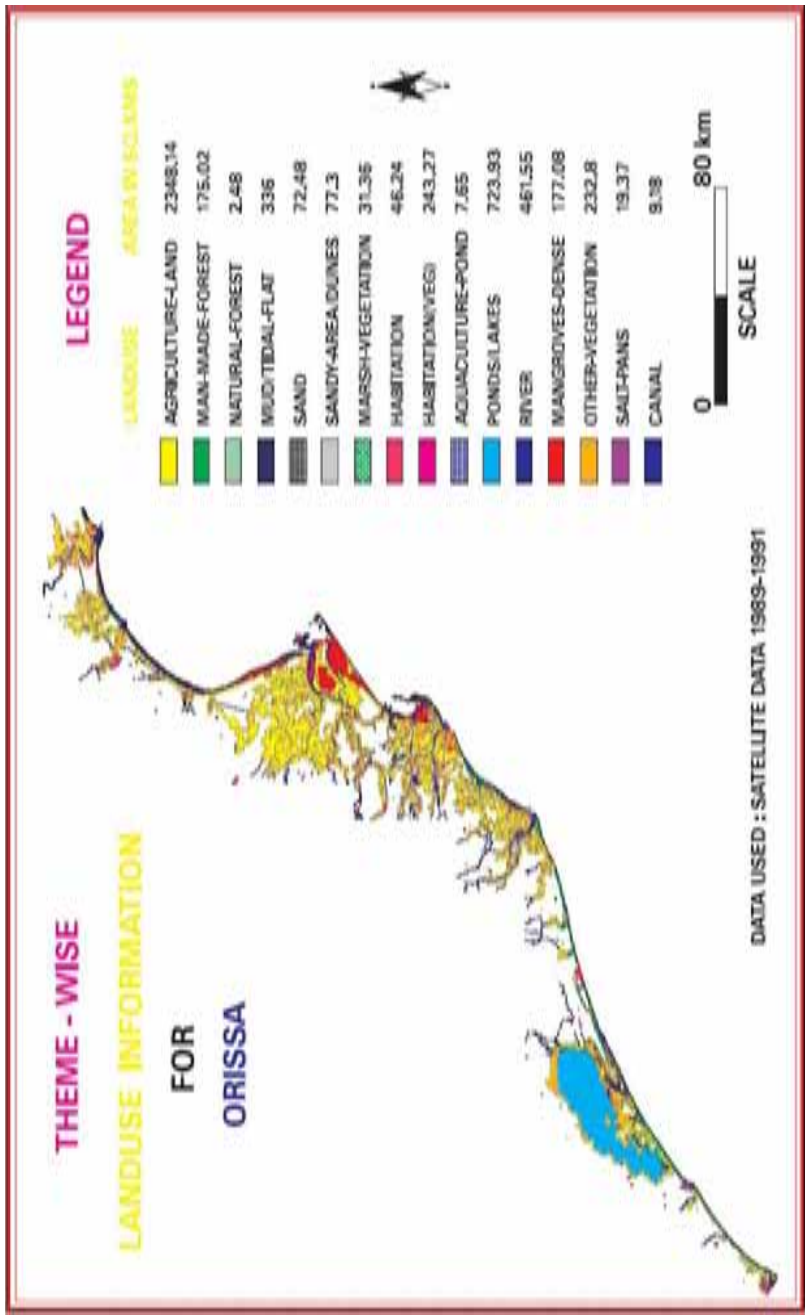


Plate 6.6: Coastal land use, Orissa

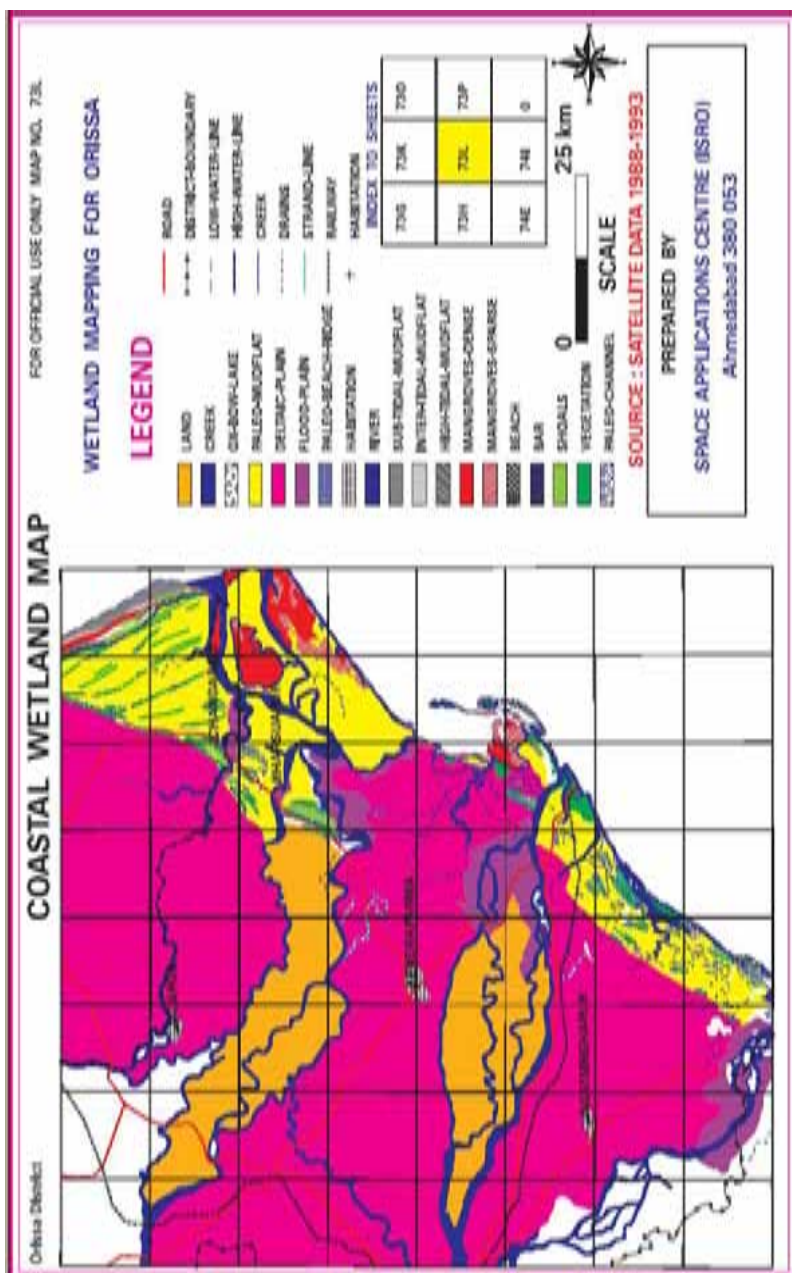


Plate 6.7: Coastal wetland map (73 L) Orissa

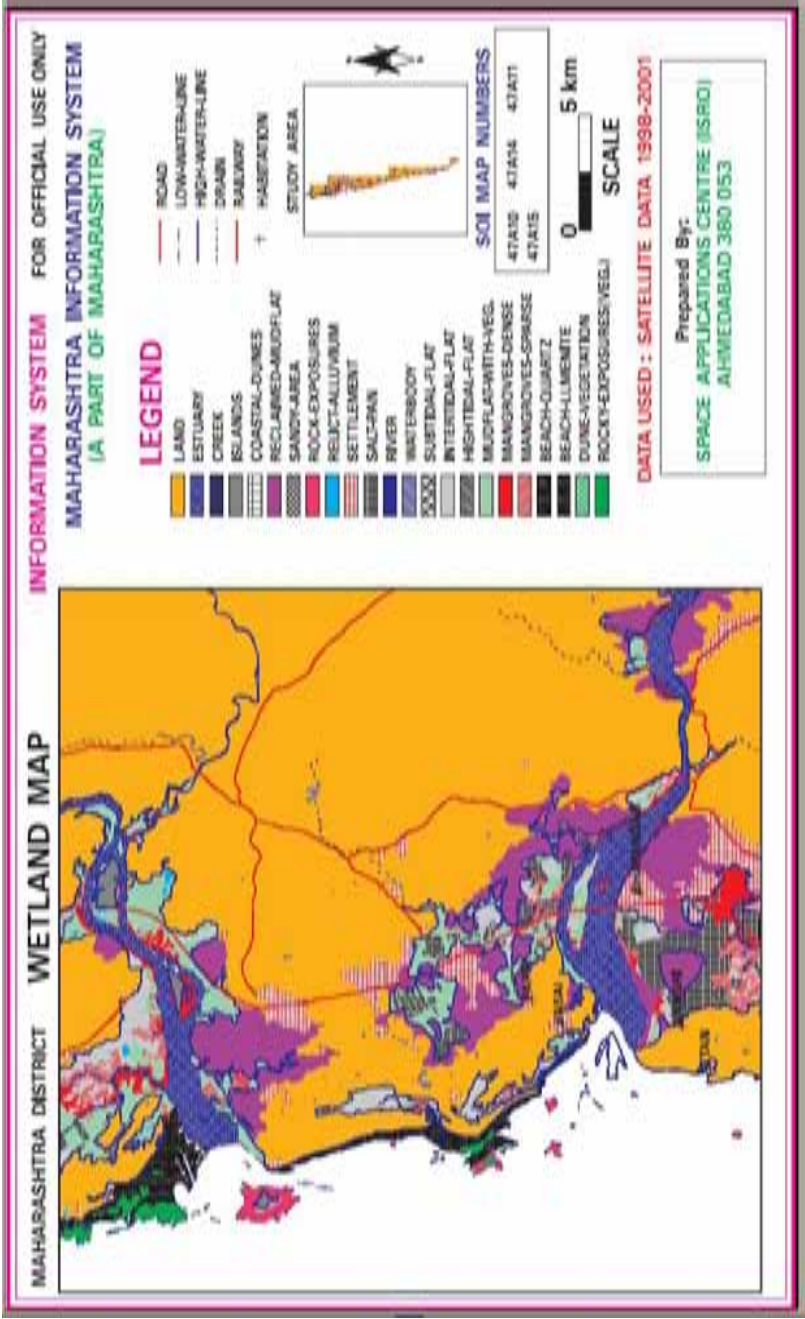


Plate 6.8: Coastal wetland map, Maharashtra

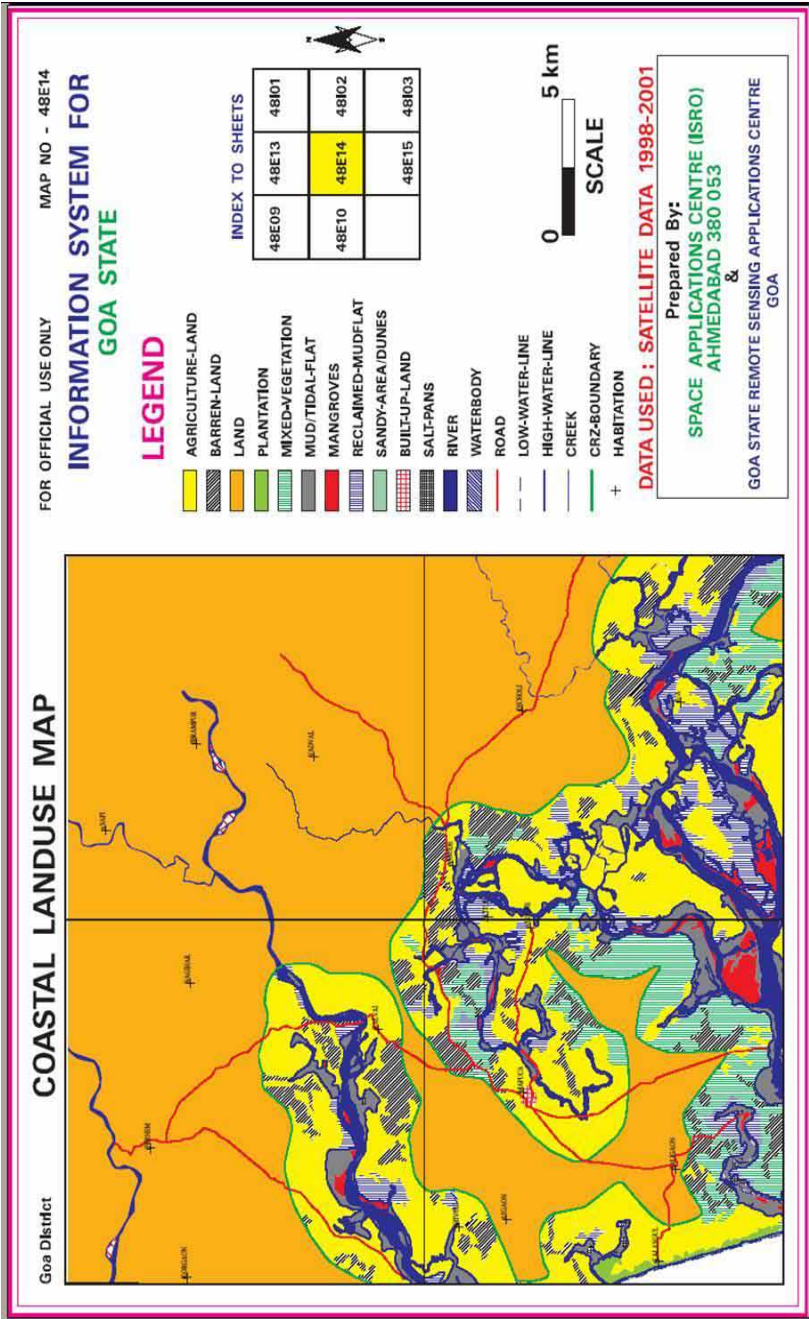


Plate 6.9: Coastal land use map, Goa

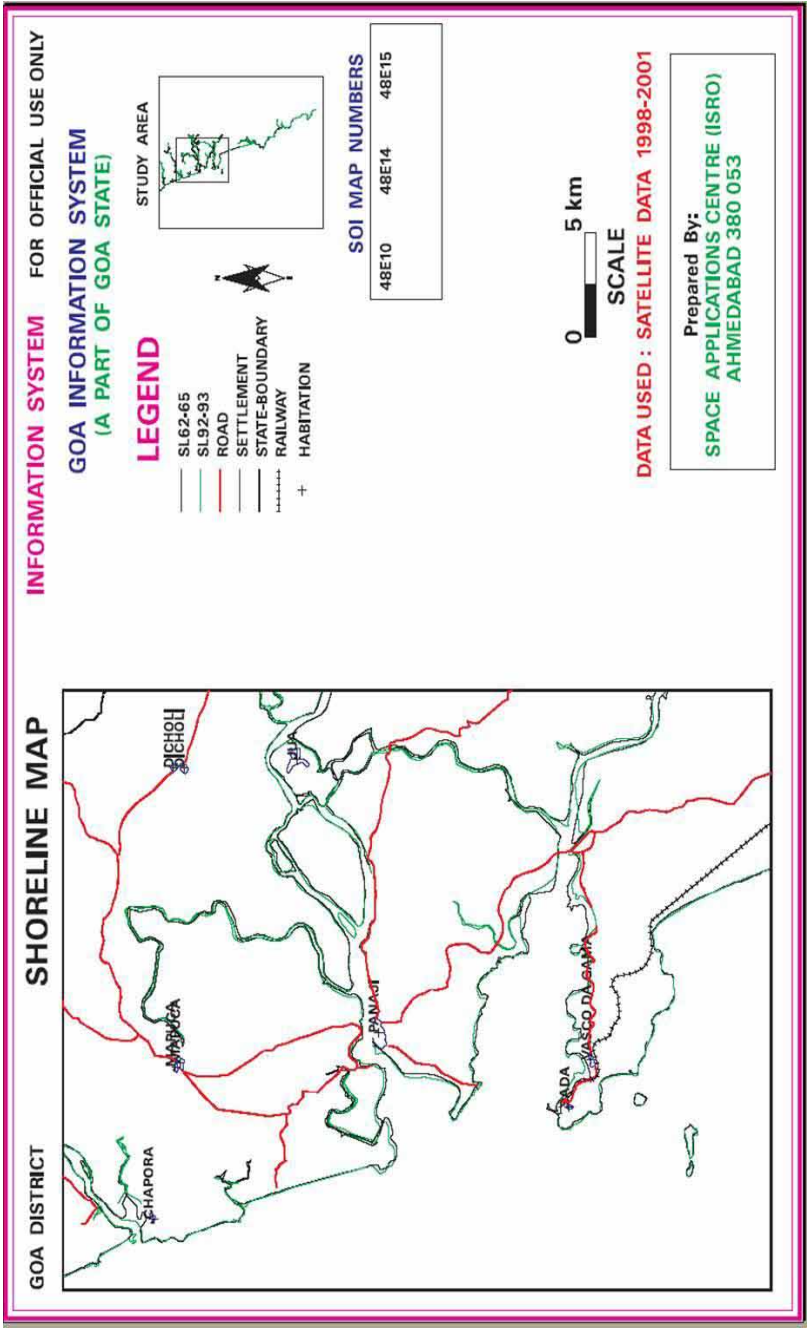


Plate 6.10: Shore line map, Goa

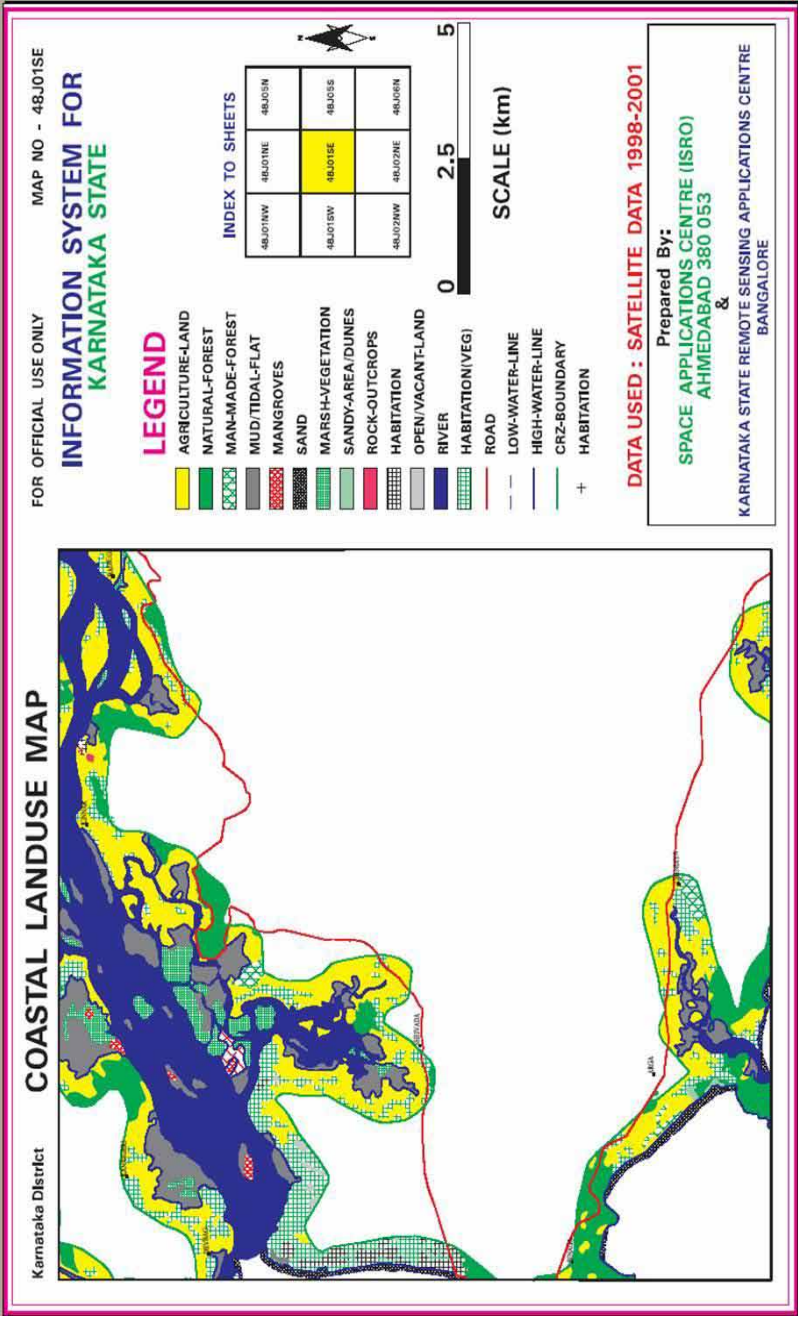


Plate 6.11: Coastal land use map, Karnataka

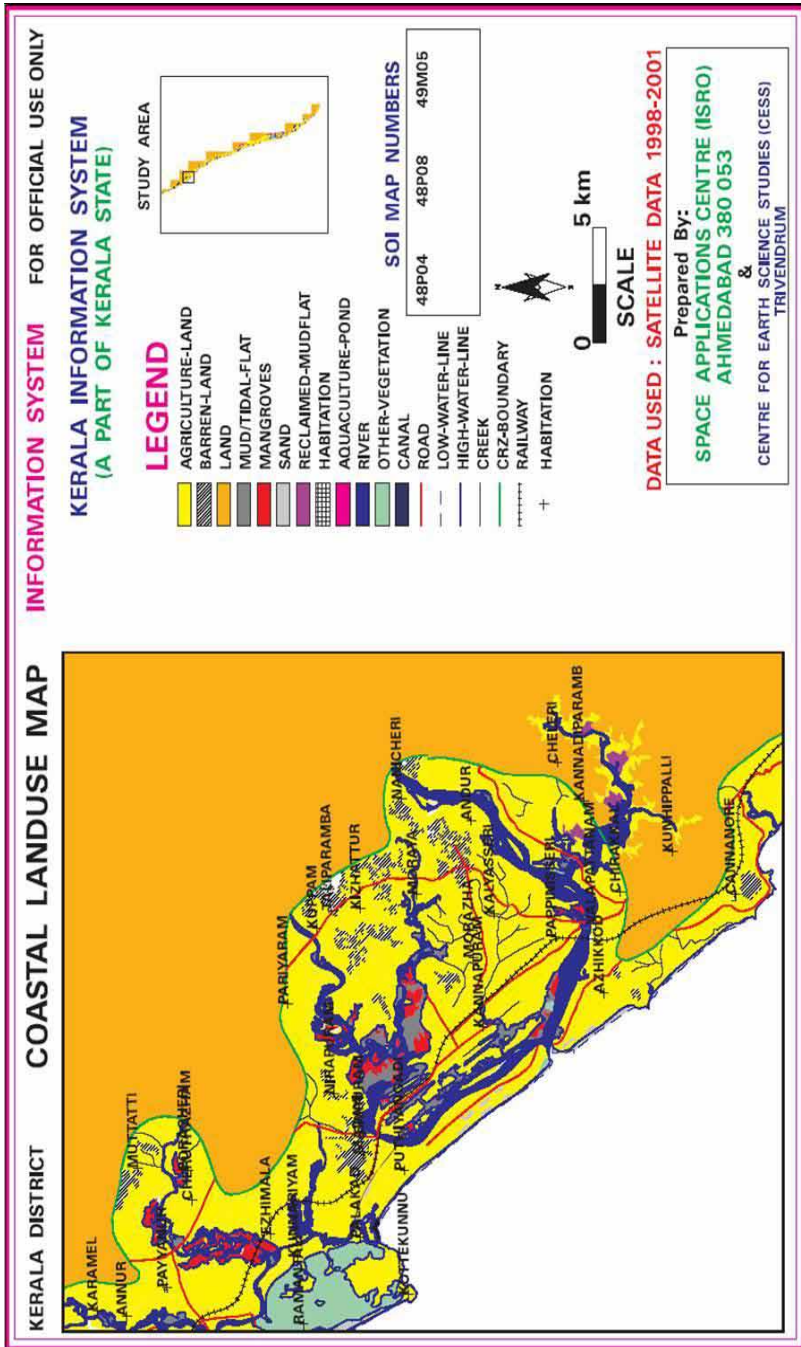


Plate 6.12: Coastal land use map, Keraka

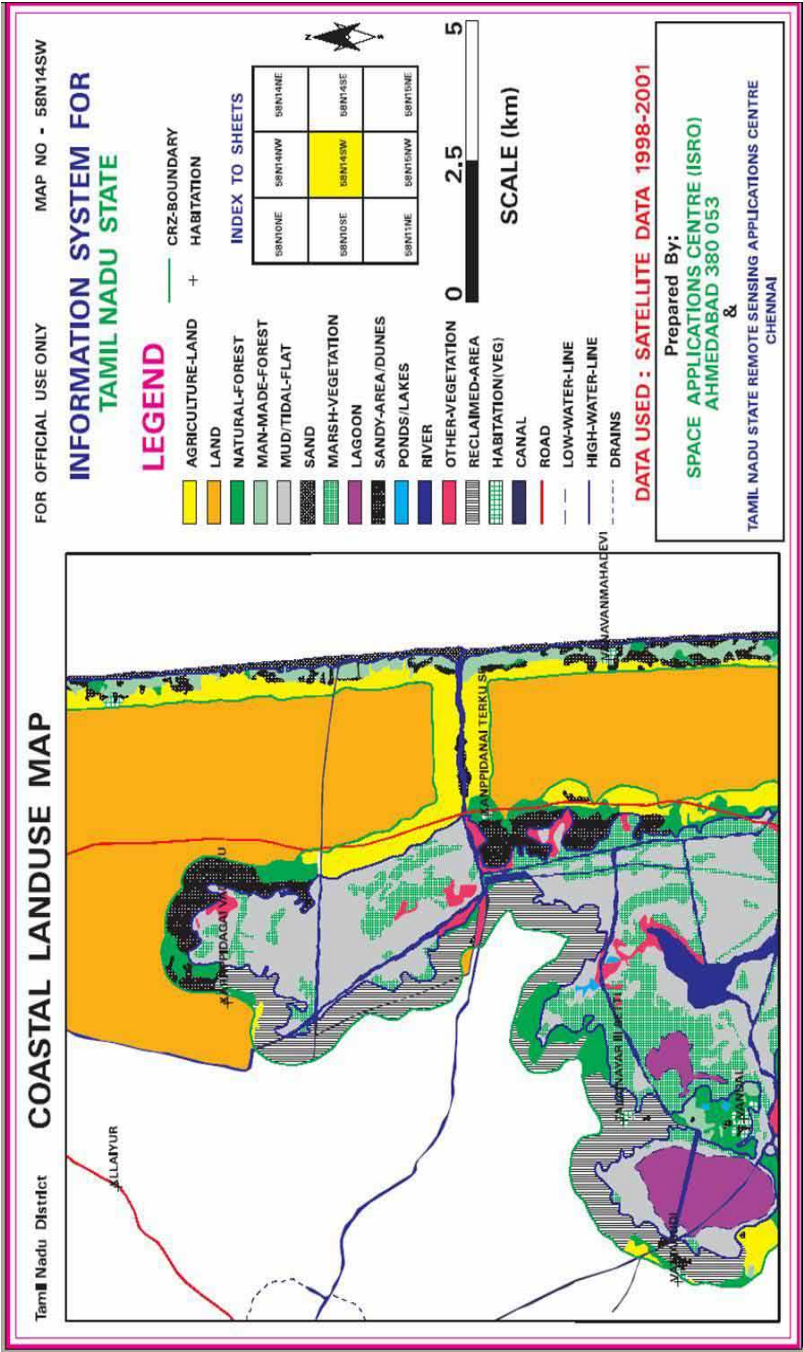


Plate 6.13: Coastal land use map, Tamilnadu

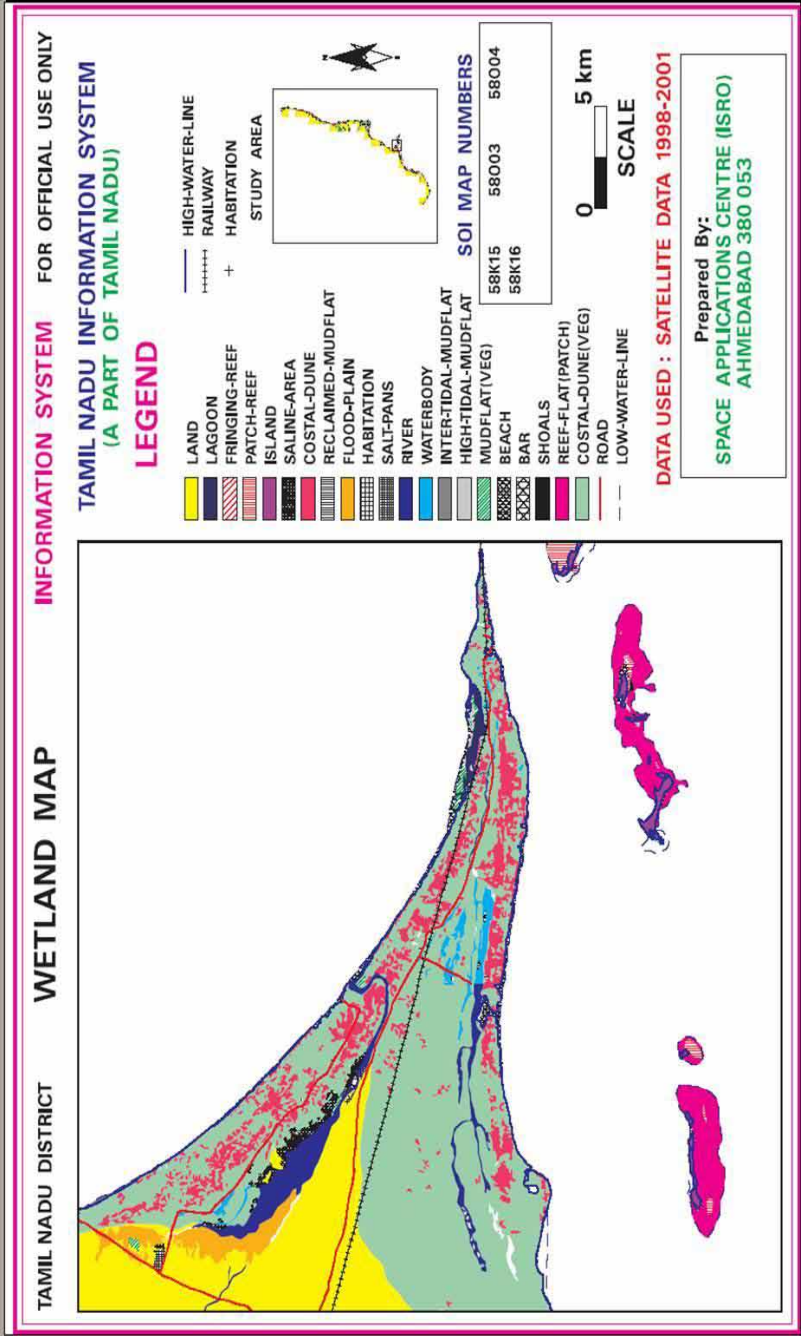


Plate 6.14: Coastal wetland map, Tamilnadu

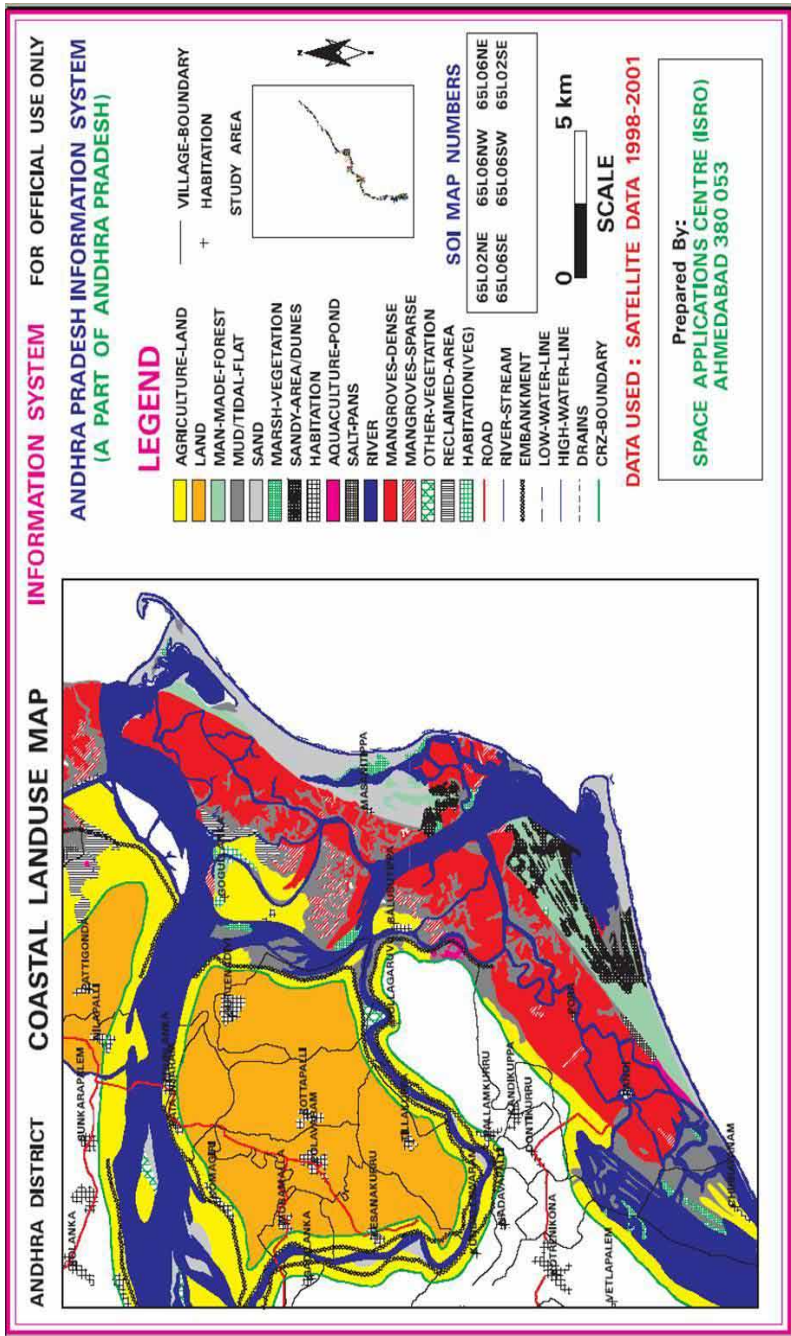


Plate 6.15: Coastal land use map, Andhra Pradesh

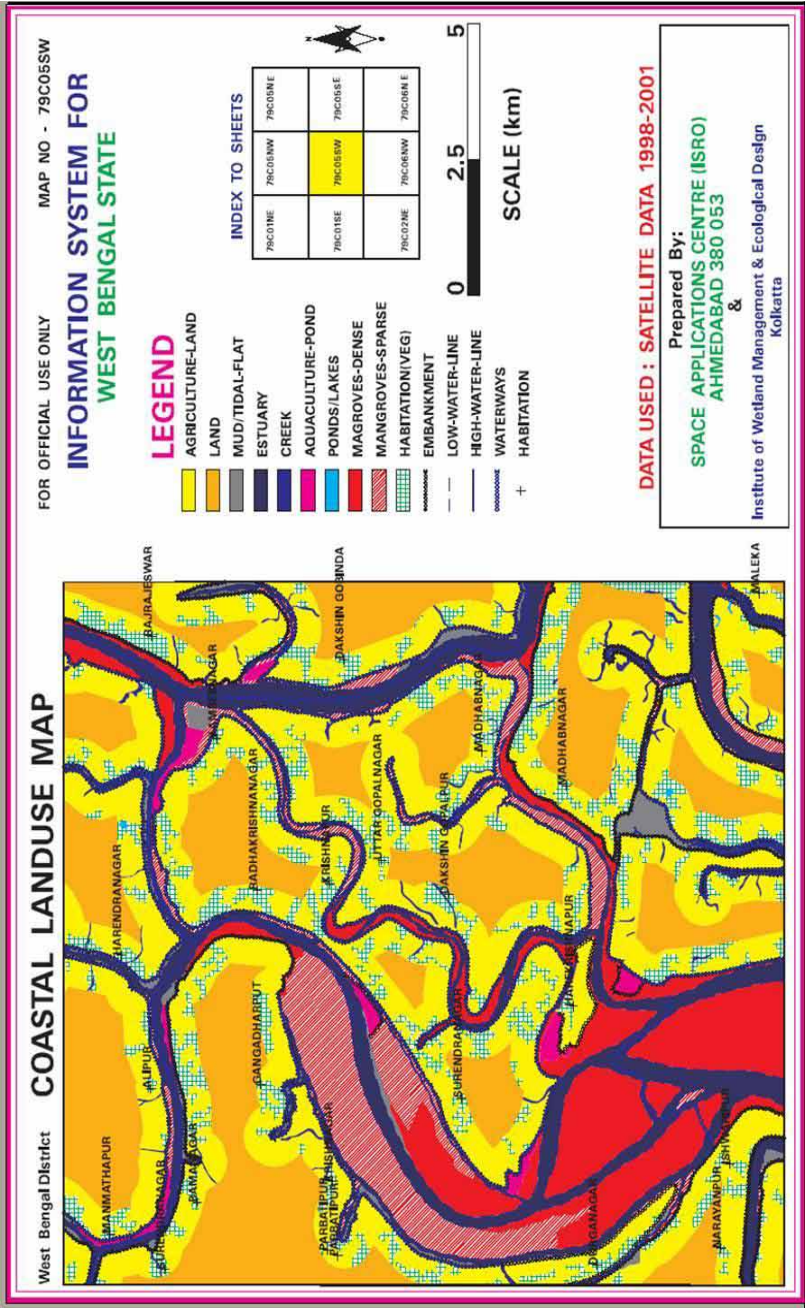


Plate 6.16: Coastal Land use map, West Bengal

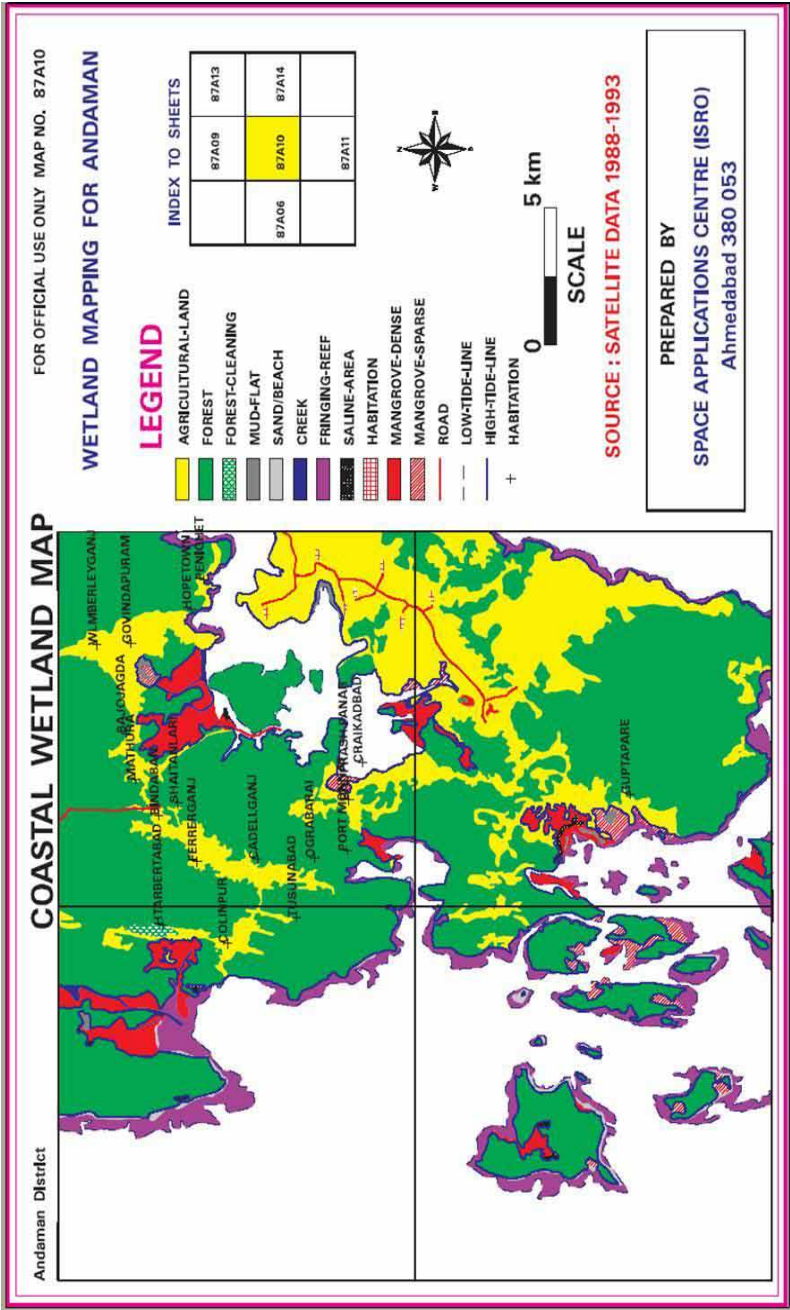
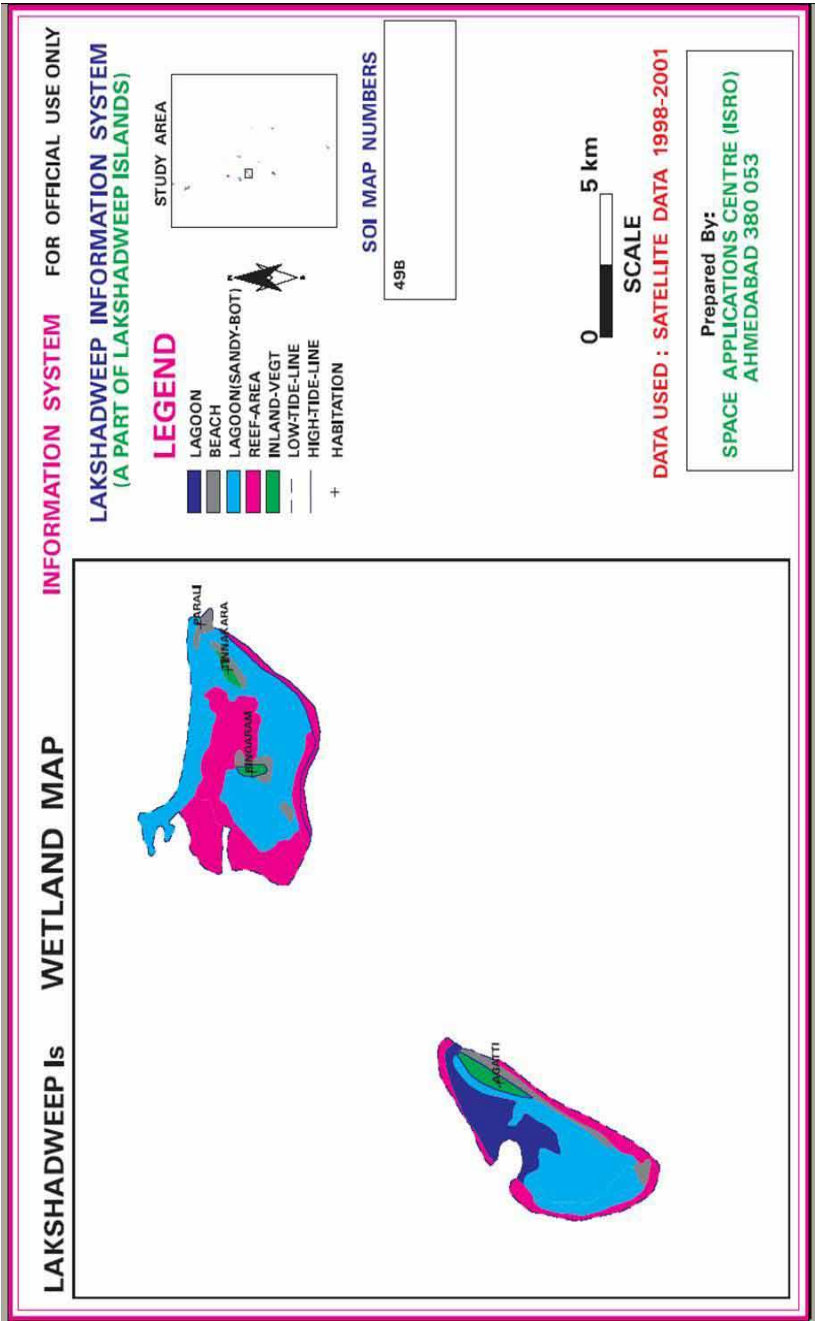


Plate 6.17: Coastal Wetland map, Andaman



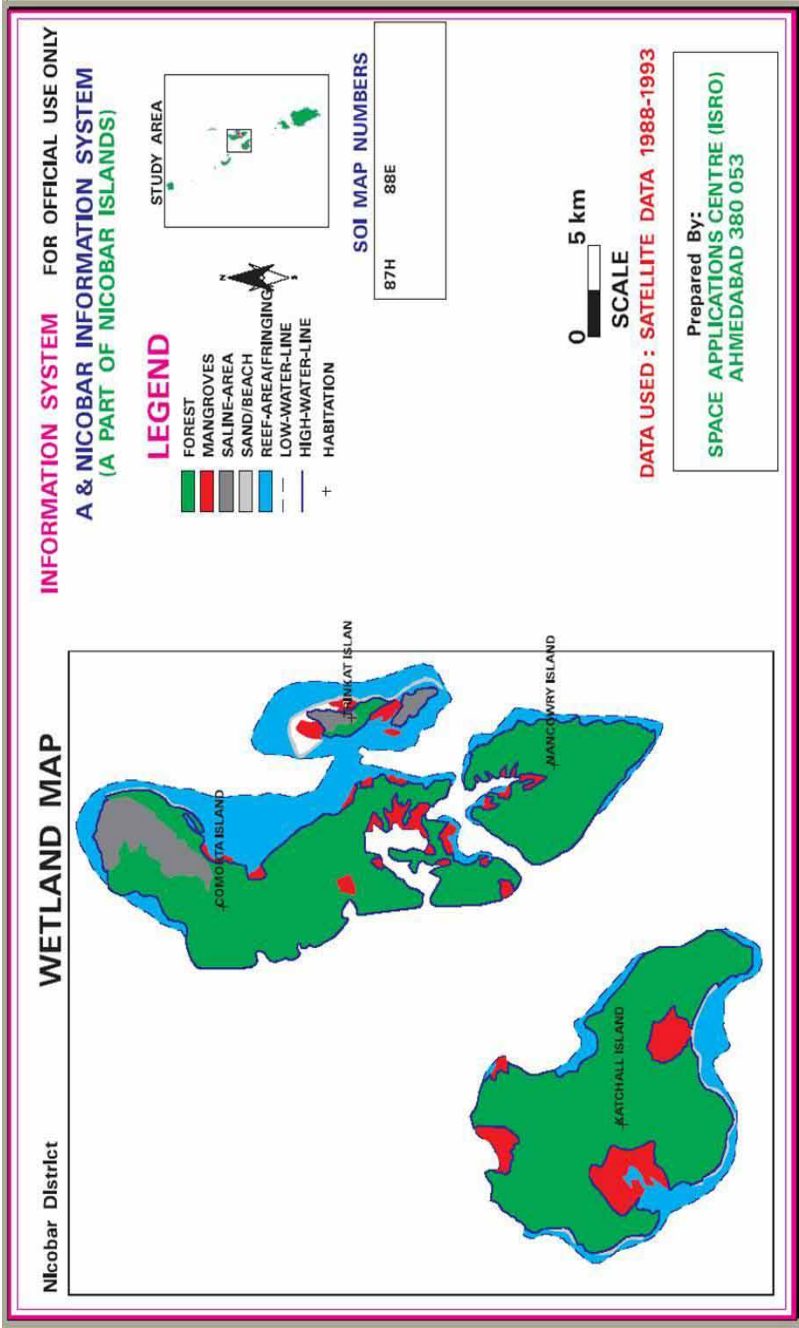


Plate 6.19: Coastal Wetland map, Nicobar Islands

7. Coastal Processes- Impact of Sea Level Rise

The land-ocean interaction in the coastal zone produces a complex range of landforms and organisms which evolve special forms of adaptation. The operating range of coastal processes is very narrow both in height and width within 10 m above or below the mean sea level and a few kilometers landward and seaward of the shoreline. Yet these narrow zones are the foci of intense economic activity in terms of agriculture, aquaculture, industry, transport, and tourism owing to their rich resource base and esthetic appeal. Therefore, no wonder the coastal zones are the densely populated regions of the world. Although constitute just about 10% of the land, the coastal zones sustain about 60% of the world's population. However, owing to their low-lying nature and extremely gentle gradients, the coastal regions are highly vulnerable to storm surges, tsunamis and inland floods. Of late, the anthropogenic forcing – both directly and indirectly became a major threat to the sustainability of these fragile environments. Urbanization and industrialization of the coastal zones and the associated chemical pollution, besides construction of seawalls, harbor structures like jetties, groins and breakwaters are degrading the coasts. In addition to these direct impacts, human activities even far inland such as construction of dams across rivers, which prevent freshwater and sediment from reaching the coastal zones are indirectly affecting the coastal environments. Above all, the much touted global warming under anthropogenic forcing is leading to serious consequences in the coastal regions and habitats all over the world. The global average temperature has increased by 0.8°C over the past century, out of which the past three decades alone recorded a rise of 0.6°C, at the rate of 0.2°C per decade as greenhouse gases became the dominant climate forcing in recent decades (Hansen et al. 2006; IPCC 2007; Rosenzweig et al. 2008; Wood 2008). Arctic ice sheet is rapidly retreating and if this trend continues, scientists fear that the polar bear population would decrease by two-thirds by mid-century. Recent studies indicated that the climate warming has resulted in a significant upward shift in the forest plant species optimum elevation averaging 29 m per decade (Lenoir et al. 2008).

The most direct impact of the sea-level rise is on the coastal zones around the world. Since these narrow zones that fringe the world oceans are low-lying, the sea-level rise would lead to accelerated erosion and shoreline retreat, besides leading to saltwater intrusion into coastal groundwater aquifers, inundation of wetlands and estuaries, and threatening historic and cultural resources as well as infrastructure (Pendleton et al. 2004).

The impact of the rising sea levels would be variable depending upon the characteristics of the coast such as geomorphology and slope and the variability of marine processes such as waves and tides along the coast. The significance of coastal geomorphology and coastal slope as the two most important factors in the response of a coastal zone to sea-level rise was amply demonstrated by the 2004-tsunami that devastated the Indian coasts besides many other nations around Indian Ocean. Several studies made along the east coast of India indicated the role of geomorphology and coastal slope in tsunami impact. It has been observed that the worst affected Nagapattinam area in the southern state of Tamil Nadu along the east coast of India had longer penetration of tsunami inland due to gentle slope of the coastland. The coastal morphology made large difference in loss of life as the low swales behind shore-parallel dune ridges claimed several lives due to lateral flows from tidal inlets or breaches in dune ridges. The overall inundation limit decreased along the shore from south to north in the state of Tamil Nadu, from a maximum of about 800 m in the southern part to about 160 m in the northern parts. However, the tsunami inundation limit has significantly increased again to 700-800m much further northward in the Krishna-Godavari delta region in the central part of AP state, where number of deaths were also reported, owing to extremely gentle slope of the area.

Mapping of coastal landforms, slopes, and the recent changes that occur, therefore assumes greater significance in understanding the coastal response to sea-level rise. Needless to mention, the modern technologies of remote sensing and geographic information system play an important role not only in mapping the various coastal features but also in developing models towards understanding the possible impact of the impending sea-level rise and identifying the vulnerable sectors of the coast, thereby help the coastal management process as a decision-support system.

In order to study the impact of sea level rise on the coastal environment, it is required to first understand the coastal processes and then develop model to carry out regional vulnerability assessment due to predicted sea level rise. The detailed tasks involved are:

- i) Preparation of coastal thematic maps such as geomorphology, shoreline changes, land use-land cover, slope by analyzing Resourcesat-1/Cartosat-1/SRTM data and creation of digital databases.
- ii) Carry out ground truth data collection for finalizing the interpretations, including calibration of SRTM DEM using DGPS.
- iii) Study and understand the coastal processes operating in the study areas through physical variables such as coastal geomorphology, coastal slope, shoreline changes, mean spring tide range, and significant wave height.
- iv) Develop an approach to assess coastal vulnerability due to predicted SLR in GIS environment.
- v) Prepare coastal vulnerability map, providing regional response zonation and identify hotspots
- vi) Carry out detailed SLR impact analysis for selected hot spots.

The details of the coastal processes operating and the coastal vulnerability assessment for the coasts of Andhra Pradesh, Tamilnadu and Gujarat coasts are discussed below.

Andhra Pradesh Coast

The east coast of India bordering the Bay of Bengal is a passive continental margin developed during separation of India from Antarctica in the Late Jurassic (Bastia and Nayak 2006). Administratively, the 2350-km-long east coast forms the eastern seaboard of three States - Orissa in the north, Andhra Pradesh (AP) in the centre, and Tamilnadu in the south. The present study area is the 1030-km-long coast of AP State. The landward limit of the coast is taken

up to 5-m contour in this study. The width of the coastal zone within the 5-m elevation above the sea level is variable. The 300-km-long Krishna-Godavari delta front zone dominates the central part AP coast where the width of the coastal belt is more than 30 km as the area is extremely gentle (Fig. 7.1). The coastal sector north of these deltas is characterized by headland-bay configuration with a number of rock promontories jutting into the sea, especially over a 185 km stretch on both sides of Visakhapatnam city. The 5-m contour line runs almost coinciding the shoreline in these parts of AP coast (Fig. 7.1). The Penner delta and Pulicat Lake (the second largest lagoon along the east coast after Chilika Lake in Orissa) are the dominant features along the coast south of the Krishna-Godavari delta region.

The region is densely populated with more than 6.5 million people (2001 Census) living within 5-m-elevation above the sea level including the port cities of Visakhapatnam, Kakinada and Machilipatnam. The AP coast is known for frequent tropical cyclones and associated floods and tidal surges causing loss of life and property in the region. For example, the 1977 cyclone that was accompanied by a 5-m storm surge killed about 10,000 people and 0.2 million livestock besides causing enormous damage to property in the Krishna delta region. The 3 to 4 meter storm surges in the 1990 and 1996 killed thousands of people and millions of livestock, besides damaging property in Godavari delta region. The 1999 super cyclone and associated 7 to 8-m-high storm surge (Lal 2001; Nayak et al. 2001) killed more than 10,000 people and devastated the Mahanadi delta region in the northern neighbouring state of Orissa along the east coast.

The future sea-level rise is likely to further intensify the storm surges (Pendleton et al. 2004), besides accelerating shoreline erosion and other problems like seawater intrusion and damage to coastal structures, thereby making the AP coast much more vulnerable in future. A coastal vulnerability assessment is made in this study aimed at identifying the degree of vulnerability of different coastal segments of AP.

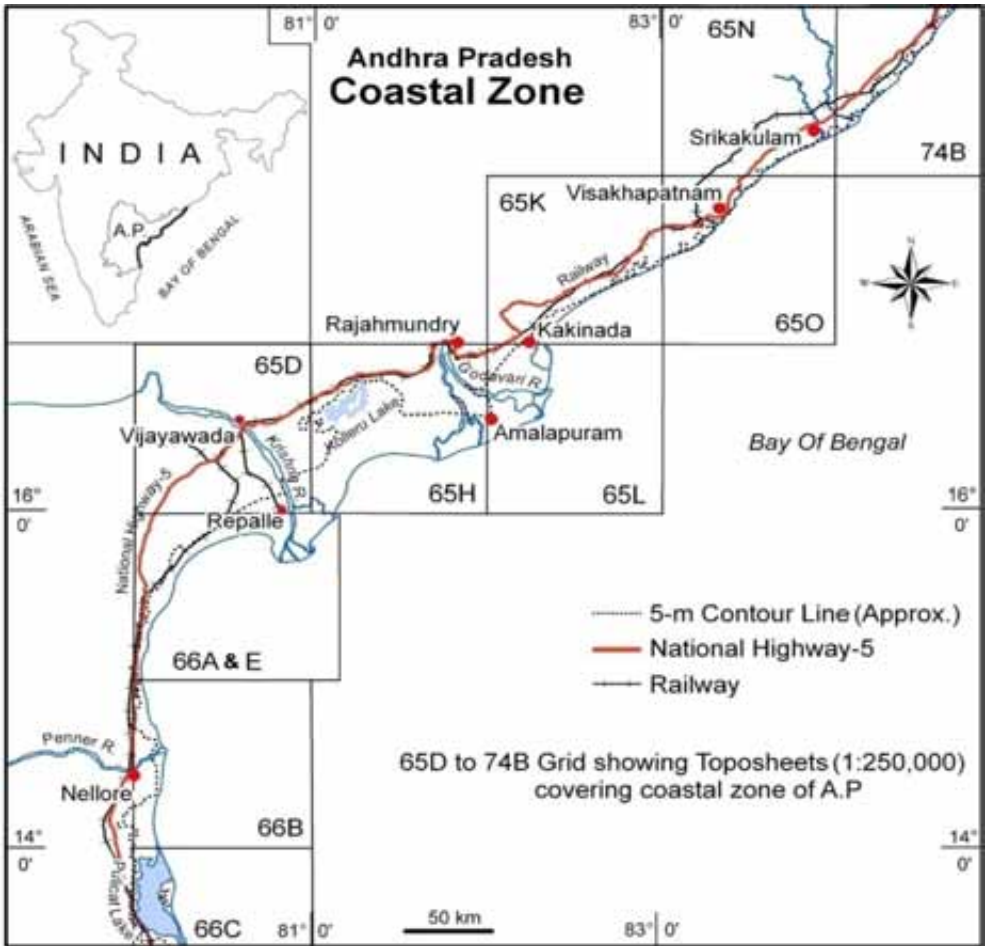


Fig. 7.1: Map showing the coastal zone of the State of Andhra Pradesh (AP)

The dotted line indicates the 5-m elevation (approx.). The entire 1030-km-long AP coast is covered by 11 toposheets of 1:250000 scale. However, two toposheets viz. 66A and 66E are combined into one for mapping in this study as the area covered is 66E is very small. The location of AP coast facing the Bay of Bengal is shown as thick line in the inset map of India.

Tamilnadu coast

Tamilnadu coast of around 1000 km in length is very unique and self styled with alternate concavities and convexities from Chennai in the north to Cape Comorin in the south due to the post collision tectonic upwarping and

subsidence, N-S trending Holocene block faulting, NE-SW trending sinistral faulting and NW-SE trending dextral faulting.

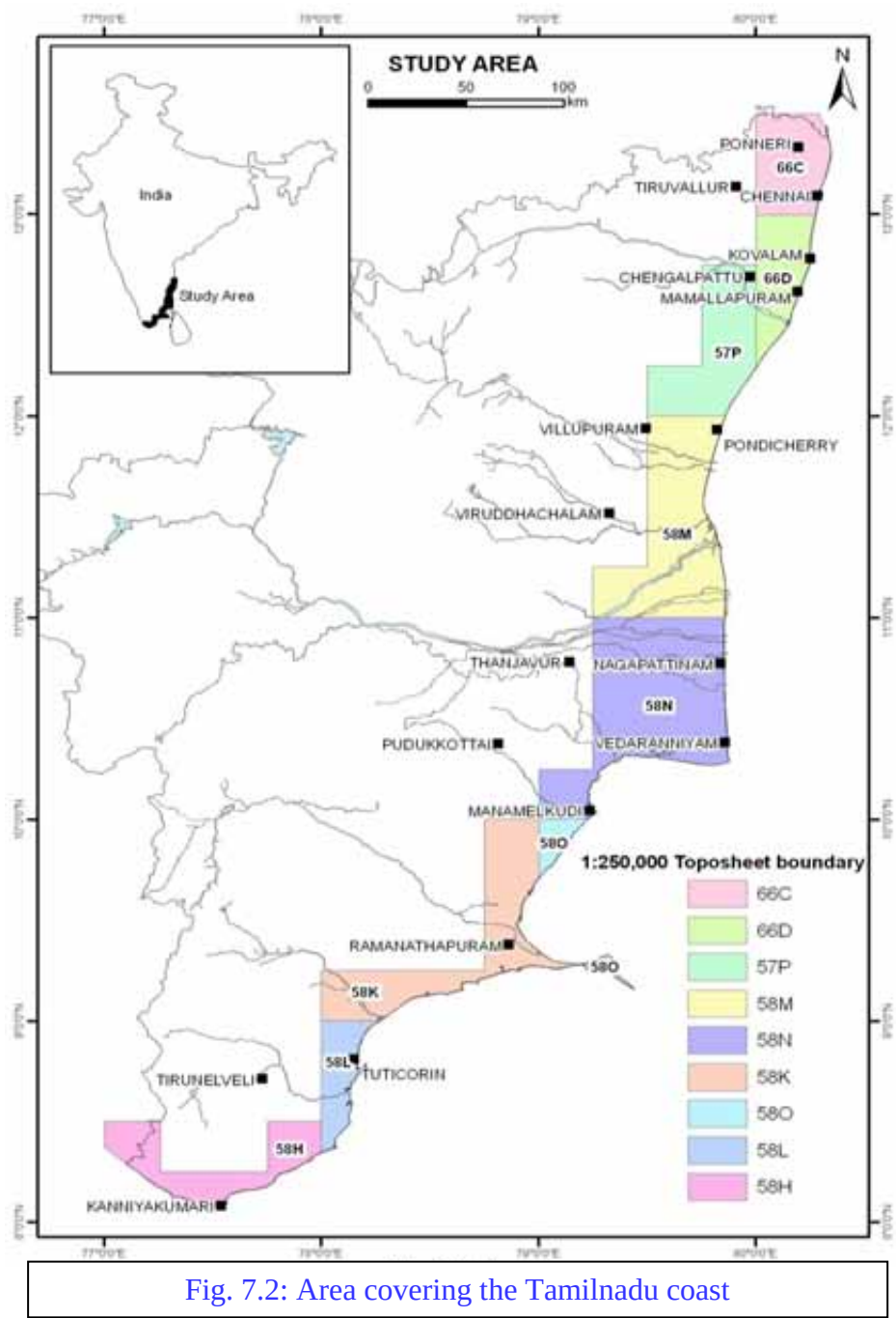


Fig. 7.2: Area covering the Tamilnadu coast

These tectonic activities seem to have greatly induced the riverine systems to develop deltas of multivariate morphology and the coastal processes to build beach ridges, swales, backwaters, estuaries and creeks of differing architecture, beaches, spits and offshore shoals and mud flats of varying patterns and chronology etc. Fig. 7.2 shows the study area covering the Tamilnadu coast.

Gujarat Coast

Gujarat is covered between $20^{\circ} 6' \text{ N}$ to $24^{\circ} 42' \text{ N}$ latitude and $68^{\circ} 10' \text{ E}$ to $74^{\circ} 28' \text{ E}$ longitude. Gujarat coast situated on the west coast of India is the longest coastline amongst the nine coastal state of India (about 1650 km) and maximum area under marine influence (Fig. 7.3). Gujarat coast constitutes about 22 percent of country's coastline. It is bounded by the Arabian sea in the west and has two gulfs i.e. Gulf of Khambhat aligned in N-S direction and Gulf of Kachchh aligned in the E-W direction. The two major indentations, Gulf of Kachchh and Gulf of Khambhat, account for over 60 percent of the coastline. This is the only state of the country having two gulfs providing opportunities of trade through sea. Gujarat coast could be broadly described into four regions as follows: the Gulf of Kachchh, the Saurashtra coast, the Gulf of Khambhat and the South Gujarat coast. Gujarat coast is distinct from the other coasts in the country with its shallow depth, wider continental shelf and vast stretches of saline and tidal mudflats. The continental shelf of Gujarat is spread over 165, 000 sq km (over 35 percent of the Indian continental shelf). Varieties of resources in vast sea water of Gujarat, covering 2, 00, 000 sq. km area of the Exclusive Economic Zone (EEZ) and 1, 65, 000 sq. of continental shelf, are important for the overall development. The Banas, Sabarmati, Mahi, Narmada and Tapi are major rivers draining into the gulf of Khambhat while the rivers Bhader, Ojat and Shetrunji are those of Kathiawar peninsula draining into the Arabian Sea. There are few seasonal small rivers draining into the gulf of Kachchh.

There are four major, five medium, twenty five minor and five desert rivers that discharge $71, 000 \text{ Mm}^3$ of water in a year to the seas, particularly in the Gulf of Khambhat and the south Gujarat coast. The coastal and marine environment of Gujarat support rich fisheries in the 375 km wide continental shelf, coral reefs around 34 islands in the Gulf of Kachchh and mangrove

vegetation on creeks, estuaries and mud-flats around the coast. Fig. 7.3 shows the area covering the Gujarat coast.

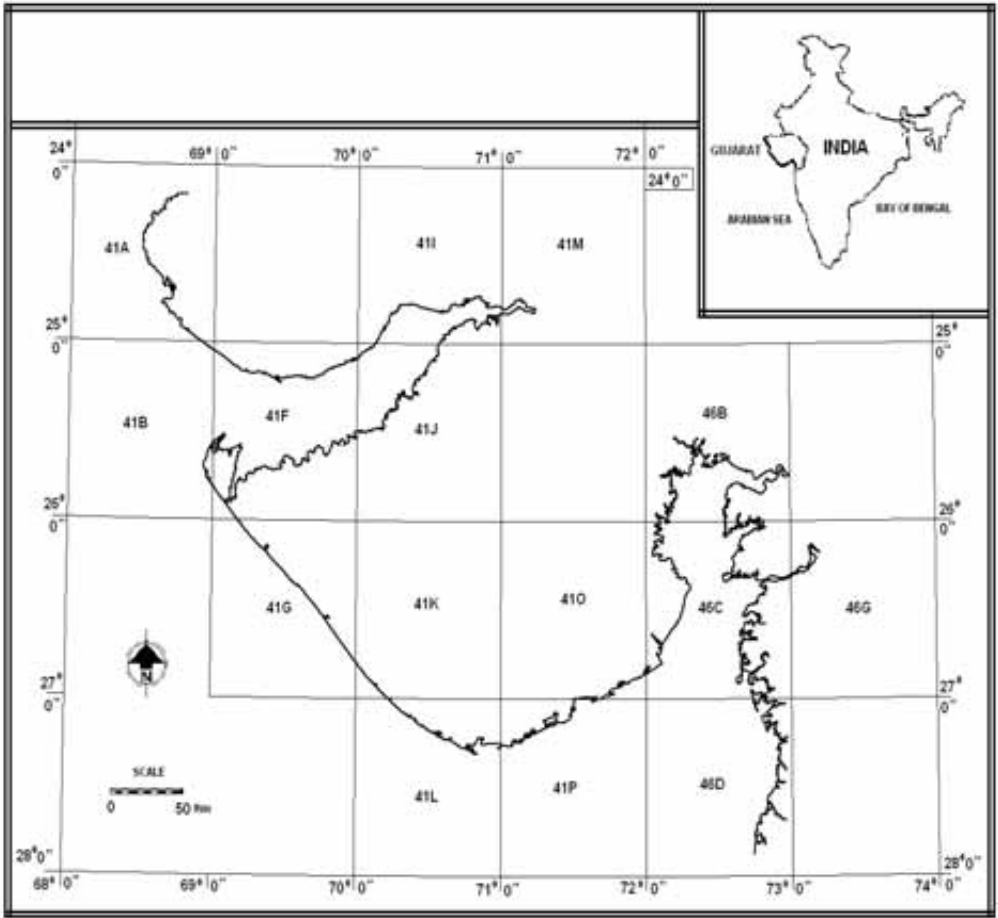


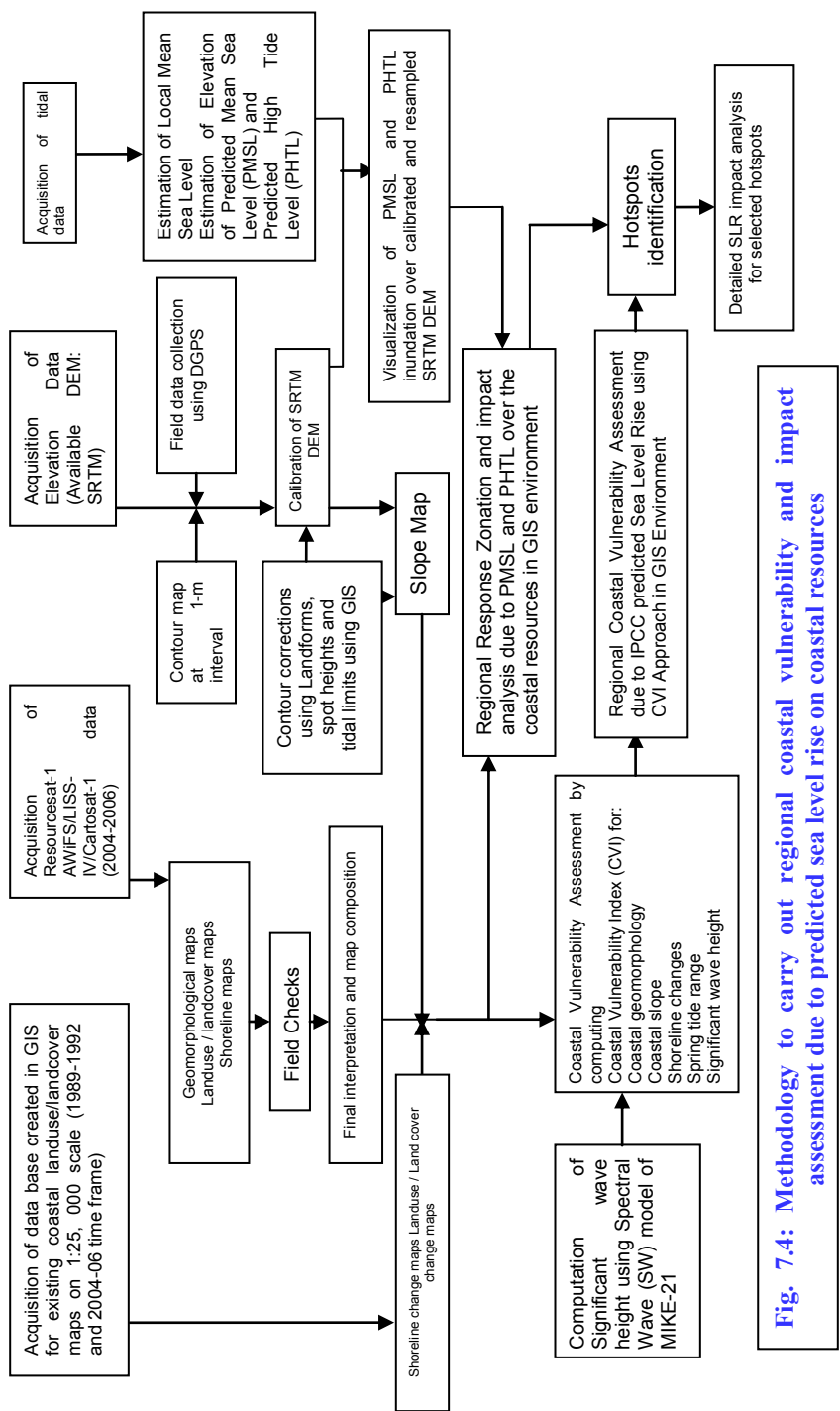
Fig. 7.3: Area covering the Gujarat coast

Approach for Assessing Coastal Vulnerability

The details of the RS and GIS based approach to carry out regional coastal vulnerability and impact assessment due to predicted sea level rise on coastal resources is given in Fig. 7.4. The main steps are as follows:

- i) Acquisition of digital data of Resourcesat-1 AWiFS/LISS-IV/Cartosat-1 data for the time period 2004-2006.
- ii) Georeferencing of satellite data using ERDAS Imagine image processing s/w and carry out on-screen interpretation to prepare coastal geomorphological, coastal land use/land cover and shoreline maps using AWiFS data on 1:250,000 and 1:50,000 scale following SOI topographical map sheet grid after digital enhancements.
- iii) Extensive field checks were carried out followed by final interpretation and map composition.
- iv) The SRTM-data based digital elevation models are downloaded from the internet sources and contours at one-metre interval were generated. The inconsistencies in the elevations depicted by the contours thus generated were corrected keeping in view the landforms and spot heights (from topographic maps).
- v) Temporal changes in the shoreline indicating the zones of erosion and accretion during the recent years were mapped by comparing the geomorphic maps from 1990 which are made available from the archives of SAC, and the present study which is based on the interpretation of AWiFS images from 2006.
- vi) Shore line change maps and landuse/land cover change maps were also prepared using land use/land cover maps prepared on 1:25, 000 scale for 1989-1992 (archives Available at SAC) and 2004-06 time frame (prepared under the current project).
- vii) Identify the elevation of the IPCC predicted SLR of 0.59 m in next 100 years by
 - a) Analyzing the Tide gauge data and identify the Elevation of LMSL (Local Mean Sea Level)

- b) Adding the LMSL value with IPCC predicted SLR value of 0.59 m and identify the elevation of Predicted Mean Sea Level (PMSL)
- viii) Identify the elevation of the HTL through DGPS survey, tide gauge data, etc.
- ix) Adding the elevation of HTL with the elevation of Predicted MSL and identify the elevation of Predicted HTL (PHTL) in next 100 years.
- x) Generation of calibrated SRTM DEM using DGPS surveyed data
- xi) Visualization of zones of PMSL and PHTL using calibrated SRTM data and generation of GIS layers.
- xii) Integration zones of PMSL and PHTL layers with geomorphology, land use/cover, physical resource maps and carried out the SLR impact analysis and identify hotspot regions.
- xiii) Wind velocity component derived from ECMWF (European Center for Medium Range Weather Forecast) assimilated with near real-time measurements through Seawinds Scatterometer onboard QuikSCAT satellite and by the three Special Sensor Microwave Imager (SSM/I) onboard DMSP (Defense Meteorological Satellite Program) satellites F13, F14, and F15 which are available from the CERSAT were modeled using Mike21 software to simulate the significant waves.
- xiv) Data on the average tide ranges at different stations along the coast were taken from the National Hydrographic Charts.
- xv) A coastal vulnerability index is prepared by integrating the data on all the coastal characteristics through GIS techniques, based on which the vulnerability levels of different segments of the coast is assessed. Considering the IPCC predicted sea-level rise of about 59 cm by the 2100, the areas likely to be affected were mapped and the loss of different land use/land cover/geomorphological features are quantitatively estimated.



xvi) From the coastal vulnerability map, hot spots were identified and detailed SLR impact analysis was carried out for selected hot spot areas.

Model Implementation

The model/ methodology developed as per the above details are implemented in three states. Details are discussed in the following section:

Andhra Pradesh Coast

Towards fulfilling the main objective of the study of assessing the impact of predicted sea-level rise along the coast of Andhra Pradesh (AP), data on five physical parameters of the coast, such as Coastal Geomorphology, Slope, Shoreline change history, Spring tide and Significant wave height are considered in this study. This section describes the methods of mapping and data generation on these five parameters. Using the IRS P6 AWiFS images, the entire coastal zone (up to +5m elevation inland) has been mapped showing the various landforms and land use/land cover features. Since geocoded image data are provided by SAC, interpretation of features for each image representing the area covered by 1:250,000 scale SOI topographic map is carried out. Therefore, a total of 11 maps have been prepared showing the geomorphic features (landforms) and various land use/ land cover features. Further, data on various other parameters such as coastal slope, shoreline change history, tides and waves have also been generated through various techniques. Preparation of geomorphology map involved identification of both active as well as relict coastal landforms. The active landforms along the coastal zones including mudflats, mangrove swamps, lagoons, tidal creeks/channels, beaches, bars, barriers, spits, and fore dunes are mapped in this study. The relict forms such as the beach ridges, paleo mudflats, etc., have also been mapped. Besides the above, features like headlands, bays, cliffs, wave-cut benches, sea stacks etc were demarcated wherever possible, within the scale limitations of AWiFS data. Interestingly, the landward limit of the relict coastal landforms that are discernible from the AWiFS images approximates the +5m elevation. Therefore, the innermost beach ridge identifiable from the satellite imagery is taken as the landward limit of the coastal zone in this study.

As the land area in the toposheet No. 66E is very less, it has been clubbed with the toposheet No.66A limiting the total number of maps to 10. In addition to the geomorphology maps, a broad land use map is shown along with data on the extent of different types of land use classes. The shoreline change map is generated by comparing the geomorphic map prepared in this study with that prepared earlier by SAC using the IRS IB LISS II images of 1990. Thus the changes along the entire AP coast, in terms of erosion and deposition during the 16-year-period between 1990 and 2006 are highlighted in this map. The data on tidal ranges are obtained from National Hydrographic Charts and the data on significant wave heights are generated using simulation models.

Geomorphology

As mentioned already, AP coast is covered in 11 toposheets of 1:250,000 scale (Fig. 7.1) are shown in 10 maps (with 66A and 66E clubbed into one map). The landform maps prepared based on the interpretation of AWiFS images are shown in Fig. 7.5 - 7.14. Each map shows the salient landforms within the coastal zone covered. Table 7.1 shows the areal extents of each landform class and the length of the coastline as per 1:250, 000 scale SOI topographical grid.

Ichchapuram area

This map covers a 117-km-long coastline of AP from a little south of Vamsadhara estuary to a few kilometers north of Iduvanipalem (I) which is the northernmost boundary of the state. The area is characterized by a number of backwater bodies namely Naupada, Nuvvalarevu (N), and Iduvanipalem (I), out of which Naupada is the largest spreading over an area of 8 km² (Fig. 7.5). The presence of such large tidal water bodies indicate that extensive areas along this coastal section are below the sea level accommodating the floods, storm and tidal surges. Possibly, these areas are controlled by tectonic activity. The area is also characterized by extensive red sand deposits of pre-Holocene origin. The predominant land use in this region is aquaculture, salt farming and paddy while a considerable area remains as mudflats. The area is also characterized by prominent coast parallel sand dunes, between the sea and backwater bodies. Some of the dunes are as high as 6-9 m and are stabilized by thick vegetation like casuarina and cashew plantations.

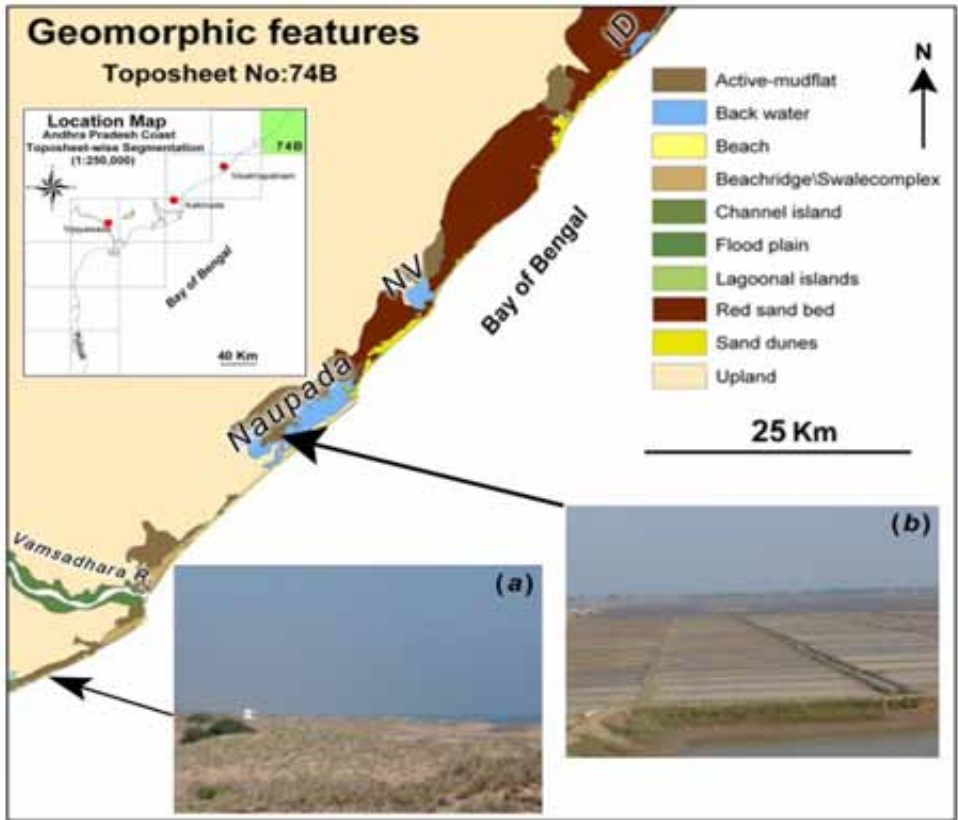


Fig. 7.5: Geomorphologic features covering northern A.P. Coast (Ichchapuram, SOI Map No. 74 B) and field photographs showing (a) High dunes stabilized with vegetation; and (b) Extensive salt pans near Naupada

Srikakulam area

The coastline in this particular toposheet area extends from the Kandivalasa estuary (KE) to a little north of Nagavali estuary. Srikakulam is the largest town in this area. The shoreline in this area is about 54 km-long. The predominant geomorphologic feature in this region is floodplain on both sides of the rivers (Fig. 7.6) where the agriculture activity is prominent. Another striking feature is red-sand beds which were stabilized mainly by the cashew plantations. Beaches in this part are very narrow with dunes ranging from 3-5 m.

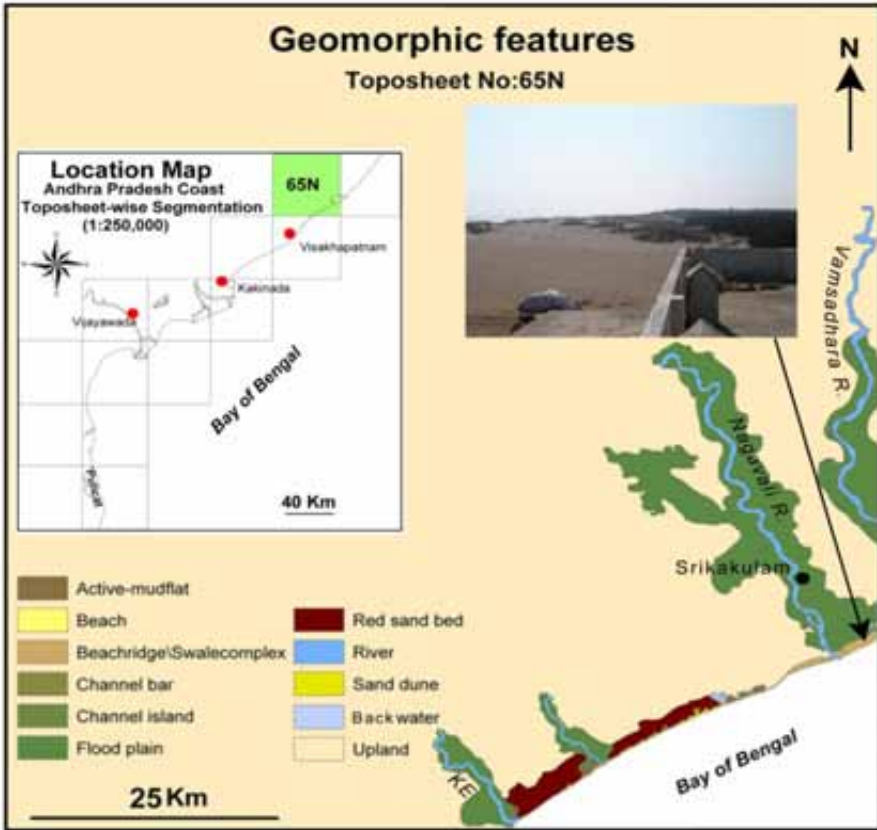


Fig. 7.6: Geomorphic features covering northern A.P. Coast (Srikakulam, SOI Map No. 65 N) and field photograph showing dunes stabilized with vegetation

Visakhapatnam area

Visakhapatnam, a million plus city are in this part of AP. It is surrounded by Kailasa hill range (KHR) in the north and Yarada hill range (YHR) in the south which is 10 km apart. The shoreline is about 90 km from Pudimadaka (P) to few kilometers north of Gosthani estuary (GE). Predominantly, the coastal strip of Visakhapatnam is rocky with several promontories jutting into the sea creating a headland and bay configuration to the coast (Fig. 7.7). The shore zone is characterized by the presence of sea cliffs, wave-cut terraces and sea stacks. Wide spread coastal red sands also occur at several locations in the Visakhapatnam region.

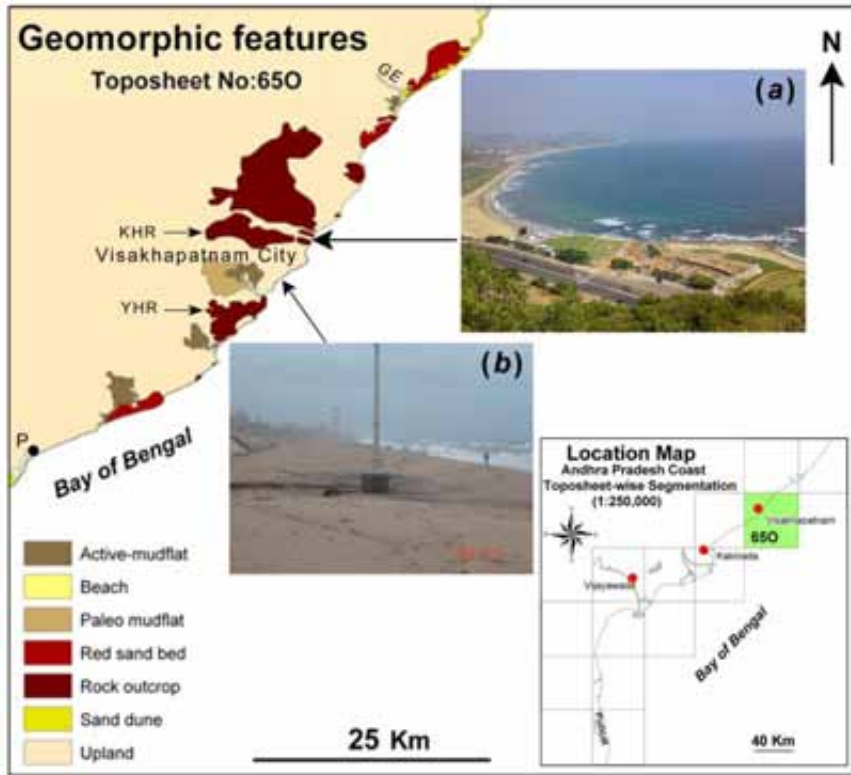


Fig. 7.7: Geomorphic features covering northern Visakhapatnam, A.P. Coast (SOI Map No. 65 O) and field photographs showing (a) Headland and bay configuration of Visakhapatnam coast; and (b) Beach in the city proper

Uppada Area

The shoreline corresponding to this particular area starts from south of Uppada to a little north of Sharada-Varaha estuary and is around 95-km-long. Uppada is a small town having population of 11090 (2001 Census). Here, well defined beach ridges are seen covered with casuarina plantations over 117 km² area. The beach covers 15 km² (Fig. 7.8). Mudflats are also striking features in this area occupying 62 km² area. The entire coast abutting Uppada is experiencing severe erosion (Fig. 7.7).

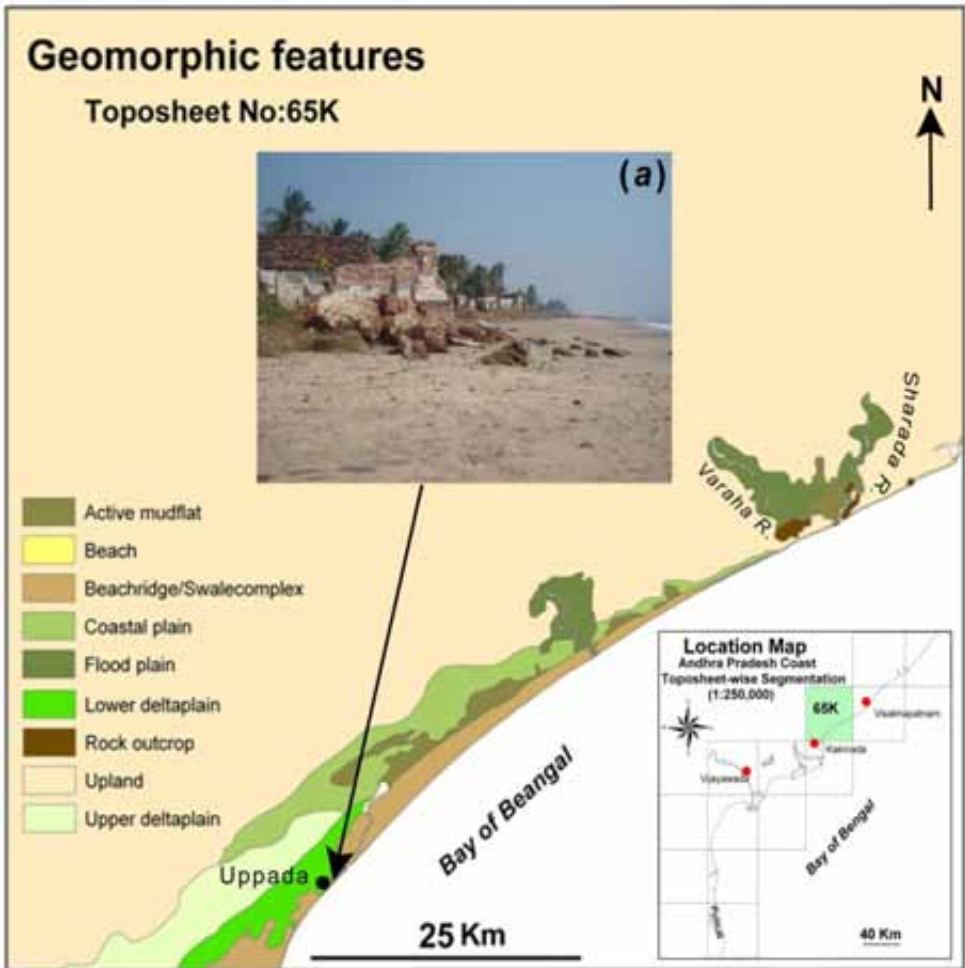


Fig. 7.8: Geomorphic features covering Uppada, A.P. Coast (SOI Map No. 65 K) and field photograph showing Uppada beach under severe erosion

Kakinada Area

The shoreline comprises of 105 km from a little north of Vainateyam estuary to north of Kakinada town. Kakinada is the largest town in the entire region, having many industries and a sea port. The entire Godavari mangroves covering of 170 km² area are from this part and the famous Kakinada spit having a length of 21 km. Mudflats occupy an area of 155 km² and the

predominant land use is salt pans and aquaculture ponds (Fig. 7.9). The beach ridges which are supposed to be earlier shorelines occupy an area of 338 km². There is a lagoon called as Pandi (Fig. 7.9 a) which occupies an area of 9.0 km² and backwater zones constitutes of 14 km².

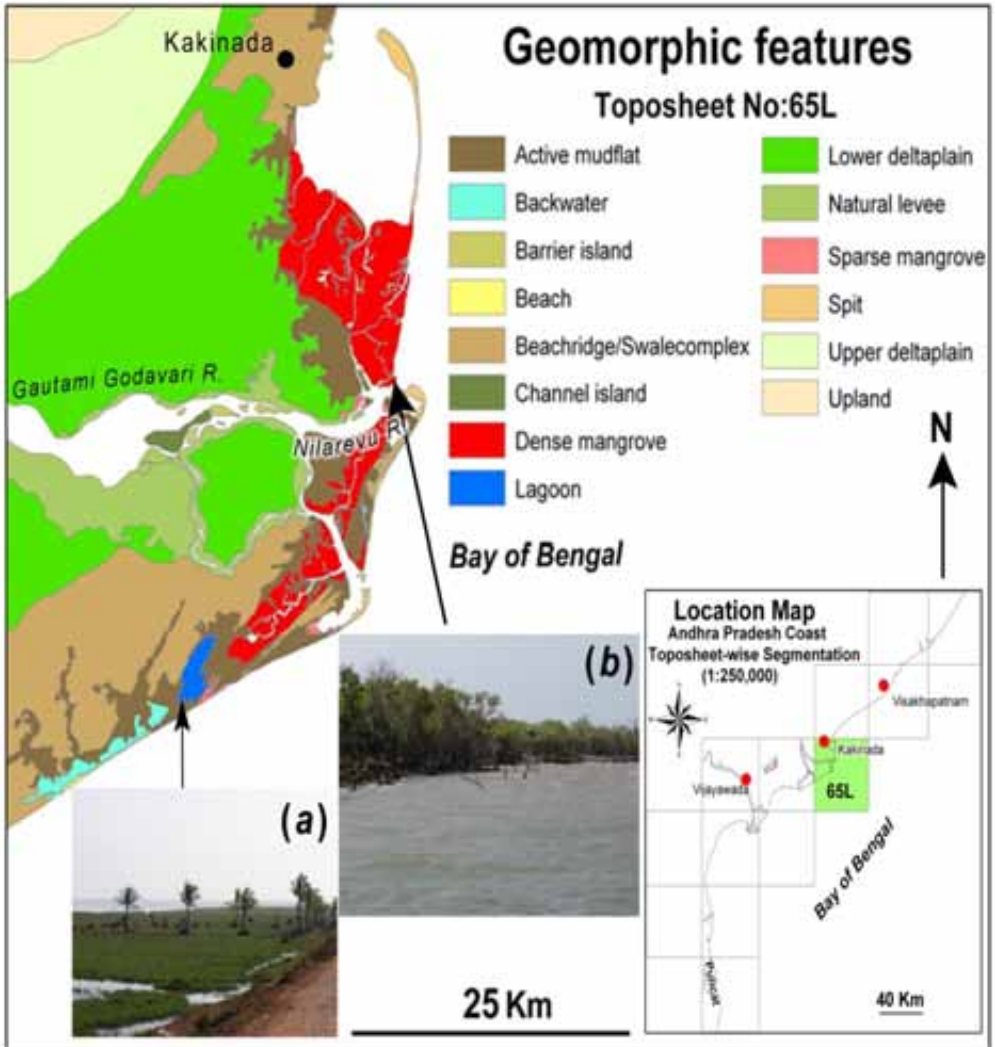


Fig. 7.9: Geomorphic features covering northern Kakinada, A.P. Coast (SOI Map No. 65 L) and field photographs showing (a) Pandi lagoon; and (b) Mangroves north of Nilarevu estuary

Bhimavaram Area

This particular toposheet area has a 120-km-long shoreline representing the western part of the Godavari delta and the inter-delta area including the Kolleru Lake. The beach ridges occupy 35-km wide belt spreading over an area of 1061 km². The dominant land use in this region is agriculture and aquaculture ponds (Fig. 7.10).

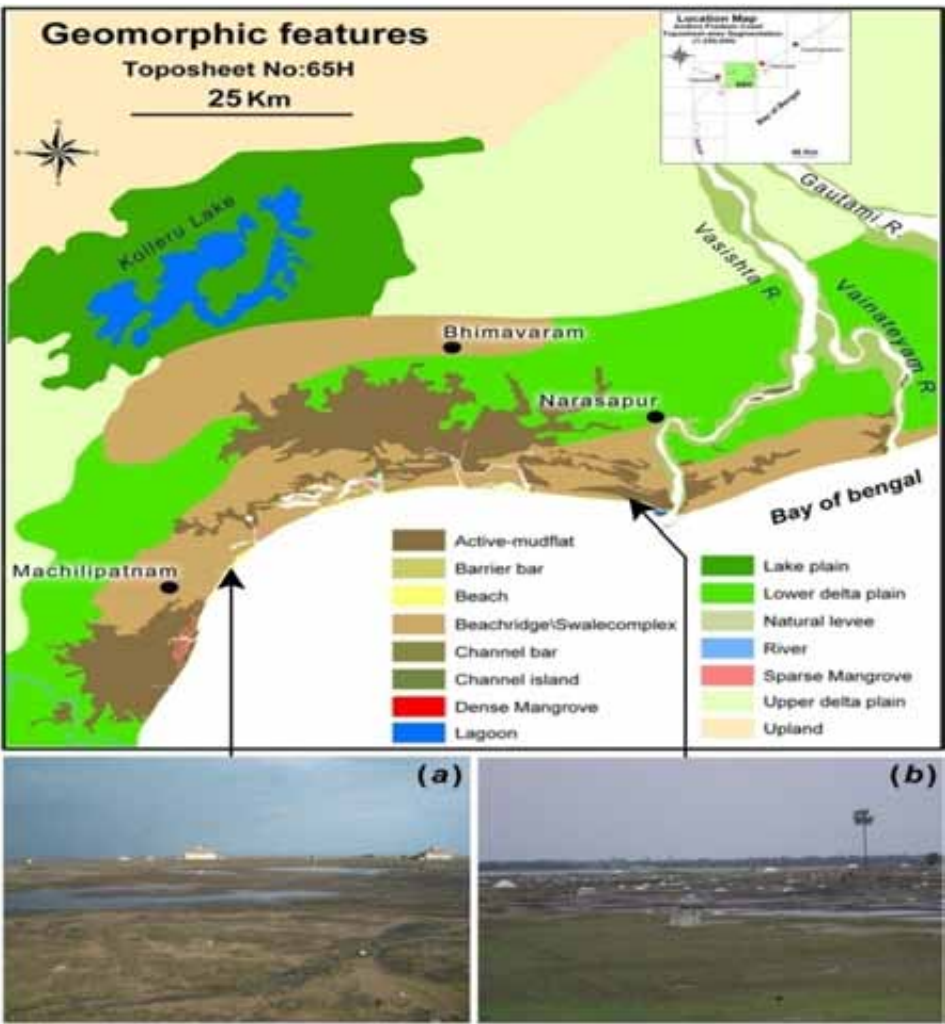


Fig. 7.10: Geomorphic features covering Bhimavaram, A.P. Coast (SOI Map No. 65 H) and field photographs showing (a) Wide beach in the Maginapudi area in Krishna delta; and (b) Extensive mudflat area in the Godavari delta

Vijayawada Area

Vijayawada is the apex of the Krishna delta, shoreline is about 95 km away from Vijayawada. The maximum area 3094 km² comprises of upper Krishna delta plain (Fig. 7.11).

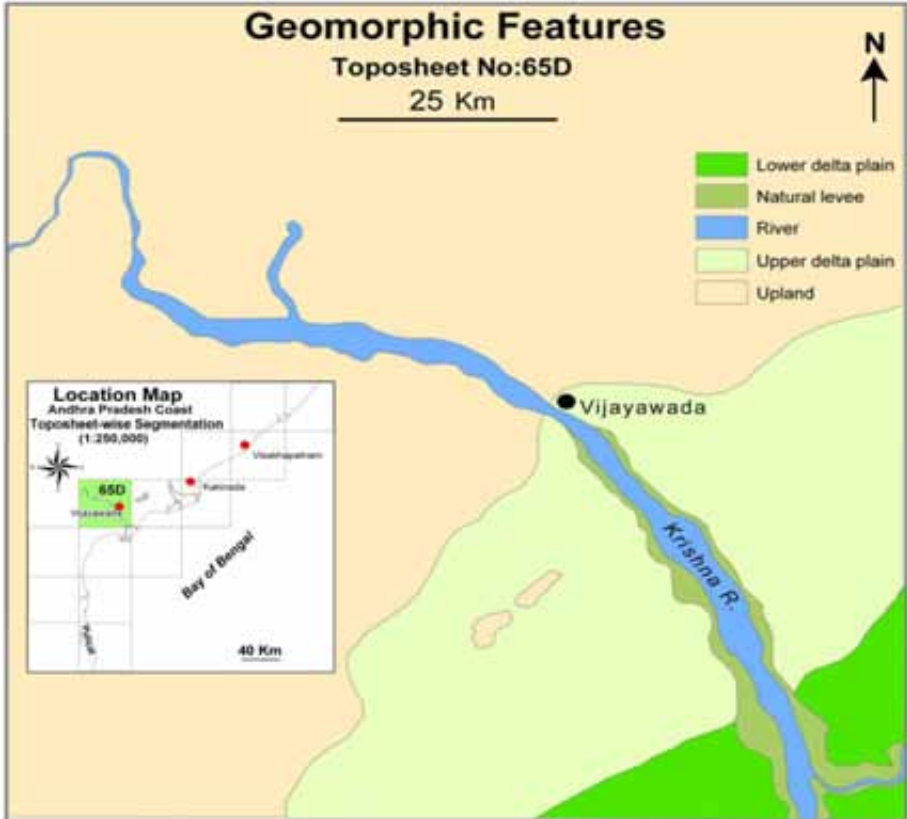


Fig. 7.11: Geomorphic features covering Vijayawada, A.P. Coast (SOI Map No. 65 D)

Nizampatnam Area

The coastline in both the 66A&E toposheets put together is almost 150-km-long in which there are different morphological features like mudflats, beach ridges, backwater zones and mangroves etc. The entire Krishna delta bulge with all its four distributaries is covered in this image. The mangrove area is

about 125 km², mudflat comprises of 466 km², beach ridges cover an area of 818 km² (Fig. 7.12). There are number of small estuaries draining into this area, some of them include Romperu, Musi, Gundlakamma, Palleru and Manneru to the south of the Krishna delta.

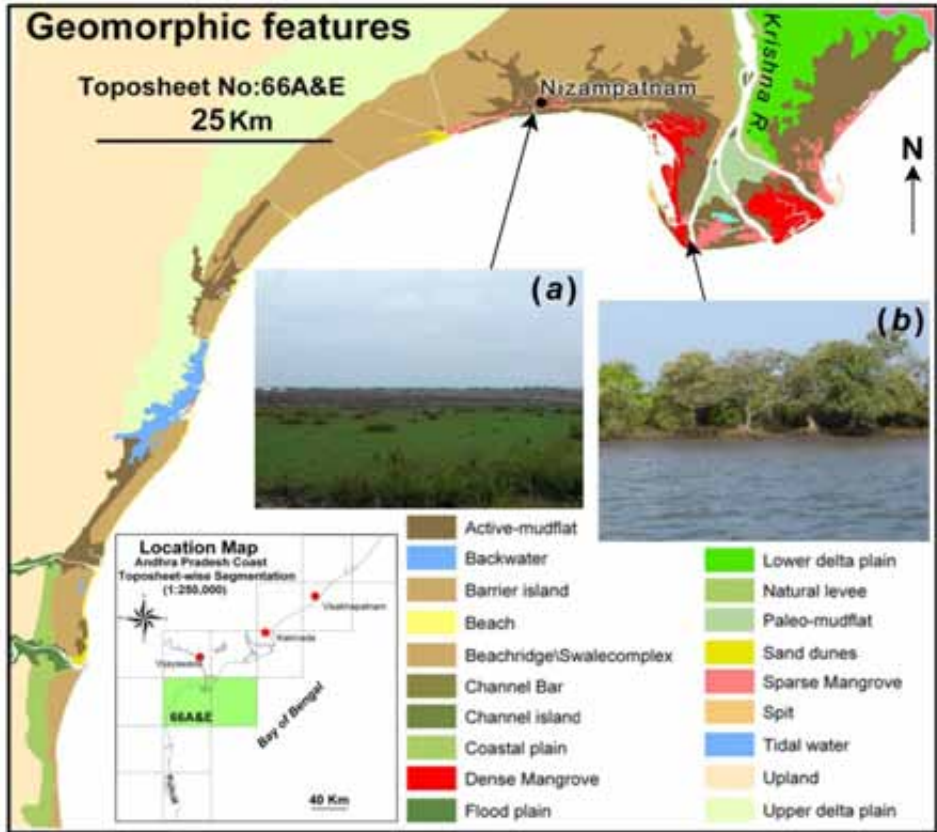


Fig. 7.12: Geomorphic features covering Nizampatnam area, A.P. Coast (SOI Map No. 66 A & E) and field photographs showing (a) Mudflat area in the Krishna delta; and (b) Mangroves present in the Krishna delta

Nellore Area

The entire Penner delta including the 116-km-long coastal zone is covered in this map with Nellore at the apex, the Penner delta extends from Upputeru River in the south to isukapalli lagoon in the north. Landforms like mudflats,

beach ridges occupying about 224 km² and 289km² respectively are the prominent features in the area (Fig. 7.13).

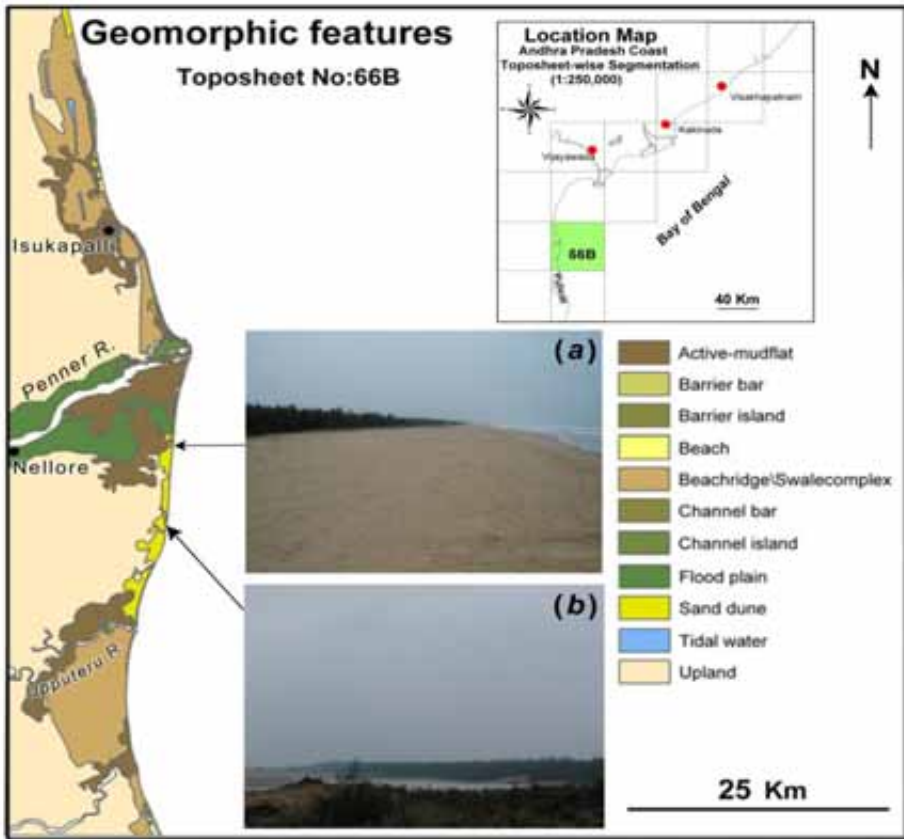


Fig. 7.13: Geomorphic features covering Nellore area, A.P. Coast (SOI Map No. 66 B) and field photographs showing (a) Beach stabilized by vegetation along the Gangapatnam coast; and (b) Beach stabilized by vegetation along the Krishnapatnam coast

Pulicat Lake Area

The entire Pulicat Lake covering an area of 620 km² comes into this particular image. The Pulicat Lake is located at the southeastern end of AP. It is the second largest lagoon along the east coast after Chilka Lake (which is in Orissa state north of AP). The Lake extends from Durgarajupatnam in the north to Pulicat village in the south. About 260 km² of the lake in the northern half is

dried up (Fig. 7.14). Quite a number of islands with a combined area of 100 km² are present in the lake body including in the dried up portion. The orientation of these islands, more or less, parallel to the coast, shows that these are the remnants of a number of beach ridges spread along the width of Pulicat Lake. Kalangi River decants into this lake creating a small bird foot delta.

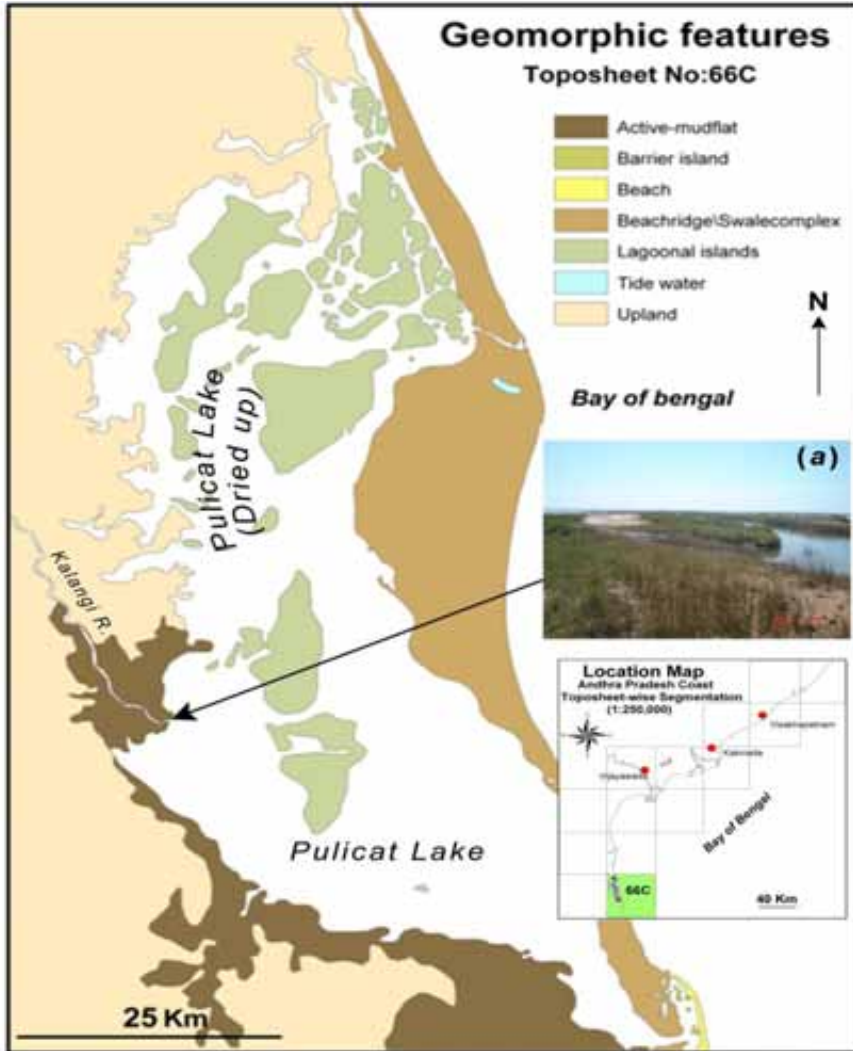


Fig. 7.14: Geomorphic features covering Pulicat Lake area, A.P. Coast (SOI Map No. 66 C) and field photographs showing (a) Kalangi delta plain along the western shore of the Pulicat lake

Table 7.1: Coastal length (km) and Area (km²) of Coastal Landforms as per 1:250, 000 scale SOI Map grid of A.P. Coast

	74B	65N	65O	65K	65L	65H	65D	66A&E	66B	66C	Total
Coastline length (km)	117	54	90	95	105	120	---	150	116	64	911
Coastal Landforms	Area of coastal landforms (km²)										
Mangroves	---	---	28	---	170	8	---	125	---	---	331
Mudflats	69	1	---	62	155	646	---	466	224	72	1695
Palaeo Mudflats	---	---	17	---	---	---	---	---	---	---	17
Spit	---	---	---	---	12	---	---	4	---	---	18
Beach Ridges	11	9	---	117	338	1061	---	818	289	202	2845
Dunes	31	4	7	---	---	---	---	---	34	---	76
Back Water	70	1	---	---	14	---	---	43	---	---	128
Natural Levee	---	---	---	---	141	324	213	34	---	---	712
Beach	7	5.3	4	15	4	14	---	21	7	2	79.3
Delta Plain	---	---	---	202	914	1504	3094	824	---	31	6569
Flood Plain	29	528	---	102	---	---	---	25	114	---	798
Lagoon	---	---	---	---	9	181	---	---	---	620	810
Red Sand beds	245	57.7	24	---	---	---	---	---	---	---	326.7
Coastal Plain	---	---	---	158	---	---	---	79	---	---	237
Total Area (km²)	462	606	80	656	1757	3738	3307	2439	668	927	14640

Land use/Land cover

Information on land use/land cover in the form of maps is very vital for spatial planning and management and utilization of land especially in the coastal areas. The land use/land cover features of AP coast are mapped from the AWiFS data as shown in Figure 7.15. The major land use features are agriculture and aquaculture besides built up area (habitations). The major urban settlements along the coast are Visakhapatnam, Kakinada and Machilipatnam, apart from a few other smaller towns and hundreds of rural settlements in this densely populated coastal zone. Coastal wetlands such as lagoons, mangrove swamps, mudflats occupy extensive areas mainly in the deltaic regions. Coastal plantations such as casuarina are associated with the beach ridges. Table 7.2 shows major land use /land cover classes under present and future inter-tidal zone due to predicted sea level rise.

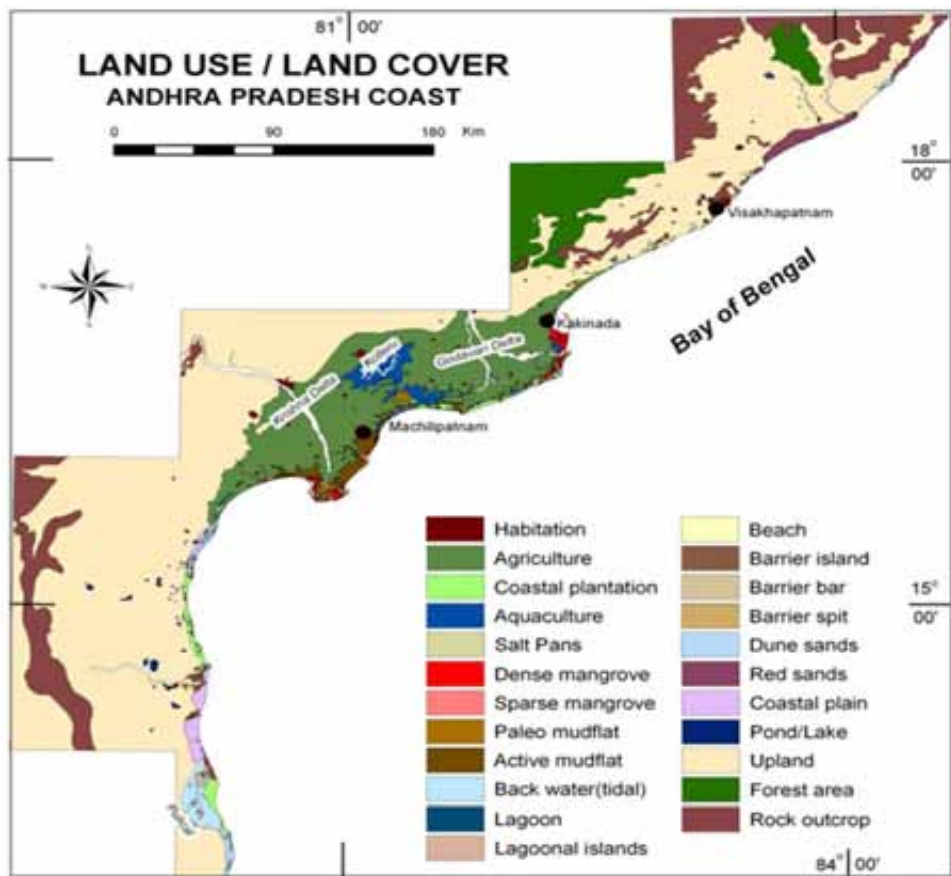


Fig. 7.15: Land use/Land cover features of the AP Coast

Table 7.2: Major land use /land cover classes under present and future inter-tidal zone due to predicted sea level rise

Contour Interval	Land Use/Land Cover Features in between 0-5m contour entire AP coast					
	Mangrove/ Lagoons/ mudflats/ Tidal creeks(km ²)	Aquaculture ponds (km ²)	Agriculture (Paddy) (km ²)	Salt pans (km ²)	Plantation s (km ²)	Total
0-1.4m (Present Inter tidal zone)	1579	231	----	96	----	1906
1.4-2.0m (Future Inter tidal zone)	30	499.3	289	135.9	279	1233.2
2.0-5.0m		961.78	4708.28	.502	1216.50	6887.06
Total	1609	1692.08	4997.28	232.4	1495.5	10026.2

Coastal Slope

Coastal slope is the major factor along with landforms to be considered in estimating the impact of sea-level rise (SLR) on any coast. The impact of SLR is insignificant along a steep coast whereas gently sloping coasts are affected by SLR as it would inundate large extents of land. The major limitation in this study is the lack of fine resolution contour maps of the entire AP coast. The SOI topographic maps show 10 m contour interval in 1:25,000 scale which are of no use since most of the area is under the 10 m elevation, except at the rocky headlands near Visakhapatnam.



Fig. 7.16: Contours extracted from the SRTM DEM. Note the 4-m contour in the intertidal mudflats which in fact should be well within 2-m elevation

To overcome the problem, the digital elevation models (DEM) of the AP coastal area available on the internet from the Shuttle Radar Topographic Mission (SRTM-90m) website (www.srtm.csi-cgiar.org) are downloaded from which contours at 1-m interval are interpolated using 3-D Analyst module in ArcGIS software. But when the contour map thus generated was overlaid on the landform map, there were many inconsistencies noticed owing to the

coarser resolution (90 m) of the SRTM data. For instance, the tidally submergible mudflats are enclosed by a 4-m contour at a number of locations in Godavari delta although such landforms are well within 2-m elevation along the AP coast where the maximum normal spring high tide is about 1.5 m above the datum (Fig. 7.16). Further, the contours appear to cross certain water bodies like lagoons and backwater zones which are incorrect. Therefore, extensive corrections have been carried out in order to bring in accuracy in the contours (Fig. 7.17) taking into consideration the nature of landforms (from satellite imagery), spot heights and tidal limits as can be noted from the SOI topographic maps. The contour data are used to generate a coastal slope map. The map is also used to extract information from other data layers such as village boundary maps and land use/land cover map.



Fig. 7.17: Contours corrected using the landform patterns

Village boundaries and statistics generation

Geo-referenced village boundary maps are tagged with population data (Census, 2001). The village boundaries were overlaid on the contours and the data have been generated. There are 1.29 million people who live in 282

villages under 2.1m contour, spread over nine coastal districts of Andhra Pradesh. Within the Krishna-Godavari delta region alone in the central part of AP coast, 0.57 million people are living in 97 villages (Fig. 7.18).

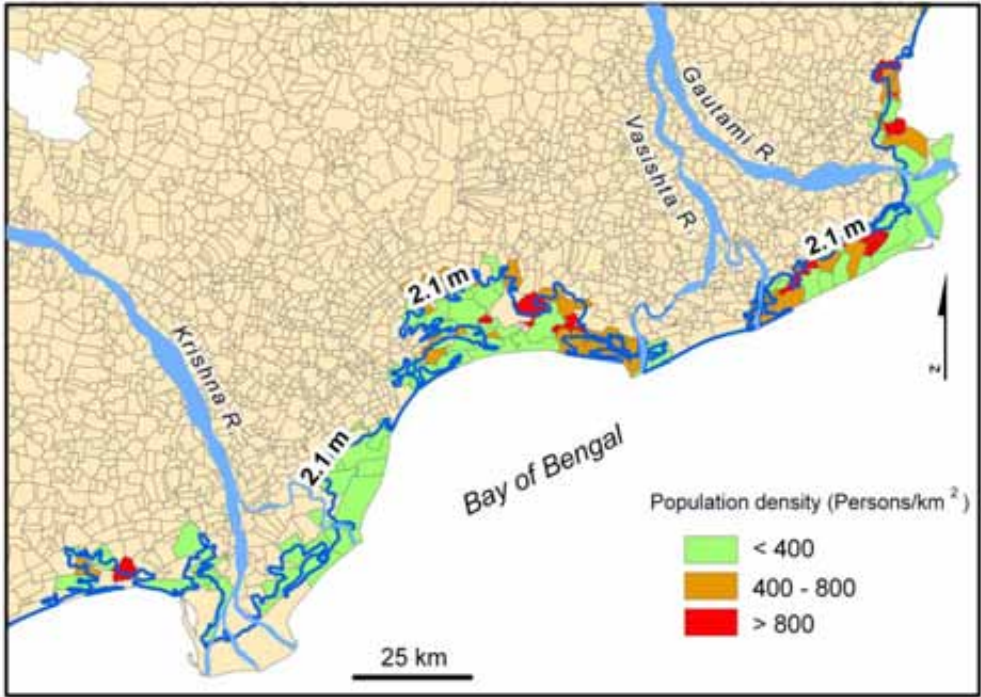


Fig. 7.18: Village boundaries and distribution of Population density within 2.1 m elevation along the coast of the Krishna-Godavari deltas

Shoreline change history

The broad trends in the shoreline behavior in the recent past can be attributed to several reasons like reduction in the sediment supply due to dam construction in the upper reaches and thereby sediment compaction in the down coast leading to the sea-levels to rise, besides local tectonics that might lead to subsidence or uplift in the region. In the absence of data on tectonic activity, especially its effect on the coastal zone, the trends of shoreline change through time, which reflect the interaction of various phenomena that characterize the coastal zone, helps in assessing the coastal vulnerability. Therefore, the shoreline change history has been studied by comparing the

shoreline position in 1990 traced from the IRS 1B LISS II (prepared by SAC), with that traced from the 2006 AWiFS image. In addition, extensive field observations have been made to corroborate the results. The shoreline change map showed significant changes along the AP coast (Fig. 7.19 & 7.20). Interestingly, erosion seems to be the dominant phenomenon along the AP coast, both in terms of the length of coast affected as well as the areal extent. About 418-km-long sections of AP coast were eroded with a loss of 87 km² area, while deposition occurred along 275 km coastal sections where the area added was 57 km². Thus there was a net loss of 30km² area in 16 years.

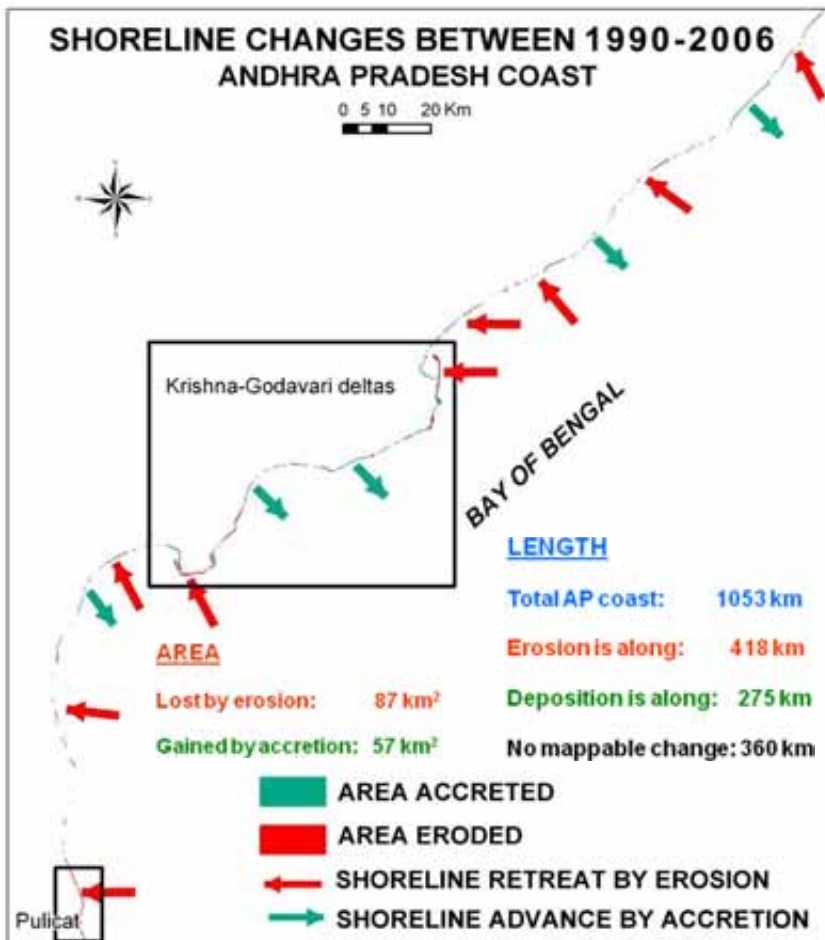


Fig. 7.19: Shoreline changes along the AP coast



Bhimunipatnam



Bunker exposed at Visakhapatnam



Temple collapsed near Uppada



Mangrove erosion near
Nilarevu mouth

Fig. 7.20: Photos representing the coastal erosion along different sections of the AP coast

Spring Tide Range

Even though the entire AP coast is under microtidal environment ($<2\text{m}$) as can be seen from the Indian National Hydrographic Office, the tidal fluctuations in some low-lying and extremely gently sloping parts of Krishna-Godavari deltas and Pulicat Lake will reach up to several kilometers inland thereby making it an important parameter. Instead of the average tidal range (which is an average

of the spring and neap tides), the spring tide range is considered in this study for understanding the role of tides along the AP coast. Therefore, the difference between the spring high tide and the spring low tide levels is calculated for all the stations. However, data on tidal ranges are available for only 9 stations from the National Hydrographic Charts.

Significant wave height

Information on waves along a coast is required for better planning of coastal facilities and to predict the vulnerability of a coast (Sanil et al, 2006). As there are no wave data for the AP coast, computer simulated wave models are used in this study. The Spectral Wave model of Mike-21, a software developed by the Danish Hydraulic Institute, Denmark was used for simulation of the waves. The data on the significant wave heights pertaining to July and August 2005 thus derived from the simulation model were tested for accuracy with the buoy-measured wave data (pertaining to the same period) at one station, i.e. Machilipatnam.

Physical variables and vulnerability ranking

Five physical variables are considered in this study to assess the vulnerability of AP coast to the predicted sea-level rise. They are (1) Coastal geomorphology, (2) Coastal slope, (3) Shoreline change during the recent years, (4) Mean spring tide range, and (5) Significant wave height. Earlier studies elsewhere considered some more parameters also for estimating the coastal vulnerability. For instance, Pendleton et al. (2004); Thieler and Hammer-Klose (1999) included relative sea-level rise as a sixth parameter besides the five listed above in the vulnerability calculations for a part of the Californian coast. Since the predicted sea-level rise of 0.6 m is taken as a constant (based on IPCC 2007 predictions of 0.59 m), sea-level rise as a variable is not considered in our study. Doukakis (2005) considered subsidence as one of the variables. Since there is no data on subsidence rates, it is not included in the present study. Gornitz (1991), Deiz et al. (2007) included elevation (instead of slope), geology and sea-level rise (including the effect of local tectonics) as three of the total seven variables in their respective studies. Geology as related to the substratum is not separately used as a variable in our

study since the landform material is taken care of in geomorphology, and for the reasons explained above, sea-level rise is not considered a variable in our study. Relative ranking is assigned to various coastal segments based on the vulnerability level in terms of each of the five parameters considered in the study. As such, the entire AP coast is divided into five vulnerability classes – very low, low, moderate, high and very high, separately for each of the five variables with slight modifications to the ranking system adopted in earlier studies referred (Diez et al. 2007; Doukakis 2005; Gornitz 1991; Pendleton et al. 2004; Thieler and Hammer-Klose 1999). Therefore, depending up on the nature of each of these variables the entire AP coast is segmented and assigned a vulnerability rank ranging from 1 to 5 with rank 1 representing very low vulnerability and rank 5 indicating very high vulnerability as detailed in the following sections.

Geomorphology

Morphology of the coast plays an important role in determining the impact of sea-level rise. Landforms and the material that compose them reflect their relative responses to sea-level rise since every landform offers certain degree of resistance to erosion (Thieler and Hammer-Klose 1999). While the rocky cliffs and wave-cut benches offer maximum resistance and therefore very less vulnerable, the soft sandy and muddy forms such as dunes, mudflats, mangroves, etc., that offer least resistance, on the other hand, are extremely vulnerable to sea-level rise. A detailed geomorphic map (Fig. 7.21) showing the various coastal landforms is prepared in this study based on the interpretation of satellite images (IRS P6 AWiFS data from 2006) substantiated by field observations during the last two years. The AP coast like the entire east coast of India is predominated by depositional landforms such as beach ridge-swale complexes, mangrove swamps, mudflats, spits, barriers, lagoons, estuaries, and tidal inlets except in a few localities on both sides of Visakhapatnam city where a number of rocky headlands are fringed by cliffs, wave-cut benches, sea stacks and other related erosional landforms (Fig. 7.21) as noted in some previous studies as well (Nageswara Rao and Sadakata 1993; Nageswara Rao et al. 2005). The Krishna-Godavari twin deltas in the central parts and the Penner delta and Pulicat Lake to the south along the AP coast are very low-lying as evident from landforms like beaches, mudflats, mangrove

swamps and tidal channels/creeks that spread up to more than 10-15 km inland even in this microtidal environment.

The normal spring high tide reaches up to about 35 km upstream in the distributary courses of Krishna and Godavari rivers up to the maximum Holocene transgression limit, which is marked by the landward limit of the beach ridges, i.e., former shorelines (Nageswara Rao and Sadakata 1993). Considering the nature of landforms qualitatively, the entire AP coast is segmented into five vulnerability classes as detailed in Table 7.3.

Table 7.3: Coastal vulnerability classification based on the five physical variables

Variable	Coastal Vulnerability Rank				
	Very Low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)
Geomorphology	Rocky coasts	Embayed/indented coasts	Beach ridges; high dunes (>3 m) vegetated	Low fore dunes (<3m); Estuaries; lagoons	Mudflats; Mangroves; Beaches; Barriers/Spits
Coastal Slope (%)	>1.00	0.50 – 1.00	0.10 – 0.50	0.05 – 0.10	<0.05
Shoreline Change (m/yr)	Accretion >5.0	Accretion <5.0	Nil	Erosion <5.0	Erosion >5.0
Mean Spring tide range (m)	<1.0	1.0 - 2.0	2.0 – 4.0	4.0 – 6.0	>6.0
Significant wave height (m)	<0.55	0.55 – 0.85	0.85 – 1.05	1.05 – 1.25	>1.25

Following this ranking, each segment of the coast is assigned with a vulnerability rank number (indicating vulnerability level of the coast) as depicted in Fig. 7.21 depending up on the nature of the landforms at different locations along the AP coast for further analysis in geographic information system (GIS).

Coastal slope

Coastal slope is the major factor to be considered along with the coastal morphology in estimating the impact of sea-level rise on a given coast. On a steep coast, the impact of sea-level rise would be insignificant contrary to a gently sloping coast where any rise in sea level would inundate large extents of land. The major constraint in our study is lack of fine resolution contour maps of the area. The Survey of India (SOI) topographic maps show 10-m contour interval in 1:25,000 scale which are of no use since most of the area of study is far below 10m, except the rocky headlands near Visakhapatnam. The digital elevation models (DEM) of the AP coastal area available on the internet from the Shuttle Radar Topographic Mission (SRTM) website (www.srtm.csi-cgiar.org) are downloaded from which contours at 1-meter interval are interpolated using the 3-D Analyst module in ArcGIS software. But when the contour map thus generated was overlaid on the landform map, many inconsistencies were noticed owing to the coarse resolution (90 m) of the SRTM data. For example, the tidally submergible mudflats are enclosed by a 4-metre contour at a number of locations like in Godavari delta, although such landforms are well within 2-m elevation along the AP coast where the maximum normal spring tide is about 1.5 m above the datum at any location. Further, the contours appear to cross certain coastal water bodies like lagoons and backwater zones, which is not realistic. Therefore, extensive corrections were made to bring in accuracy in the contours in the area taking into consideration the nature of landforms (from satellite imagery), and spot heights and tidal limits as can be noted from the SOI topographic maps. Using the 'Edit' mode in ArcMAP for this purpose, the contour layer was overlaid on satellite images and topographic maps alternately while the contours are adjusted. Firstly, the innermost beach-ridge all along the AP coast, which runs at different distances inland from the present shoreline from a few hundred meters to even up to 35 km as in Krishna-Godavari delta region, is taken as 5-m contour. Similarly, the high-tide line which is either marked in the SOI topographic maps or interpreted in this study as the landward limit of mangrove swamps and active tidal mudflats, is taken as 1.5 m line because the maximum mean spring high-tide anywhere along AP coast is about 1.5m on an average as can be noted from the hydrographic charts.

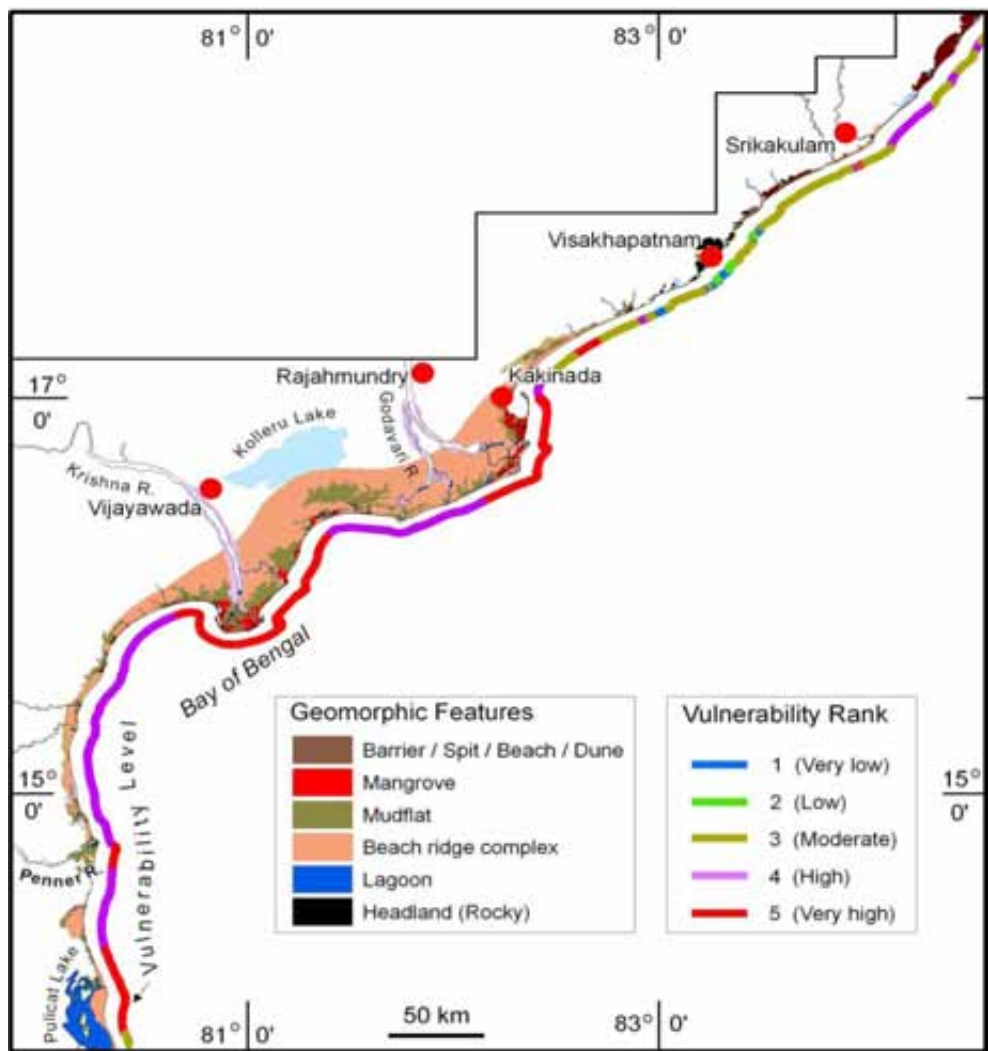


Fig. 7.21: Geomorphology of the AP coast up to ~5m elevation (except at the rock headlands). Inset shows the outline of AP State in India. The thick colored parallel line all along the coast indicates the vulnerability ranking of various segments of the AP coast based on the relative resistance of the geomorphic features that fringe the coast

Therefore, all the intertidal areas along AP coast fall between the shoreline and the 1.5-m contour in the map. A 0.6 m contour is also interpolated between the shoreline (zero-metre contour) and the 1.5m contour. This is meant to represent

the approximate limit of the IPCC (2007) predicted sea-level rise of 0.59 m by the end of the 2100. Beach ridges which are at various elevations from 2 m up to 5 m in the AP coast are taken into consideration while interpolating the contours all along the AP coast. The contours thus generated are used to prepare a slope map for the AP coast (Fig. 7.22) through triangulated irregular network (TIN) method in 3-D Analyst module of ArcGIS. The slope values ranged from 0.00980% to 1.20566%. These values are divided into five values <0.3, 0.3-0.6, 0.6-0.9, 0.9-1.2, >1.2. Lower the value of the slope higher the vulnerability. The entire range of slopes is categorized into five rank classes from 1 to 5 keeping in view the fact that higher the slope value, lower the vulnerability of the coast. The five vulnerability classes and the slope range in each class are adopted from Pendleton et al. (2004) as shown in Table 7.3. Based on this vulnerability ranking, each segment of the coastline is assigned with a vulnerability rank number (indicating the vulnerability level of the coast) as shown in Fig. 7.22 for further GIS analysis.

Shoreline Change

The broad trends in shoreline behavior in the recent past are helpful to a certain extent in understanding the coastal response to future sea-level rise. The geomorphological and land use maps in digital form that are prepared earlier based on the interpretation of satellite images (IRS 1B Linear Imaging Self Scanning Sensor 2) pertaining to the year 1990 that are available with us are used to make comparison with the present (2006) coastline map. By overlaying technique in GIS, the shift in shoreline during the 16-year period from 1990 to 2006 is extracted (Fig. 7.23). Altogether, shoreline retreated in different segments of AP coast over a combined length of 418 km accounting for loss of 87 km² coastal area.

Particularly, the shoreline retreat is more pronounced along the Krishna-Godavari delta front (as evident from the field observations Fig. 7.24), although these deltas are supposed to be the major depocenters during the past several thousands of years. Shoreline advancement into the sea due to accretion occurred at several locations including certain deltaic sectors as well. The total land gained by accretion is about 57 km² over a length of about 275 km. The remaining 347-km-long coast has not shown any notable change

during the period. Considering the rate of change, vulnerability ranking is assigned to various coastal segments as shown in Table 7.1. Applying this classification, all the coastal sectors along the AP coast are ranked from one to five as depicted in Fig. 7.23 for further analysis.

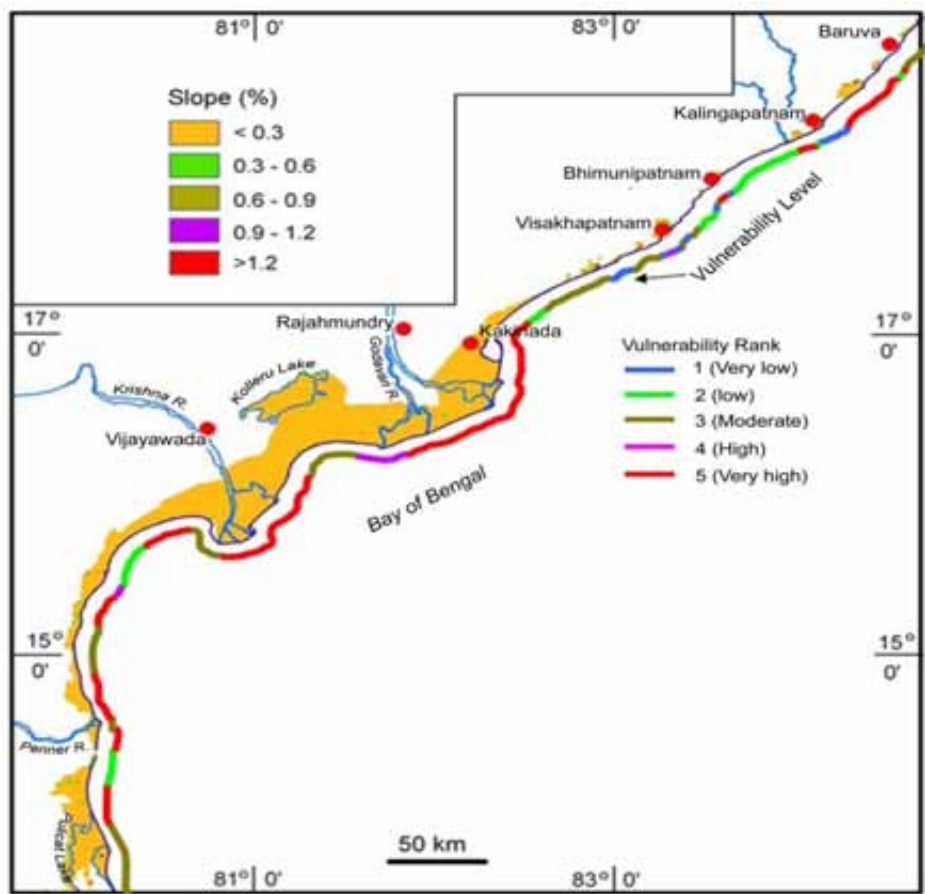


Fig. 7.22: Slope map of the Andhra Pradesh coastal zone. The thick colored parallel line all along the coast indicates the vulnerability ranking of the various segments based on the slope conditions

Spring-tide range

As can be seen from the tidal ranges shown in the hydrographic charts published by the Indian National Hydrographic Office, the AP coast is under the influence of a microtidal environment. The mean spring tide range (the

average of spring high- and low-tides) is taken into consideration from 9 stations all along the coast (Fig. 7.25). The spring-tide range at Krishnapatnam in the south is the lowest at 0.7m, whereas the highest range of 1.4 m is at Visakhapatnam in the northern sector of the AP coast. Based on the tidal ranges at these 9 points, the entire coastline is segmented to assign the tide range value of the nearest tide station.

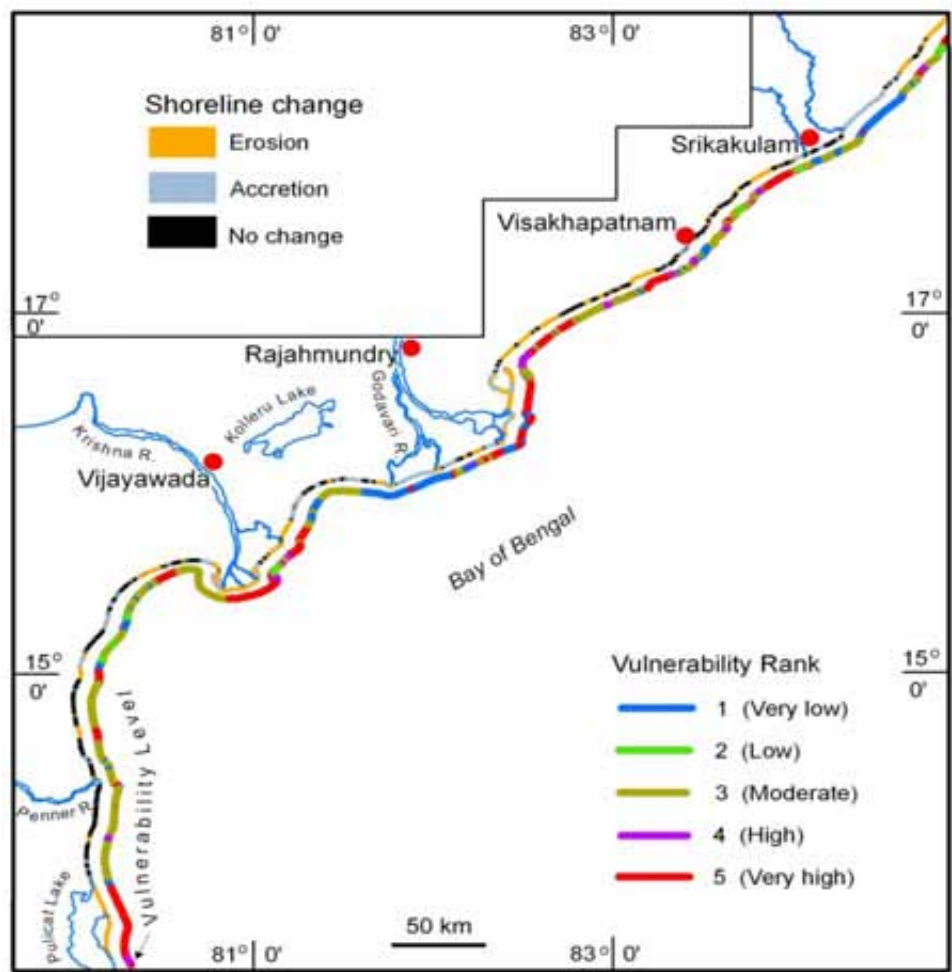


Fig. 7.23: Map showing changes in the shoreline due to erosion and accretion in different sectors of AP coast during a 16-year period between 1990 and 2006. The shoreline retreated by erosion mainly along the low-lying sections of the Krishna and Godavari deltas. The thick colored parallel line all along the coast indicates the vulnerability ranking of the various segments based on the shoreline change history.



Fig. 7.24: Coastal erosion and shoreline retreat along the Krishna-Godavari delta region in Andhra Pradesh during the 16-year period (1990-2006). (a) The shoreline at Uppada village in the northeastern end of the Godavari delta retreated by 200 m with the sea engulfing almost one half of the village; (b) ONGC test drill site in the central part of the Godavari delta, which was more than 200 m inland about 10 years ago is now in the intertidal zone; Beach ridges which were behind the beach and fore dune are being breached (c), and the casuarina plantations over them (d) are uprooted in the southern part of the Godavari delta; (e) the bottom-set prodelta clay beds are exposed due to heavy erosion in the central part of the Krishna delta where the shoreline retreated by 400m in 16 years; and (f) the shoreline retreated by 500 m and mangrove vegetation is destroyed by the advancing sea in the western part of the Krishna delta.

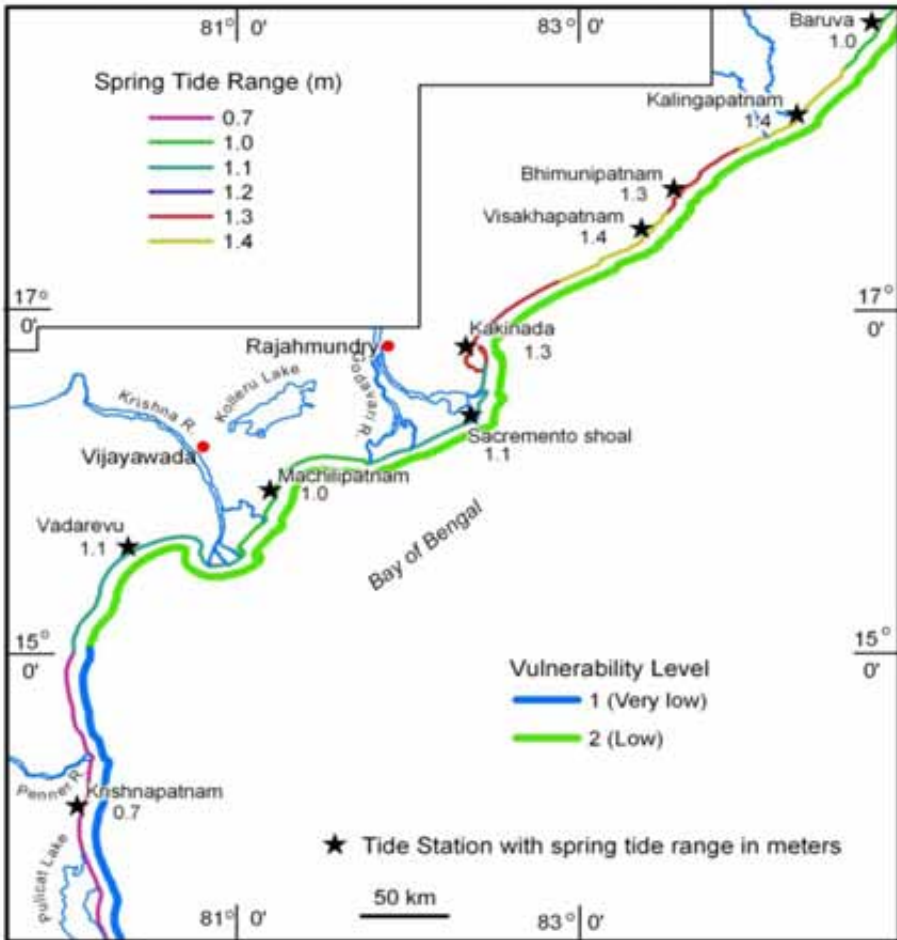


Fig. 7.25: Map showing the spring tide range along the AP coast. The data are based on National Hydrographic Charts wherein tide ranges for 9 stations along the coast are available. The thick colored parallel line all along the coast indicates the vulnerability ranking of the various segments based on the tidal variations.

For instance, the coastline between Krishnapatnam (0.7 m) and Vadarevu (1.1 m) to its immediate north is divided into 2 equal segments with the segment near Krishnapatnam representing the tidal range of 0.7 m, while the segment near Vadarevu representing the tidal range of 1.1 m. Similarly, the coastline between Vadarevu (1.1 m) and Machilipatnam (1.0 m) is segmented into two equal parts to represent 1.1 m near Vadarevu and 1.0 m near Machilipatnam.

Thus the entire AP coastline is segmented based on the tidal range values at the 9 stations. Subsequently, the vulnerability ranking is given (Table 7.3) following the vulnerability ranges from Diez et al. (2007). Since the tidal range is between 0.7 m and 1.4 m, the entire AP coast has fallen into only two categories, namely very low vulnerable level (<1.0 m) and low vulnerable level (1.0 to 2.0 m) as far as the tidal range is considered. Accordingly, the coast is segmented as shown in Fig. 7.25.

Significant wave height

In the absence of *in situ* wave data for the AP coast, computer simulated wave models are used in this study. The Spectral Wave (SW) model of MIKE-21, a software developed by the Danish Hydraulic Institute, Denmark was used for simulation of the waves. Wind velocity component derived from ECMWF (European Center for Medium Range Weather Forecast) assimilated with near real-time measurements through Seawinds scatterometer onboard QuikSCAT satellite and by the three Special Sensor Microwave Imager (SSM/I) onboard DMSP (Defense Meteorological Satellite Program) satellites F13, F14, and F15 which are available from the CERSAT (Centre ERS d'Archivage et de Traitement-French ERS Processing and Archiving Facility) website (<ftp://ftp.ifremer.fr/ifremer/cersat/products/gridded/mwf-blended/data/>) were input into the model for generating the waves. The model simulates the growth, decay and transformation of wind-generated waves and swells in offshore and coastal areas (Vethamony et al. 2006). The model comprises phenomenon like wind induced wave growth, nonlinear wave interaction, wave breaking, bottom friction, shoaling and refraction. The governing principle is the 'wave action balance equation' formulated in Cartesian coordinates. The conservation of equation of wave is:

$$\frac{\partial N}{\partial t} + \nabla \cdot (\vec{v}N) = \frac{S}{\sigma}$$

Where $N(\vec{x}, \sigma, \theta, t)$ is the action density, t is the time, $\vec{x} = (x, y)$ is the Cartesian coordinate, $\vec{v} = (C_x, C_y, C_\sigma, C_\theta)$ is the propagation velocity of a wave group in the four-dimensional phase space. The data on the significant wave heights (SWH) pertaining to July and August 2005 thus derived from the simulation model for the Machilipatnam region (black line in Fig. 7.26) were

compared with the measured data of the corresponding period from the buoy DS5 of NIOT (National Institute of Ocean Technology) moored off Machilipatnam (blue line in Fig. 7.26). A correlation coefficient of 0.873 with an RMS of 0.41m was obtained from the comparison between the two data sets (Fig. 7.26).

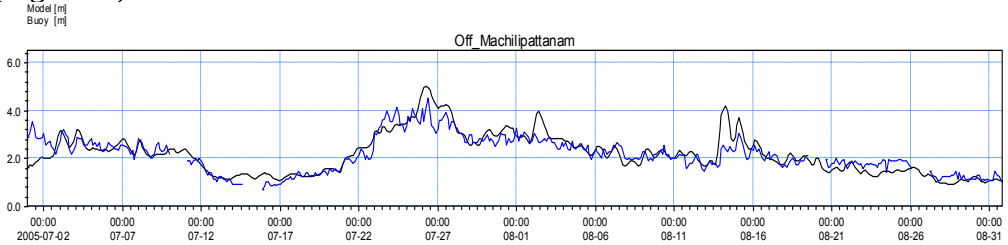


Fig. 7.26: Comparison between the model simulated (black line) and buoy measured (blue line) data on the significant wave heights at Machilipatnam

Considering the dependability of this method in estimating the wave conditions, the simulated significant wave heights (SWH) are extracted for 19 stations (Fig. 7.27) covering the entire AP coast. In order to assign the SWH values to the entire coast from the SWH values of the 19 discrete locations, the coastal segment between two consecutive wave stations is divided into two equal parts and the SWH value of the nearest station is assigned to each coastal division. For instance, the coastal sector between Pulicat and Durgarajapatnam stations is divided into two equal parts and the segment north of Pulicat is assigned the SWH value of 1.2 m similar to that of the Pulicat station and the coastal segment south of Durgarajapatnam is assigned with 1.08 m. Likewise, the entire AP coast is segmented and the corresponding SWH value is assigned to each section. Further, considering the SWH values of different coastal sections, the entire AP coast is classified into five vulnerability levels (Fig. 7.27) adopting the SWH ranges (Table 7.3) from Pendleton et al. (2004), and Thieler and Hammer-klose (1999).

Relative proportions of vulnerability levels

The percent shoreline length in each of the five vulnerability rank levels of all the five variables are shown in Table 7.4.

Table 7.4: Length of the shoreline in each of the vulnerability class of the five variables. The length is in km, and its per cent share in parenthesis (in bold)

Variable	Length of shoreline in km (with its % share in bold) in each of the Vulnerability Class (rank)				
	Very Low (1)	Low (2)	Moderate (3)	High (4)	Very High (5)
Geomorphology	21.1 (2.1)	18.6 (1.8)	286.6 (27.8)	380.7 (36.9)	323.0 (31.4)
Coastal Slope	73.8 (7.1)	134.3 (13.1)	256.5 (24.9)	50.0 (4.9)	515.4 (50.0)
Shoreline Change	221.5 (21.5)	22.4 (2.2)	379.2 (36.8)	89.5 (8.7)	317.4 (30.8)
Mean Spring tide range	205.0 (19.9)	825.0 (80.1)	----	----	----
Significant Wave Height	220.7 (21.4)	61.8 (6.1)	301.1 (29.2)	270.5 (26.2)	175.9 (17.1)

Geomorphologically, about 70% of AP coast is in high to very-high vulnerable level. Only about 3% of the coast represented by rock promontories and embayed and indented sections comes under very-low to low categories. In terms of coastal slopes, as much as 50% of AP coast falls into very-high vulnerable category. The recent history of shoreline behavior in terms of erosion and accretion indicated that comparatively larger sections of the shoreline that has not experienced any considerable change accounted for 36.8%, while about 31% experienced a very high degree of erosion. The notable characteristic of AP coast is that it is under a microtidal environment with the entire AP coast under low to very low vulnerability categories only. The wave influence along AP coast is of moderately high with about 43% of the shoreline comes under high to very high vulnerability classes. Moderate class accounts for about 30%. Overall, the data on the percentages of each of the vulnerability classes of the five variables show certain degree of variability. It is necessary therefore to integrate all the variables in order to obtain a reliable index to assess the vulnerability of different sections of the coast.

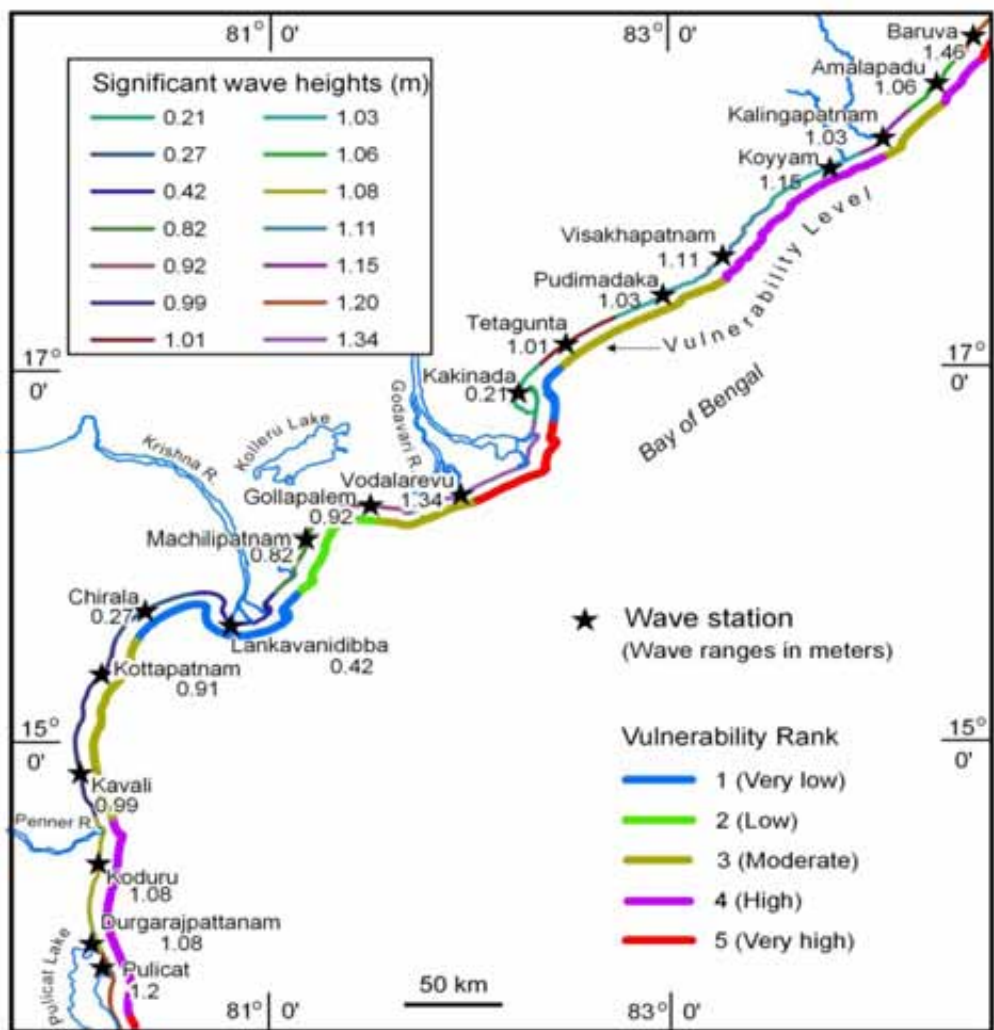


Fig. 7.27: Map showing the significant wave heights along AP coast. The thick colored parallel line all along the coast indicates the vulnerability ranking of the various segments based on the SWH values.

Coastal Vulnerability Index and Risk Assessment

The rank values of all the five physical variables are integrated to develop a coastal vulnerability index (CVI) through GIS techniques. The integration of the rank values of the variables may be done either through multiplicative

method or through additive method. In multiplicative method, the rank values all the variables of a given coastal segment are multiplied with each other in order to obtain a single value which is considered as the vulnerability index representing that particular coastal segment. On the other hand, in the additive method, the rank values of all the variables of a given coastal segment are summed up to arrive at the index value. These two basic ways of indexation can be modified several ways depending up on which of these two methods or their derivatives best represent the conditions along a given coast. For instance, the CVI was calculated by Diez et al. (2007), Doukakis (2005), Gornitz (1991), and Thieler and Hammer-Klose (1999) as the square root of the product of the ranking factors (1 to 5 for each parameter) divided by the number of parameters considered. Gornitz (1991) opined that although the CVI can be computed as either the sum or product of the parameters, the latter has the advantage of expanding the range of values. Diez et al. (2007) on the other hand, by examining both the sum as well as the product of all the variables, observed that the CVI as the sum of differentially weighted variables was more responsive to the environmental diversity. Our calculations using both the methods also indicated that the sum of the five variables, the rank numbers (1 to 5) of each, multiplied by a specified weightage value, as detailed below, represents the conditions along the AP coast better.

Coastal Vulnerability Index

Geomorphology and the slope of the coast are the two major factors influencing the coastal response to sea-level rise. Therefore, the rank values of both these variables are given more weightage than the other three variables. Therefore the rank values of different coastal segments as far as these two variables are concerned are multiplied four times and the resultant values are used in additive method for the CVI calculation. Similarly, the variable ‘shoreline change’ is assigned a weightage value of 2, while the rank numbers representing the tide range and significant wave height are taken for calculation without assigning any additional weightages. Thus the CVI of each coastal segments of the entire AP coast is calculated using the following formula:

$$CVI = 4g + 4s + 2c + t + w$$

Where g refers to vulnerability ranking of geomorphology of the coastal segment in question, s refers to that of coastal slope, c to that of shoreline change, t refers to spring tide-range and w refers to the vulnerability rank of the significant wave height. The multiplication factors 4 and 2 used in the formula represent the weightage factors assigned to the variables geomorphology and slope, and shoreline change, respectively. The data are processed in geographic information system software (we used ArcGIS). Each variable in the form of a 'Shape File' is taken into GIS and the vulnerability ranks of all the coastal segments for the five variables are entered into the corresponding attribute tables against the unique ID of each coastal segment. Similarly, the weighted values of each variable for each coastal segment are automatically generated as per the weightages given in another column in the respective attribute tables in the system. Then the shape files are joined using the 'Spatial Join' option in 'Overlay' module in 'ArcTools' menu. In order to integrate all the variables, we have taken the coastline as a line feature in GIS, whereas in earlier studies the coast was divided into spatial grids of 1-minute interval (Pendleton et al. 2004), 15-minute interval (Diez et al. 2007), or as closely spaced points along the coast (Doukakis 2005). However such grid cell, or point sampling would have some amount of generalization thereby affecting the accuracy of the final results. Therefore, the entire coast is taken as a line feature in GIS in which every point along the coast is considered for the analysis. The final output map contains the attributes of all the five variables. Thus the final map generated combining all the variables showed 307 segments of the coast each having a unique identity number in its corresponding attribute table. Another column is added to this attribute table for the CVI formula so that the system generated the CVI values for all the 307 coastal segments of the AP coast.

Risk levels of AP coast

The CVI values thus obtained ranged from 15 to 57. The entire range of CVI values can be divided into four equal parts (Diez et al. 2007; Gornitz 1991), quartiles (Pendleton et al. 2004) or percentiles (Doukakis 2005) each indicating certain risk level of the coastline to sea-level rise. The lower range of CVI values indicate low-risk, followed by moderate-risk, high-risk and finally the upper range of values indicating the coast at very high-risk level. We tested these methods. The CVI values when divided into four equal parts, only the

rocky coasts along the AP coast have fallen into the low risk coasts. However, in the quartile/percentile methods method even the sand dune coasts also come under the low-risk category. But a comparison of the geomorphology map (Fig. 7.21) and the shoreline change map (Fig. 7.23) show wide-spread erosion along certain dune-front coastal sectors like along the Pulicat Lake coast, which cannot be classified as low-risk coast. Therefore, the entire range of CVI values (15 to 57) are divided into four equal parts in this study. Accordingly, the coastal risk level map for the AP coast is generated by grouping various coastal segments into the four risk classes (Fig. 7.28).

Tamil Nadu Coast

Geomorphology

The geomorphology map for entire Tamil Nadu coastal sectors was prepared by interpreting raw and digitally processed IRS P6 LISS 3 and AWiFS and LANDSAT satellite data. While interpreting the geomorphology, wherever necessary, the satellite data was subjected to various image processing techniques viz: Density slicing, Linear stretching, Filtering, Band ratioing using different combinations of four band data, Principal component analysis, Decorrelation stretching etc. using ENVI image processing software and some samples are shown Fig. 7.29. At places, satellite data was wrapped over the SRTM based DEM and geomorphic features were interpreted with 3D visualization.

For the preparation of geomorphology map, the classification as given Table 7.5 has been used. The geomorphology of the area showed that the area is represented by a package of landforms of tectonic origin, viz: dissected and undissected uplands and pediments; fluvial origin viz. flood plains, palaeo channels, river beds, sand bars etc and fluvio marine and marine origin like deltaic plains, beach ridges and swales, tidal flats, mangroves, creeks, beaches, etc. as shown in Fig. 7.30.

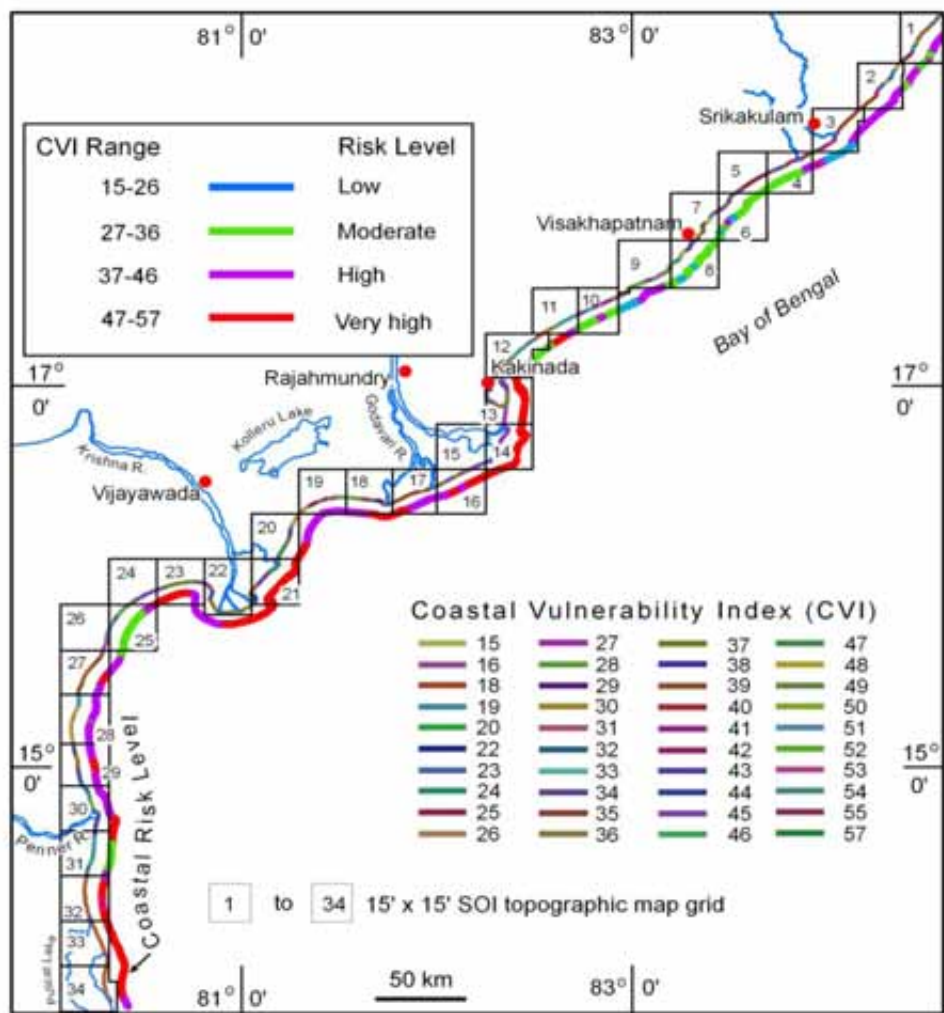


Fig. 7.28: Coastal vulnerability index (CVI) and risk levels of different segments of AP coast. Each color of the coastline indicates a particular CVI value from 15 to 57 (Note there are no coastal segments with CVI values of 17, 21 and 56). The thick colored parallel line all along the coast shows the risk levels of the coast based on the categorization of CVI values into four risk classes as shown in the upper left legend. The black colored squares along the coastline (from 1 to 34) represent the grid of SOI topographic maps. The actual map IDs and the risk level of the coast covered by each map are detailed in Table 7.3

Table 7.5: Geomorphological Classification system adopted in the study

	Landforms	Symbol	Dominant Process (symbol)	Level vulnerability SLR	Proposed representation	id
1	Beach	BC	Marine (m)	High (3)	BCm3	1
2	Barrier islands	BI	Marine(m)	High (3)	BI m3	2
3	Spit	SP	Marine(m)	High (3)	SPm3	3
4	Backwater	BW	Marine(m)	High (3)	BWm3	4
5	Lagoon	LG	Marine(m)	High (3)	LGm3	5
6	Present swale	PRSW	Marine(m)	High (3)	PRSWm3	6
7	Mangrove swamp	MS	Marine (m)	High (3)	MSm3	7
8	Tidal Creek	TC	Marine (m)	High (3)	TCm3	8
9	Palaeo lagoon	PL	Marine(m)	High (3)	MGm3	9
10	Mudflat	MF	Marine(m)	High (3)	MFm3	10
11	Protruding delta	PRD	Marine (m)	High (3)	PRDm3	11
12	Tidal lake	TL	Marine (m)	Medium (2)	TLm2	12
13	Palaeo mudflat	MP	Marine (m)	Medium (2)	MPm2	13
14	Palaeo swale	PSW	Marine (m)	Medium (2)	PSWm2	14
15	Sand dune	SD	Eolian (w)	Medium (2)	SDw2	15
16	Beach ridge	BR	Marine (mw)	Medium (2)	BRmw2	16
17	Strand plain complex	SPC	Marine (m)	Medium (2)	SPCm2	17
18	Coastal Plains	CP	Fluvio-marine (fm)	Medium (2)	CPfm2	18
19	Palaeo swale overprinted by delta	PSOD	Fluvio-marine (fm)	Medium (2)	PSODfm2	19
20	River	R	Fluvial (f)	High (3)	Rf3	20
21	Channel bar	CB	Fluvial (f)	High (3)	CBf3	21
22	Channel island	CI	Fluvial (f)	Medium (2)	CI f2	22
23	Floodplain	FP	Fluvial (f)	Medium (2)	FPf2	23
24	Palaeochannel	PC	Fluvial (f)	Medium (2)	PCf2	24
25	Palaeochannel over printed by misfit stream	PCMS	Fluvial (f)	High (3)	PCMSf3	25
26	Delta plain (lower)	DL	Fluvio-marine (fm)	Medium (2)	DLfm2	26
27	Delta plain (upper)	DU	Fluvial (f)	Low (1)	DPf1	27
28	Deltaic plain / Deltaic lobes	DP/DL	Fluvio-marine (f)	Medium (2)	DP/DLfm2	28
29	Inter lobal depression	ILD	Fluvial (f)	Medium (2)	ILDf2	29
30	Inter fluvial sandbars	IFS	Fluvial (f)	Medium (2)	IFSf2	30
31	Meander plain	MP	Fluvial (f)	Medium (2)	MPf2	31
32	Meander scar	MS	Fluvial (f)	Medium (2)	MSf2	32

33	Natural levee	NL	Fluvial(f)	Medium (2)	NLf2	33
34	Lake plain	LP	Fluvial(f)	Medium (2)	LDf2	34
35	Headland	HL	Fluvial(f)	Medium (2)	HLf2	35
36	Tank	T				36
37	Rocky outcrop/ upland unclassified	UNCLAS SIFIED	Nil	Nil	Nil	37

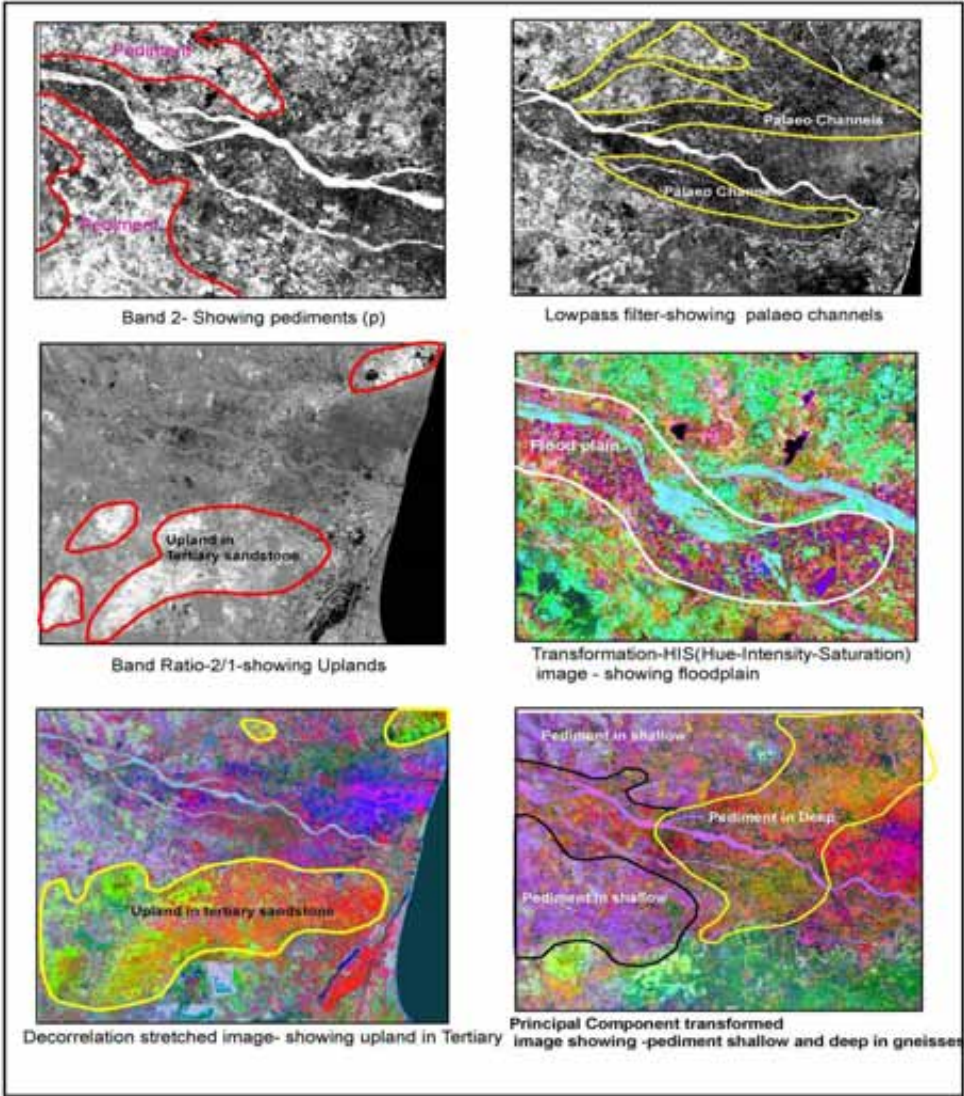


Fig. 7.29: Digitally processed IRS LISS 3 data showing geomorphic features in Ponnaiyar coastal region

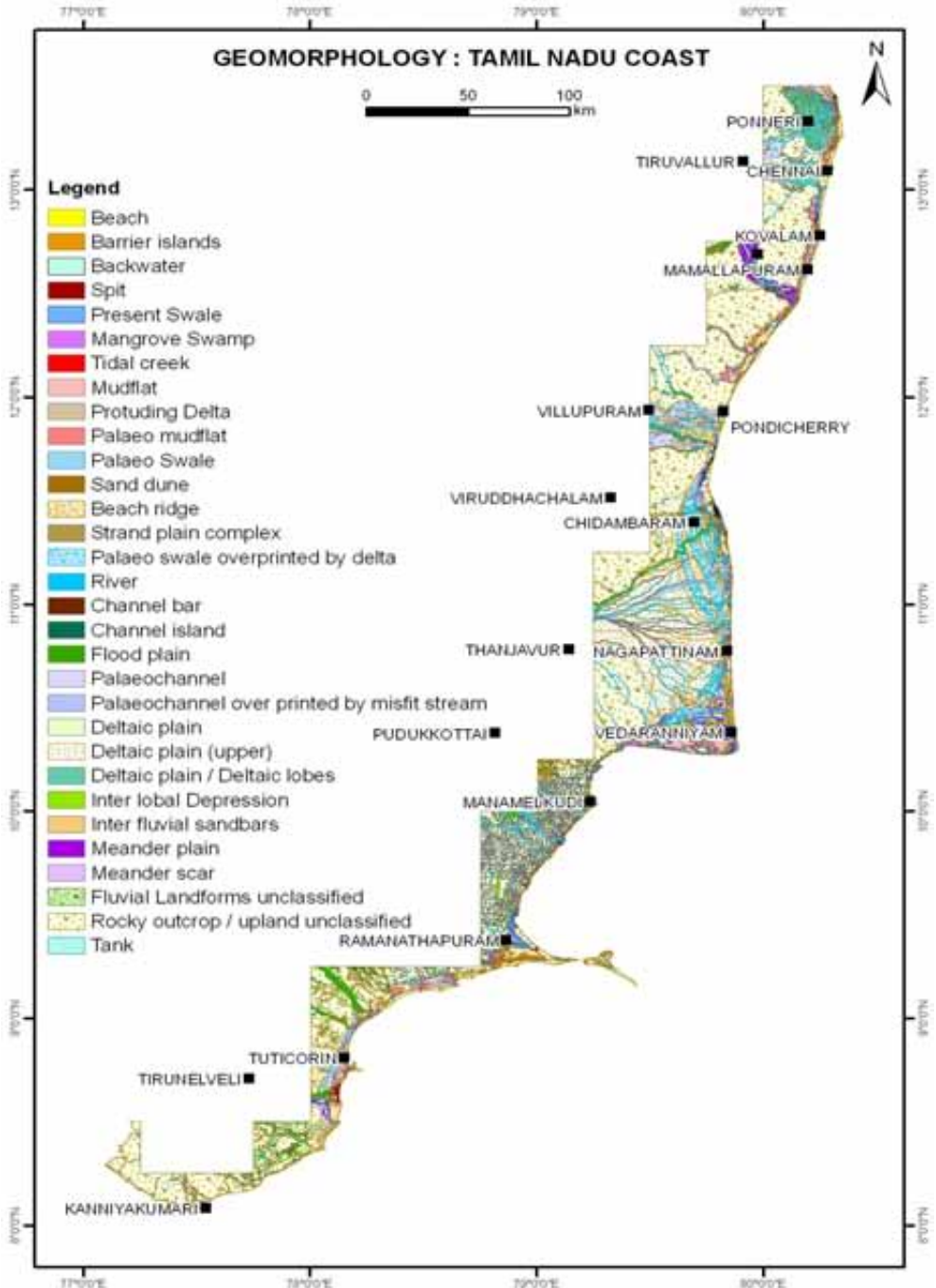


Fig. 7.30: Geomorphological map of the Tamilnadu coast

Landuse/landcover

Similarly, landuse/landcover map was prepared for the Tamil Nadu coast using digitally processed satellite data (Fig. 7.31). For better interpretation, post and pre monsoon IRS P6 AWIFS data were used. Wherever necessary, image processing techniques and SRTM DEM wrapped FCC data were also used for interpretation. For the preparation of landuse/landcover map, the classification system given in Table 7.6 has been used.

Table 7.6: Landuse / Landcover classification system adopted in the study

	Level I	Level II	Level III
1	Wetland		
1.1		Mudflat /tidal flat	
1.1.1			Sub - tidal
1.1.2			Inter - tidal
1.1.3			High tidal
1.2		Beach / Patch	
1.3		Spit	
1.4		Bar/barrier / island	
1.5		Shoals	
1.6		Beach ridge	
1.7		Rocky coast	
1.8		Rock exposure	
1.9		Mangrove	
1.9.1			Very Dense
1.9.2			Dense
1.9.3			Sparse
1.9.4			Degraded
1.10		Salt-marsh/Marsh vegetation	
1. 10.1			Dense
1. 10.2			Moderately dense
1. 10.3			Sparse
1.11		Algae	
1.11.1			Dense
1.11.2			Moderately dense
1.11.3			Sparse
1.12		Sea grass	
1.12.1			Dense
1.12.2			Moderately dense
1.12.3			Sparse
1.13		Mud with vegetation	
1.14		Sand with vegetation	

1.15		Scrub	
1.15.1			Dense
1.15.2			Sparse
1.15.3			Degraded
1.16		Coral reef	
1.16.1			Fringing
1.16.2			Platform
1.16.3			Patch
1.16.4			Atoll
1.16.5			Coral Lagoon
1.16.6			Coral pinnacle
1.16.7			Coralline shelf
1.16.8			Coral head
2	Water bodies		
2.1		Estuary	
2.2		Creek	
2.3		Lagoon	
2.4		Bay	
2.5		Pond/lake	
2.6		Oxbow lake	
2.7		Meanders	
2.8		Cooling pond	
2.9		Water treatment plant	
2.10		River/stream	
2.11		Canal	
2.12		Waterlogged	
2.13		Reservoir / tank	
3	Barren/ wasteland		
3.1		Mining areas / dumps	
3.2		rock outcrops / gullied / eroded/barren land	
3.3		Brick kiln	
3.4		Sandy area	
4	Shore land		
4.1		Saline area	
4.2		Coastal dunes	
4.2.1			Dune with vegetation
4.2.2			Dune without vegetation
5	Built-up land		
5.1		Habitation	
5.1.1			Towns / Cities
5.1.2			Villages
5.2		Open/vacant land	
5.3		Industrial area	

5.4		Waste dumping	
5.5		Transportation	
5.5.1			Roads
5.5.2			Railways
5.5.3			Port/Harbour/jetty
5.5.4			Waterways
5.5.5			Airport
6	Agricultural land		
6.1		Crop land	
6.2		Fallow land	
7	Plantation		
8	Forest		
8.1		Dense forest	
8.2		Open forest	
9	Other features		
9.1		Aquaculture ponds	
9.2		Salt pans	
9.3		Cliff	
9.4		Seawall/Embankment	

Visualization of Predicted Mean Sea Level and Predicted High Tide Levels of Tamil Nadu Coast

Local Mean Sea Level of Tamil Nadu coast

To estimate the predicted MSL due to sea level rise in the next 100 yrs, the local MSL was identified first for the Tamil Nadu coast. For the same, the average monthly tidal level data was downloaded from the PSMSL (Permanent Service for Mean Sea Level) website (www.pol.ac.uk/psml) for 1952 to 2003, for the tide gauge stations of Chennai, Nagapattinam, Thangachimadam (near Rameshwaram) and Tuticorin. These were graphically analyzed with tidal heights in the Y axis and the corresponding months in the X axis. The same showed the mean tidal level or Local Mean Sea Level (LMSL) for Chennai, Nagapattinam, Thangachimadam and Tuticorin coasts respectively 0.63 m, 0.41 m, 0.42 m and 0.63 m (Fig. 7.32a - 7.32d). These LMSL data were extrapolated to entire Tamil Nadu coast as in Fig. 7.33.

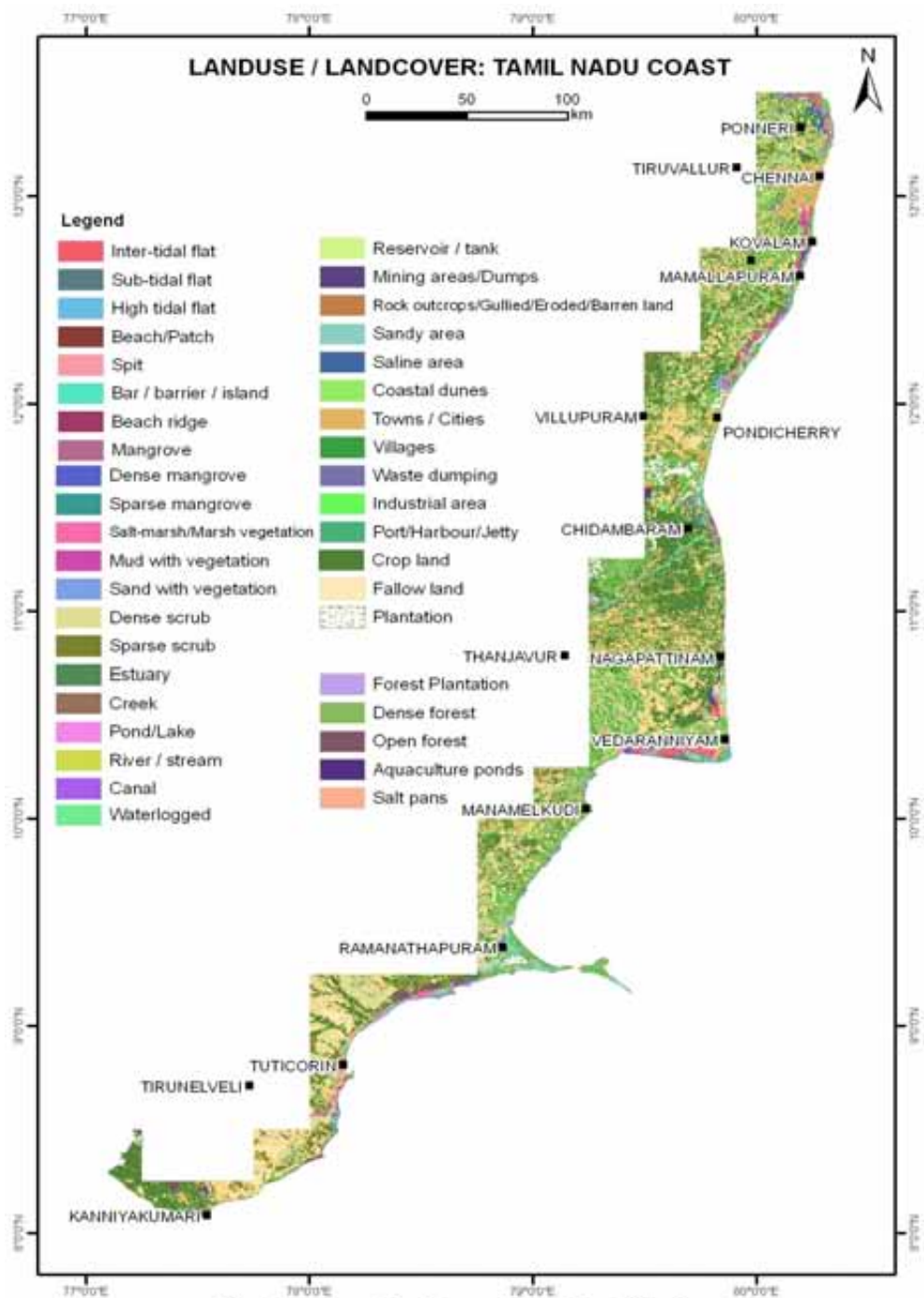


Fig. 7.31: Land use/land cover map of the Tamilnadu coast

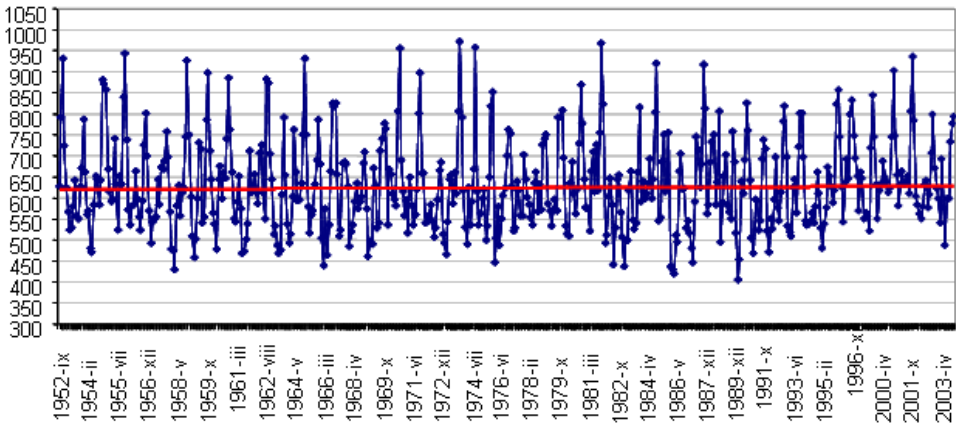


Fig. 7.32a: Tide gauge data of Chennai harbour showing the LMSL of 0.63 m

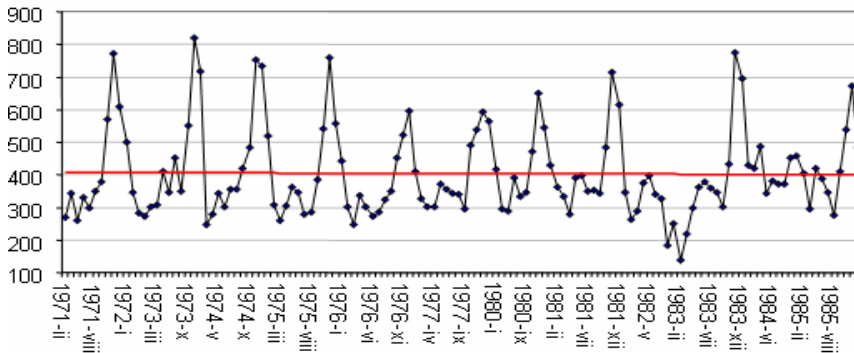


Fig. 7.32b: Tide gauge data of Nagapattinam harbour showing the LMSL of 0.41 m

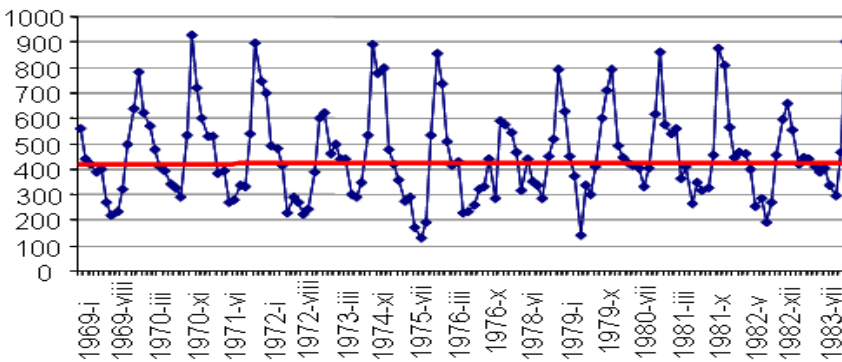


Fig. 7.32c: Tide gauge data of Thangachimadam harbour showing the LMSL of 0.42 m

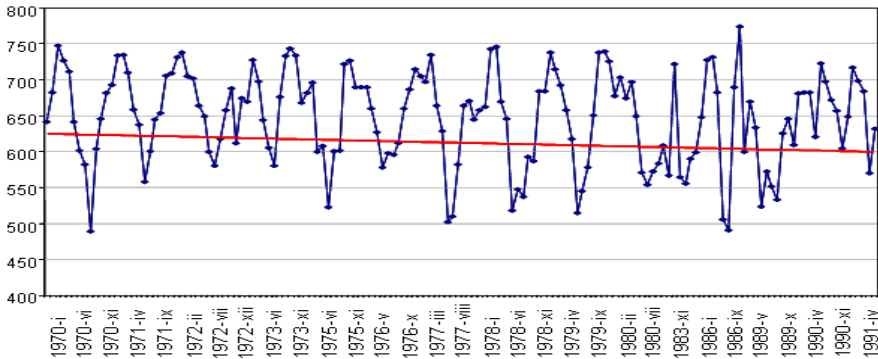


Fig. 7.32d: Tide gauge data of Tuticorin harbour showing the LMSL of 0.63 m

Elevations of Predicted Mean Sea Level of Tamil Nadu coast

The IPCC SRES has predicted that the sea level may rise to the order of 0.17 m to 0.59 m in the next 100 years due to thermal expansion of seawater, ice melting, etc. However, the IPCC SRES has further inferred the specific value of 0.59 m as the over all global sea level rise. So, the same SLR value was kept as such in the present study. The predicted sea level rise of 0.59 m was added with LMSL values of Tamil Nadu coastal sectors and the elevation of the predicted MSL for the next 100 yrs for the Tamil Nadu coastal regions was worked out (Fig. 7.33). The same show that

- ➔ The PMSL (Predicted Mean Sea Level) for Chennai – Cuddalore coastal sectors is 1.2 m
- ➔ The PMSL (Predicted Mean Sea Level) for Cauvery deltaic coastal region is 1.0 m
- ➔ The PMSL (Predicted Mean Sea Level) for Rameshwaram - Tuticorin – Capecomorin coastal regions is 1.2 m

Elevation of Predicted High Tide Level (PHTL) of Tamil Nadu Coast

The sea level is expected to rise by +0.59 m as per IPCC in the next 100 yrs and attains the elevation of +1 m with reference to LMSL (Local Mean Sea

Level) in the Tamil Nadu coastal region and leading to the submergence of low lying coastal areas. While the sea level rises, at the same time, correspondingly present limit of the high tide level will be shifted towards landward side i.e. the boundary of inter tidal zone will be further shifted inside the land and leading to erosion, degradation, pollution, etc. of coastal resources due to inter tidal activity within this area.

So, following the estimation of elevation of predicted MSL in next 100 years, the elevation of such Predicted High Tide Line (PHTL) in next 100 years was demarcated. For the same, at first present elevation of HTL was brought out using DGPS (using Sokkia stratus DGPS instrument) surveys, analysis of tide gauge data and literature data. The DGPS survey was conducted in 50 locations in the northern part of the Cauvery delta (Coleroon – Tirumullaivasal sector) along the low water line (Fig. 7.34a) which gave an average elevation of 0.33 m for the low tide level (LTL) and along the high tide line (HTL) (Fig. 7.34b) which gave an average elevation of 1.90 m for the High Tide Level (HTL). Comparison of this 1.90 m elevation of HTL with local MSL of 0.41m (derived from the near by Nagapattinam tide gauge station) indicate that the average high tide level is 1.5 m. But, average height of the tide reported in Chennai Harbour and Tuticorin Harbour is 1.2 m. Further, National Hydrographic chart of Tamil Nadu coast shows maximum height of the high tide is 1.2 m. From the above, for the present study, the height of the high tide level was taken as 1.2 m for Tamil Nadu coast.

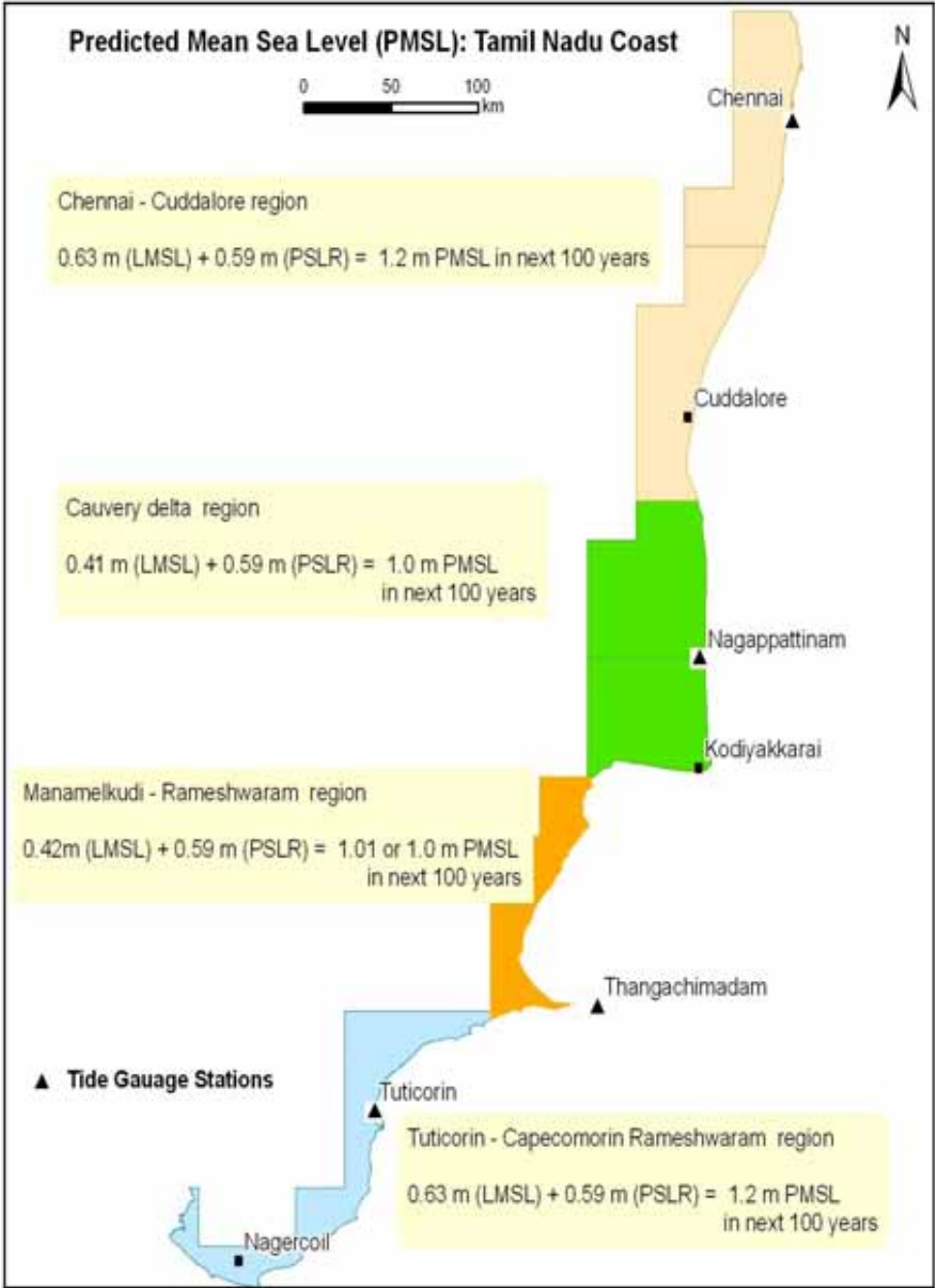


Fig. 7.33: PMSL zonation map of the Tamilnadu coast



Fig. 7.34a: DGPS survey at Low Tide Level

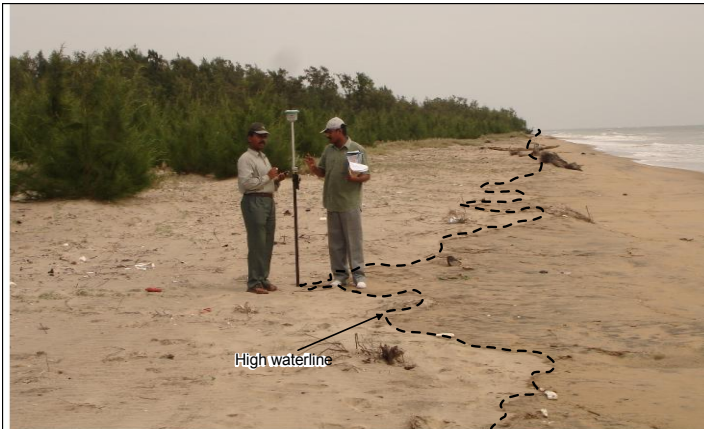


Fig. 7.34b: DGPS survey at High Tide Level along Coleroon coast

Finally the elevation of the predicted HTL was worked out by adding the predicted MSL with the present height of the high tide level (1.2 m) (Fig. 7.35). The same shows that

- ➔ The PHTL (Predicted High Tide Level) for Chennai – Cuddalore coastal sectors is 2.4 m
- ➔ The PHTL (Predicted High Tide Level) for Cauvery deltaic coastal region is 2.2 m

➔ The PHTL (Predicted High Tide Level) for Rameshwaram - Tuticorin – Capecomorin coastal regions is 2.4 m

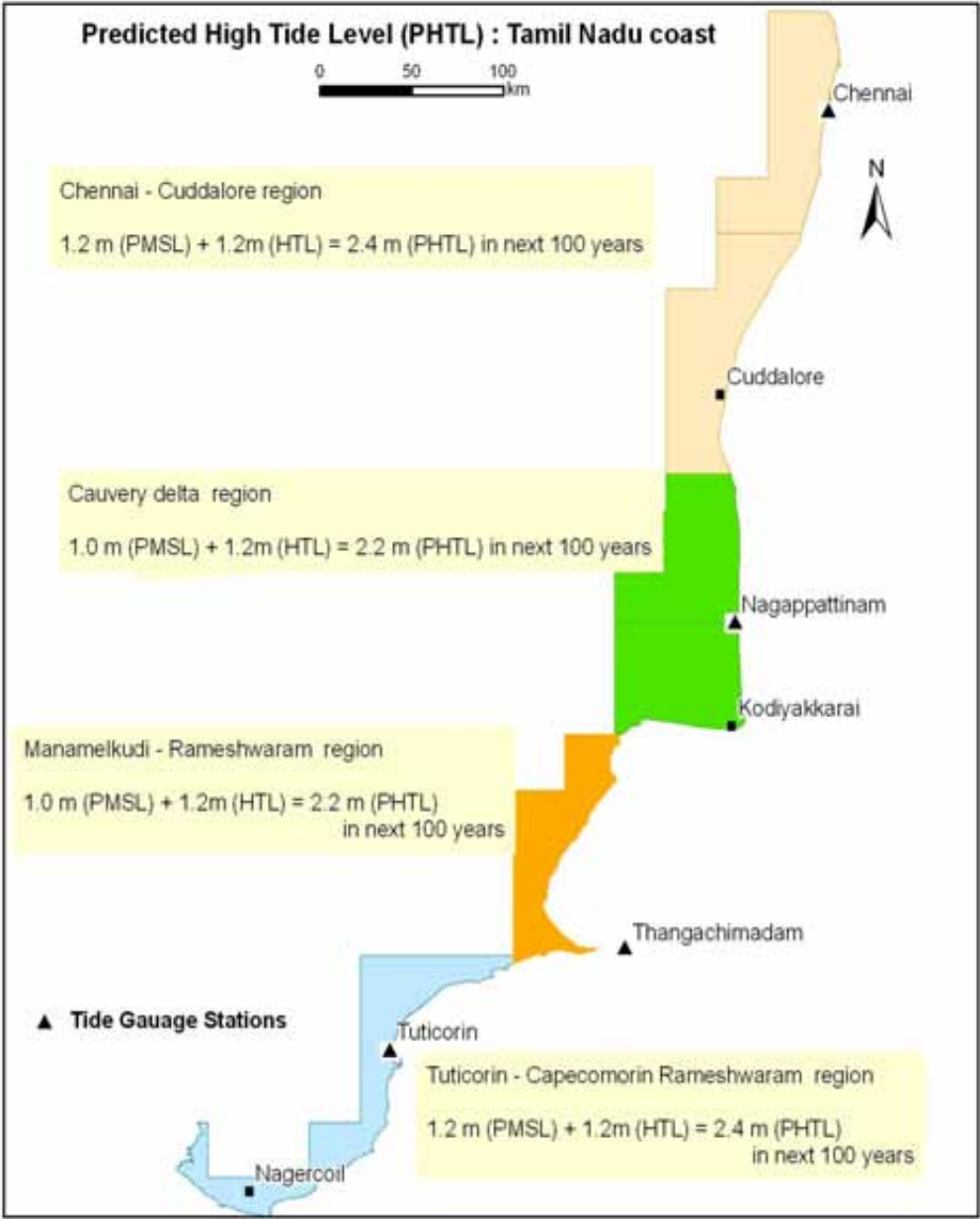


Fig. 7.35: Predicted High Tide Level of Tamilnadu coast

Visualization of PMSL and PHTL

a) Generation of calibrated SRTM DEM

Subsequent to the identification of elevation of the PMSL and PHTL for the Tamil Nadu coastal sectors, the pattern and the limits of inundation due to PMSL and PHTL was visualized. For the same, as no fine resolution topographic data was available, SRTM (Shuttle Radar Topographic Mission) data of NASA was downloaded from the web site (www.srtm.csi.cgiar.org). The SRTM data provides elevations for the ground segment size (pixel) of 90m² with the elevation accuracies of 0 to 5 meters in the coastal and plain regions and 5-10 m in mountainous regions. The SRTM data were cross checked for their accuracy by conducting DGPS (Differential Global Positioning System) surveys in over 100 locations in various terrain conditions (Fig. 7.36a). Such DGPS measured data and the corresponding SRTM elevation data of the 100 locations showed good correlation as shown by the scatter plot of the coastal region (Fig. 7.36b) and the Tiruchirappalli plain region (Fig. 7.36c).

However, to have fine resolution in the elevations, the SRTM data was calibrated as detailed below. The bi-variate regression analysis was carried out between the 100 DGPS elevation data and the corresponding 100 SRTM data, by keeping the former as the dependant variable and the latter as the independent variable, using SPSS software. The same revealed the correlation coefficient of 0.996 indicating an excellent correlation between the both. So, by using the Coefficient A and B values, the elevations of the SRTM data were calibrated using the following regression equation.

Dependent Variable = Coefficient A + (Coefficient B * SRTM Data)

(or)

Ground elevation = $-0.779 + (0.991 * \text{SRTM})$

By using the above equation, each pixel (ground segment) of the down loaded SRTM data was calibrated using the Spatial Analyst module of Arc GIS.

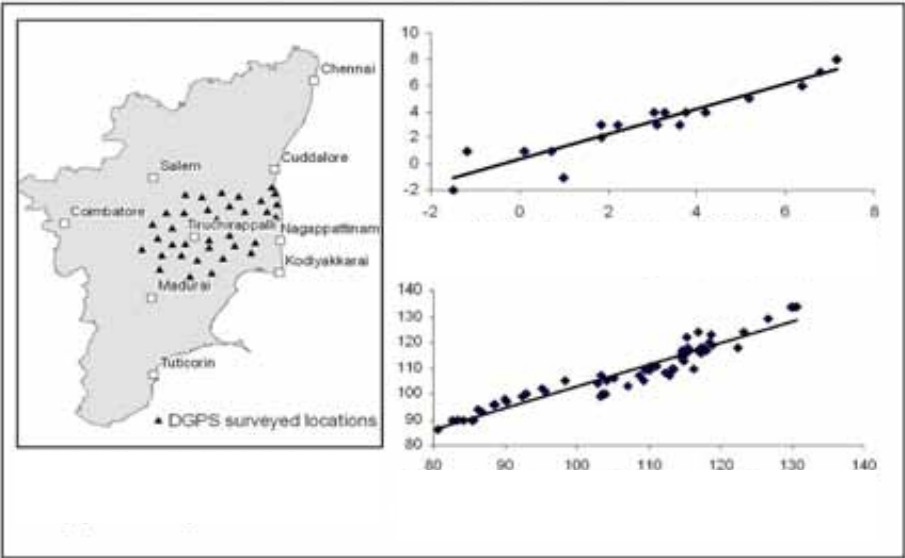


Fig. 7.36a: DGPS Survey locations – Study Area – Tiruchirapalli – Nagapattinam region; Figure 7.36b: Scatter Plot between DGPS values and SRTM values in coastal region (study area); Figure 7.36c: Scatter plot between DGPS values and SRTM values in Tiruchirapalli plains

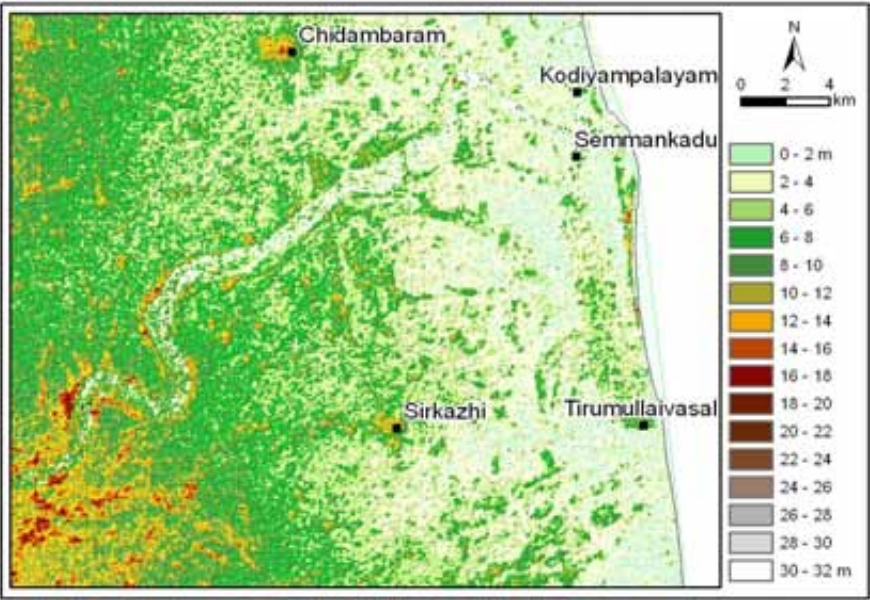


Fig. 7.37a: Downloaded SRTM data

However, in order to achieve still finer spatial and elevation resolution, the SRTM data with 90m spatial resolution was resampled to 30m spatial resolution using spatial analyst module of ArcGIS. By using such calibrated and resampled SRTM data, new resampled SRTM DEM was generated using ArcGIS software. For example, the density sliced outputs of downloaded SRTM and resampled and calibrated SRTM data were shown in Fig. 7.37a & 7.37b.

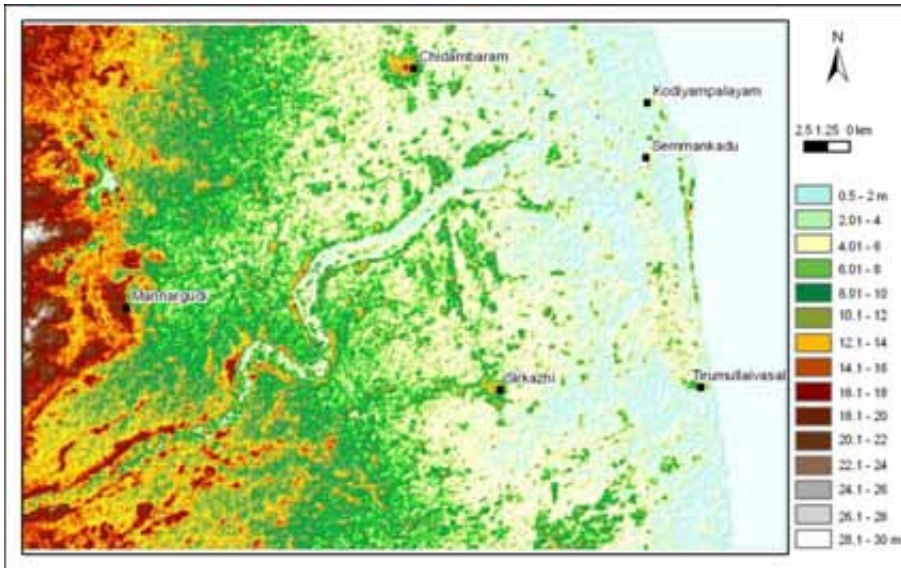


Fig. 7.37b: Calibrated and resampled SRTM data

b) Visualization of PMSL and PHTL inundation over Calibrated and Resampled SRTM DEM

If the estimated Predicted MSL was 1m, then all the pixels having less than or equal to 1m elevations in calibrated and resampled SRTM data were buffered out as zones prone for submergence due to such predicted SLR or PMSL in another 100 years, were visualized. Similarly, the calibrated and resampled SRTM pixels falling under the elevation range of 1 to 2.2 m were buffered out as the zones prone for inter tidal activities and the related degradation like erosion, deposition, salinity, pollution, etc., due to such predicted shift of the high tide line (PHTL) in the next 100 years. Such zones prone for both

submergence and degradation were vectorised from the calibrated and resampled SRTM data using ArcGIS and the same is shown in Fig. 7.38. Similarly, the predicted MSL and predicted HTL were visualized for entire Tamil Nadu coast and the same is shown in Fig. 7.39.

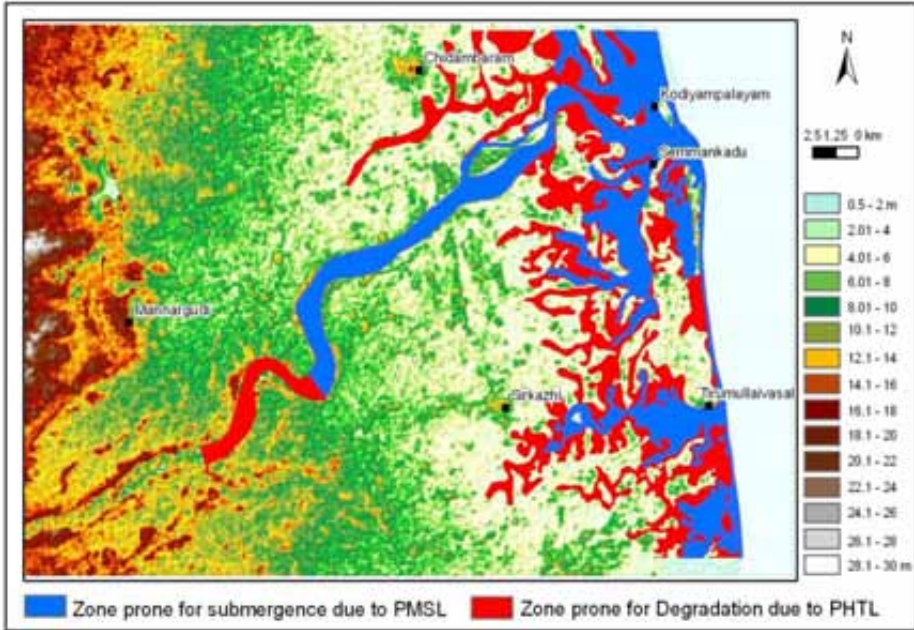


Fig. 7.38: Visualization of Predicted SLR (PMSL) and Predicted High Tide Line (PHTL) over calibrated and resampled SRTM data

Coastal Vulnerability mapping with special reference to Sea Level Rise

After analyzing the sector wise SLR impact studies along Tamil Nadu coast, a study was undertaken to analyse the vulnerability of Tamil Nadu coast using Rank and Weightage method.

A lot of international studies for assessing vulnerability of a coast to climate change have been developed from the IPCC Common Methodology for vulnerability assessment developed in 1991. For example, the coastal vulnerability index (CVI) developed by the United States Geological Survey (Gornitz 1991) based on the geomorphology, coastal slope, relative sea-level rise, shoreline erosion/accretion, mean tidal range and mean wave height.

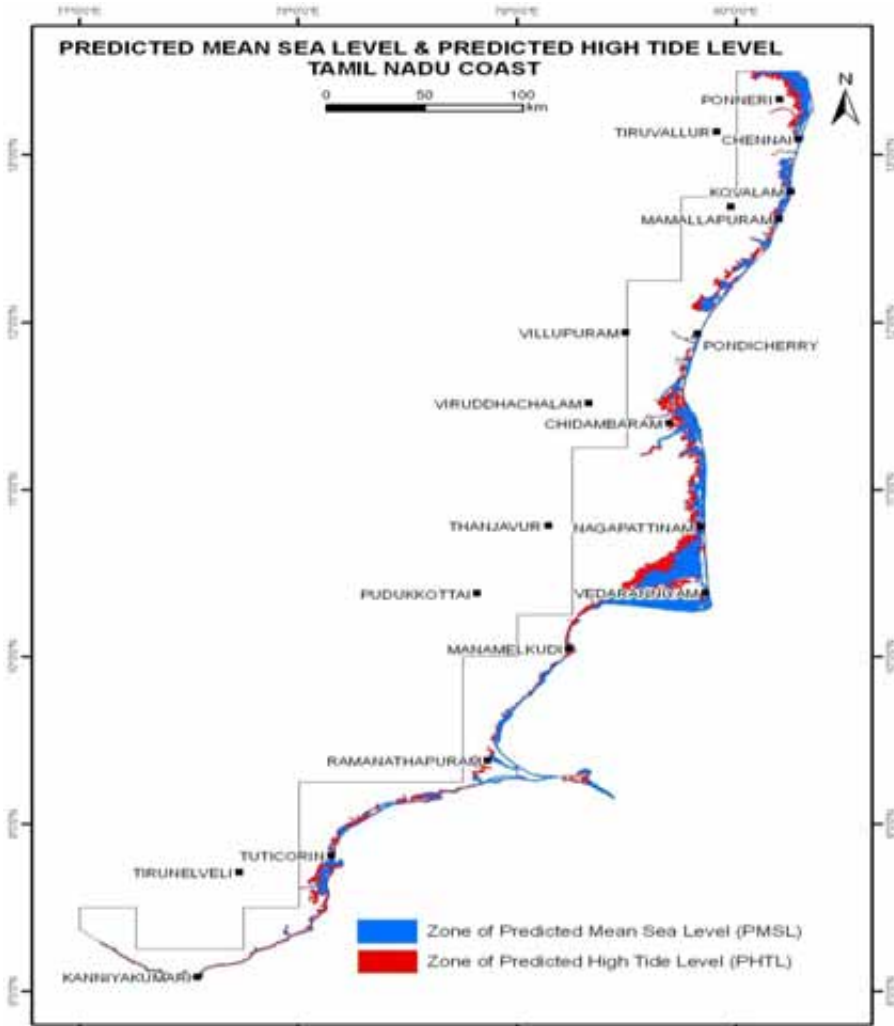


Fig. 7.39: Zones of PMSL and PHTL visualized from the calibrated SRTM data

Recently, Nageswara Rao et al (2008) have brought out the coastal vulnerability mapping for Andhra Pradesh coast lines using various physical variables like geomorphology, slopes, shoreline changes, mean spring tide range and wave height.

With the above background, the coastal vulnerability mapping for Tamil Nadu coast was carried out using various available physical parameters such as:

- ➔ Geomorphology
- ➔ Coastal slope
- ➔ Shoreline changes (Erosion and Accretion)
- ➔ Mean tidal range of the coastal segments

Geomorphology

The Geomorphology map (Fig. 7.30) was critically analyzed and on the basis of its vulnerability to sea level rise and possible inundation, the coast line was divided into following five classes (ranks) and the same is shown in Fig. 7.40.

- 1 - Very low (Rocky coasts, Cliffed coasts)
- 2 - Low (uplands, pediments, Medium cliffs, Indented coasts)
- 3 - Moderate (Low cliffs, alluvial plains, beach ridges)
- 4 - High (Estuary, lagoon, creeks, backwater)
- 5 - Very high (Barrier beaches, sand beaches, saltmarsh, mud flats, deltas, mangrove)

Slope

The percentage of slopes of the Tamil Nadu coastal region was prepared from the digitally processed SRTM data using ENVI image processing software. As per slope is concerned, 95% coastal segments fall in 1% slopes, and according to the coastal vulnerability, the coastline was classified into five classes (ranks) such as

- 1 - Very low (Slope > 0.81 %)
- 2 - Low (Slope $0.61 - 0.8$ %)
- 3 - Moderate (Slope $0.41 - 0.6$ %)
- 4 - High (Slope $0.21 - 4$ %)
- 5 - Very high (Slope < 0.2 %)

These are shown in Fig. 7.41.

Shoreline changes (erosion and accretion coasts)

By analyzing the multi-dated satellite data of same season (LANDSAT TM 1990, LANDSAT ETM 2000 and IRS P6 LISS 3 satellite data), the shoreline changes (i.e.) erosion and accretion coasts of Tamil Nadu was brought out. According to the erosion and accretion pattern, the coastline was divided into five classes (ranks) (Fig. 7.42) such as

1 - Very low ($> +2$ m/yr)	- Accretion
2 - Low (1 to 2 m/yr)	
3 - Moderate (- 1 to +1 m /yr)	
4 - High (- 1.1 to - 2.0 m/yr)	
5 - Very high (> -2 m /yr)	- Erosion

Mean spring tidal height

Mean spring tidal height data were collected from National Hydrographic Chart at 13 locations and extrapolated into entire coastal segments of Tamil Nadu coast. The same shows that the 0.6m to 1.2 m mean tidal range elevation variations was observed along Tamil Nadu coastal sectors. On the basis of mean spring tidal height, according to the vulnerability, the coastal sectors were divided into five classes (ranks) (Fig. 7.43).

- 1 - Very low (Tidal height < 0.6 m)
- 2 - Low (Tidal height 0.61 – 0.7m)
- 3 - Moderate (Tidal height 0.9m)
- 4 - High (Tidal height 1m)
- 5 - Very high (Tidal height > 1 m)

Coastal Vulnerability Index

After ranking the each geosystem parameters in to 1-5 according to their coastal vulnerability, coastal vulnerability index was worked out using the above variables and assigning the relative weightages according to their significance in coastal vulnerability with special reference to global warming and related sea level rise using the following formula.

$$CVI = 4 G + 3 SL + 2 SC + 1 TH$$

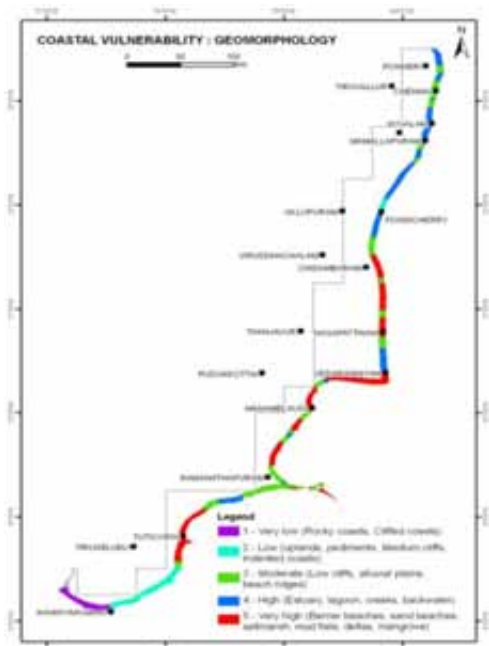


Fig. 7.40: Coastal Geomorphology & Vulnerability

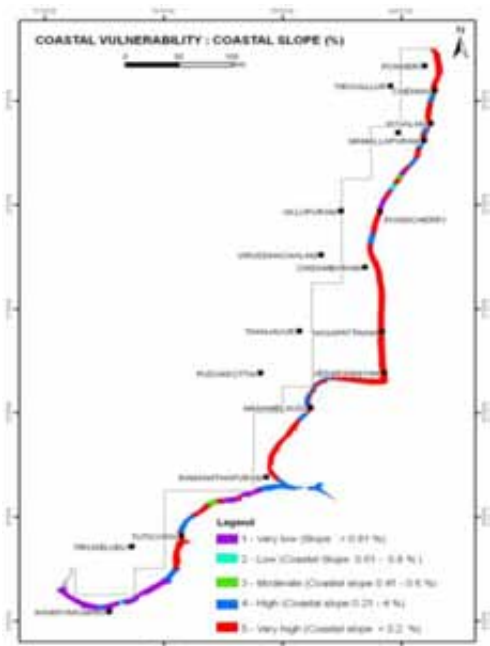


Fig. 7.41: Coastal Slope & Vulnerability

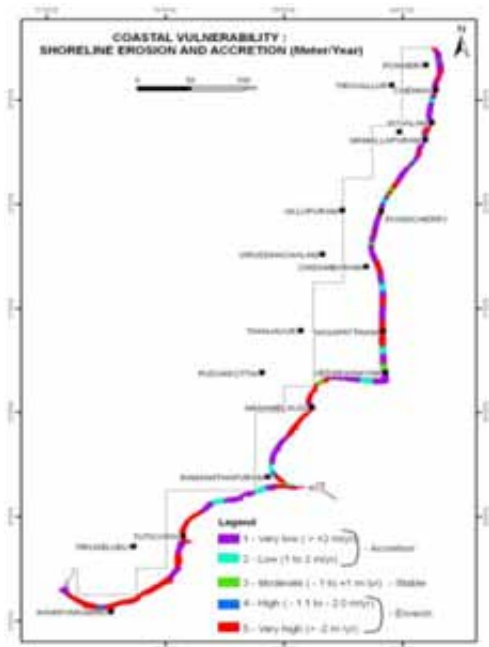


Fig. 7.42: Coastal Erosion and Accretion & Vulnerability

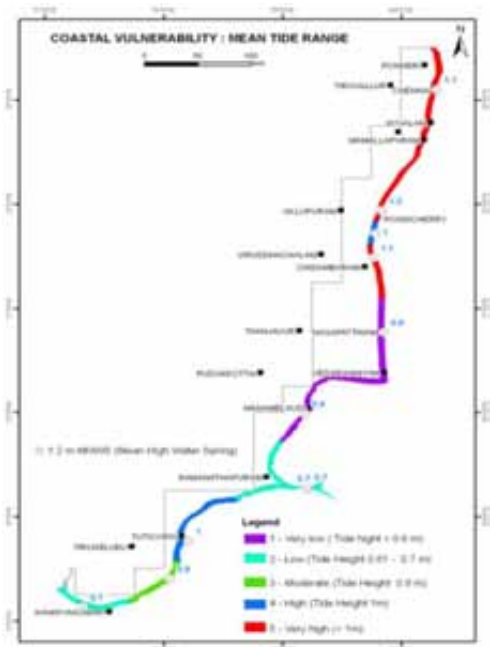


Fig. 7.43: Coastal Tidal activity & Vulnerability

- CVI - Coastal Vulnerability Index
- G - Geomorphology
- SL - Slope
- SC - Shoreline change
- TH - Mean Tidal Height

Using the above formula in the GIS environment, CVI (Coastal Vulnerability Index) were brought out for entire Tamil Nadu coast. The same shows that the CVI ranging from 11-50 (Fig. 7.44a) and these CVI were classified Low (CVI = 11 to 20), Moderate (CVI = 21 to 30), High (CVI = 31 to 40) and Very High (CVI = 41 to 50) vulnerable coasts and the same is shown in Fig. 7.44b.

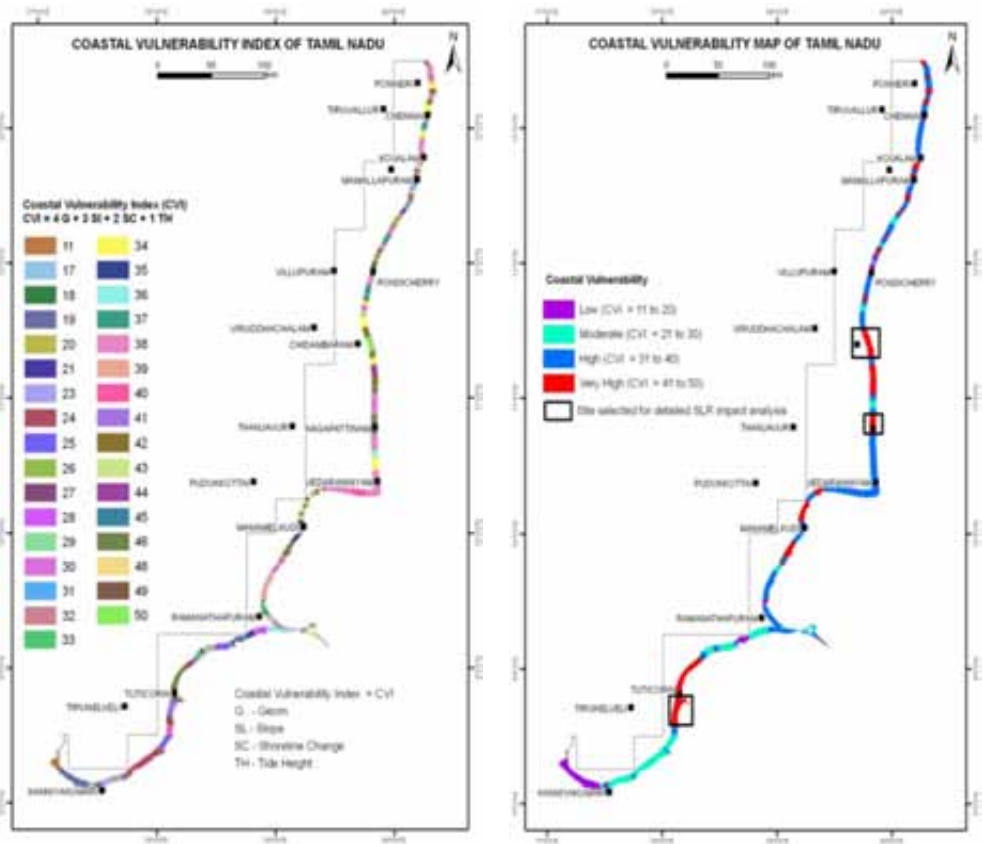


Fig. 7.44 a: Coastal Vulnerability Index of Tamilnadu coast; b: Risk map of Tamilnadu coast based on CVI

Hot Spot Selection

After preparing the coastal vulnerability mapping for Tamil Nadu coast, three hot spots were selected for detailed SLR impact analysis where the coastal vulnerability index is very high. The first hot spot falling along the Chidambaram region (Colleroon river mouth), second one in Nagapattinam region and third one along the Tuticorin (Tambaraparani river) region (Fig. 7.44b).

The coastal vulnerability map so prepared for Tamil Nadu coast by the above methodology is coinciding with the tsunami inundation, storm surges and coastal erosion scenario of Tamil Nadu coast. Further, during tsunami 2004, Pondicherry, Cuddalore, Colleroon coast and Nagapattinam coastal region faced ferocious tsunami waves and related disasters in greater extent. Now those regions were fall in the high and very high coastal vulnerability index. At the same time, Manamelkudi and Tuticorin region have fallen in higher vulnerability, but they have lesser tsunami impact compare to other coastal pockets because of Srilanka obstructed the tsunami waves. The southern tip of Tamil Nadu coastal region falls in the low vulnerability grade as these region having higher slope and rocky coast. Further, the present study indicates that the 300 km coastal length fall in very high vulnerability 350 km coastal length fall in the high vulnerability grade. The present research study shows that the Tamil Nadu coast is highly vulnerable to global warming and related sea level rise.

Gujarat Coast

Geomorphology

Geologically and geomorphologically, the Gujarat coast is quite distinct from the rest of the West coast of India. Reflecting a strong structural control, the coast line shows much variations in its trend, shoreline features and near and off-shore conditions. Gujarat coast shows tide dominating and wave dominating coastal processes in general. Fluvio-marine processes are observed along creeks, estuary and river mouths. Following coastal geomorphological

classes were mapped using Resourcesat-1 AWiFS images for the Gujarat coast (Figure 7.45):

I. Landforms indicating past sea level

1. Palaeoflats/Salt Flats
2. Paleomud flats (Concealed)
3. Old deltaic plains
4. Strandlines

II. Landforms due to current coastal processes

5. Creeks/Estuary/Streams/Depressions
6. Sub-Tidal Mudflats
7. Inter-Tidal Mudflats
8. Mangroves
9. Coral Reefs
10. High-Tidal Mudflats
11. Rocky/Cliffy Coast
12. High lands

Among the five physical variables, the qualitative nature of geomorphologic variable plays very important role to assess the impact of sea level rise. Geomorphology indicates the relative erodibility of a section of shoreline. It is expected that the rocky cliffs and wave-cut benches offer maximum resistance and therefore very less vulnerable, the soft sandy and muddy forms such as, mudflats, mangroves, etc., that offer least resistance, are highly vulnerable to sea-level rise.

Landforms indicating past sea level:

The evidences of presence of Sea in past are observed due to presence of landforms such as Palaeoflats/Salt flat, Palaeomudflat (concealed) Old deltaic plains and strand lines. These landforms are described below:

Palaeoflats/Salt flats: These landforms are observed comprising the entire Great Rann of Kachchh (including Banni plains), Little Rann of Kachchh and northern as well western coast of the Gulf of Khambhat. These are large, low lying, muddy, salt encrusted regions above highest high tide line, indicating presence of sea in past. These regions are parts of graben valleys formed due to Khambhat and Kachchh fault systems.

Palaeomudflats (concealed): These land forms are observed north of Nalsarovar and form eastern fringe of Great Rann of Kachchh and Little Rann of Kachchh. These are lowlying old mudflats now concealed by aeolian sand or alluvium. These also indicate presence of sea in past.

Old deltaic plains: These are observed on the north-western parts of the Great Rann of Kachchh and are palaeodeltas of the river Sarasvati. These indicate extent of fluvio-marine processes operating in past.

Strandlines: Strandlines or shorelines of past are observed in the southern coast of the Saurashtra peninsula. These indicate transgression/regression processes operating in past. These are presently part of highlands.

Landforms due to current Coastal Processes

Creeks/Estuaries/Streams/Depressions:

Dense and intricate creek system is observed along western part of the Kachchh peninsula near Jakhau (e.g., Kori creek), northern part of the Gulf of Kachchh near Kandla and Navlakhi (e.g. Hansthal creek). Around 870 sq km area is observed to be covered by creeks. A large number of estuaries occur along the eastern coast of Gulf of Khambhat, notable among them are of those of rivers Sabarmati, Mahi, Dhadar, Narmada and Tapi. A large number of streams debouch from the Saurashtra peninsula in particular and low lying flood plains near the coast such as one near Porbandar forms natural depressions. A total of 1476 sq km area is under creeks/estuaries/streams/depressions category.

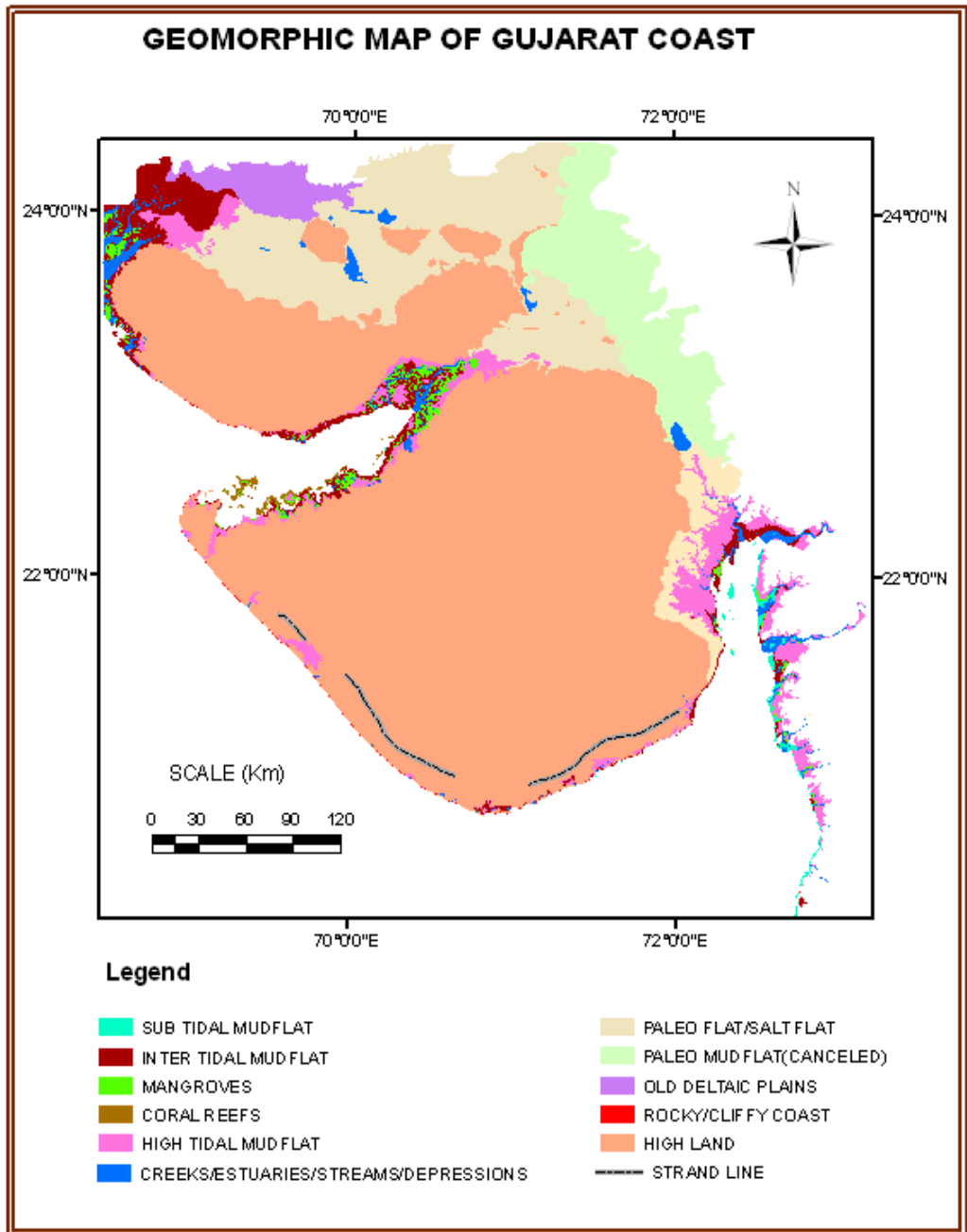


Fig. 7.45: Geomorphic map of Gujarat coast prepared using Resourcesat-1 AWiFS data

Sub-tidal mudflats: Sub-tidal mud flats are observed along the tide dominated regions such as Gulf of Kachchh and Gulf of Khambhat. These are shallow, submerged, soft, muddy landforms such as shoals, bars etc. visible in satellite images of low-tide period. These cover around 384 sq km area.

Inter-tidal mudflats: These are mudflats occurring in the inter-tidal regions, in particular between mean low-tide and high tide lines. These are exposed during low tide periods, forming muddy, marshy regions. These are also seen along the tide dominated coast of the Gulf of Kachchh as well the Gulf of Kachchh. These cover around 4140 sq km area. Sediment movement in the Gulf of Kachchh is regulated by the prograding sediments of the Indus river, which are deposited on its northern shores. The dynamic tidal barrier existing in between hinders the movement of sediments to the southern shores of the Gulf of Kachchh.

Mangroves: Mangroves are salt tolerant plant species occurring within inter-tidal regions and are observed in particular along the creeks, estuaries and coral islands. Creek mangroves are found at Kori creek and adjoining creeks and near Hansthal creek and adjoining creeks. Mangroves in and around Coral reefs are observed along Gulf of Kachchh Marine National Park. The pockets of mangroves also occur in region like Gogha in Bhavnagar, Sultanpur, Pipavav, near Jafarabad etc. Isolated pockets of mangroves are observed near the estuarine regions of the Gulf of Khambhat. Mangroves cover around 1065 sq km area. In the event of sea level rise, mangrove area may be pushed back towards the present hyper saline palaeoflat/salt flat areas in the Great and Little Rann of Kachchh.

Coral Reefs: These are one of the most important landforms in the Gulf of Kachchh. Mostly coral reefs are fringing and platform type. The coral reefs cover around 254.05 km² area. Some of reef areas are Pirotan, Narara, Kalubhar, Goose bet, Pagar, Borea etc. Coral reefs cover around 254 sq km area.

High-tidal mud flats: These are mudflat above normal high tide and are usually inundated during highest of high tide. These occupy around 5343 sq km area and occur in the tide dominating regions of the Gulf of Kachchh and

Gulf of Khambhat. They are also observed in area north of Kori creek towards the Great Rann of Kachchh. Most of the salt pans are located within high-tidal mud flat areas. These are the areas most vulnerable to sea-level rise.

Rocky/Cliffy coast: The wave dominated coast of Gujarat is mostly rocky/cliffy and is observed along Jakhau to Bhadreshwar (Southern part of Kachchh peninsula), Okha to Ghogha (southern part of Saurashtra peninsula) and Udwada to Dahanu (southern part of Mainland Gujarat). From Dwarka to Veraval the coast has characteristically straight NW-SE trend with a very thin strip of sandy beaches. The miliolites underlie the beach sand and occur as cliffs, wave-cut platforms and submerged dunes, all along the shoreline indicating Quaternary sea level fluctuations. The shoreline from Veraval to Diu trends E-W and has same characteristics. Coastline from Diu to Jhanjmer trends ENE-WSW and Jhanjmer to Ghogha and Udwada to Dahanu trends NNE-SSW. Mostly the coast is rocky with narrow crescent shaped beaches. The linear configuration of the coast, at most of the places, suggest strong tectonic influence and submerged nature of the coast. Rocky /cliffy coast offer more resistance to coastal processes and are less vulnerable.

High land: These are rocky high areas of the Kachchh and Saurashtra peninsulas and Gujarat Mainland forming buried pediplain over Tertiary to Quaternary sedimentary rocks and plateau due to Deccan Trap basalts.

On the basis of vulnerability to sea level rise and possible inundation, the coastline was divided into following vulnerable classes/ranks, these are Very High (Beaches, Mangroves, Coral Reefs, Intertidal Mudflat, Sub-tidal Mud Flats, Creeks, Shoals), High (Water logged low depressions, Lagoon, Estuaries), Moderate (Supra and High Tidal Mud Flats, Salt Flat and Salt Mars), Low (Coastal Plain and paleo mud flats), Very Low (High lands and Rocky coasts) (Fig. 7.46).

Coastal vulnerability ranking layer (line) of geomorphology was prepared based on coastal vulnerable classes/ranks. Geomorphologically about 34.53 % of the Gujarat coast is very high to high vulnerable, about 36.04% of Gujarat coast is moderate vulnerable and about 29.24% of the coast represented by rocky/cliffy and indented sections comes under very-low to low categories.

Slope

The Shuttle Radar Topographic Mission (SRTM) data based Digital elevation models (DEM) was downloaded from the internet sources (www.srtm.csi-cgiar.org). This DEM was calibrated using methodology described earlier for the A.P. coast and a slope map was generated and a vulnerability map due to slope was prepared (Fig. 7.47) considering slopes for Very High vulnerability as (<0.05), High ($0.05-0.10$), Moderate ($0.10-0.50$), Low ($0.50-1.0$) and Very Low (>1).

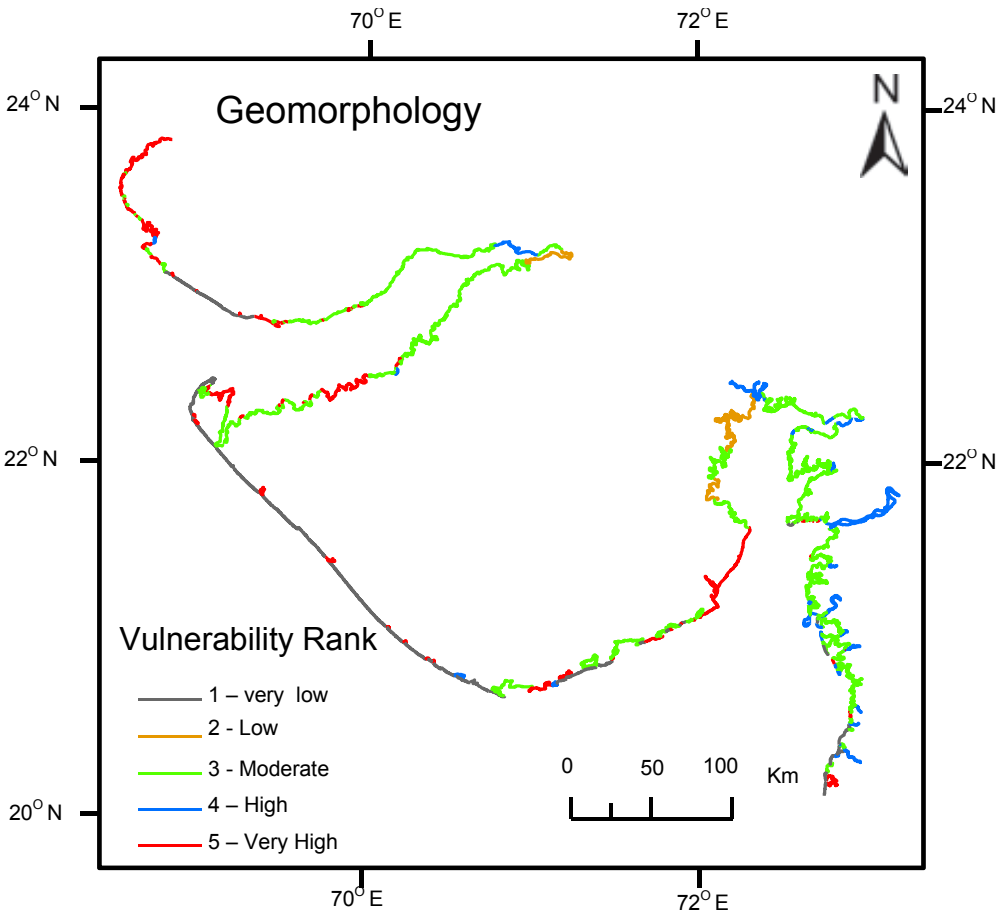


Fig. 7.46: Coastal Vulnerability on the basis of geomorphology for the Gujarat coast

The lower the slope value was found where the flatter the terrain (contour space large) the lower slope were found north of Khambhat, east of Gulf of Kutch, little north east of cori creek. The higher the slope value was found where the steeper the terrain (contour space narrow). The higher slopes are observed for Sauurastra coast, south of Bhuj, and south Gujarat coast. Coastal slopes of 26.01% of Gujarat coast falls into very-high to high vulnerable category, about 16.06% of Gujarat coast is moderate vulnerable and 57.9% fall in low to very low vulnerable category.

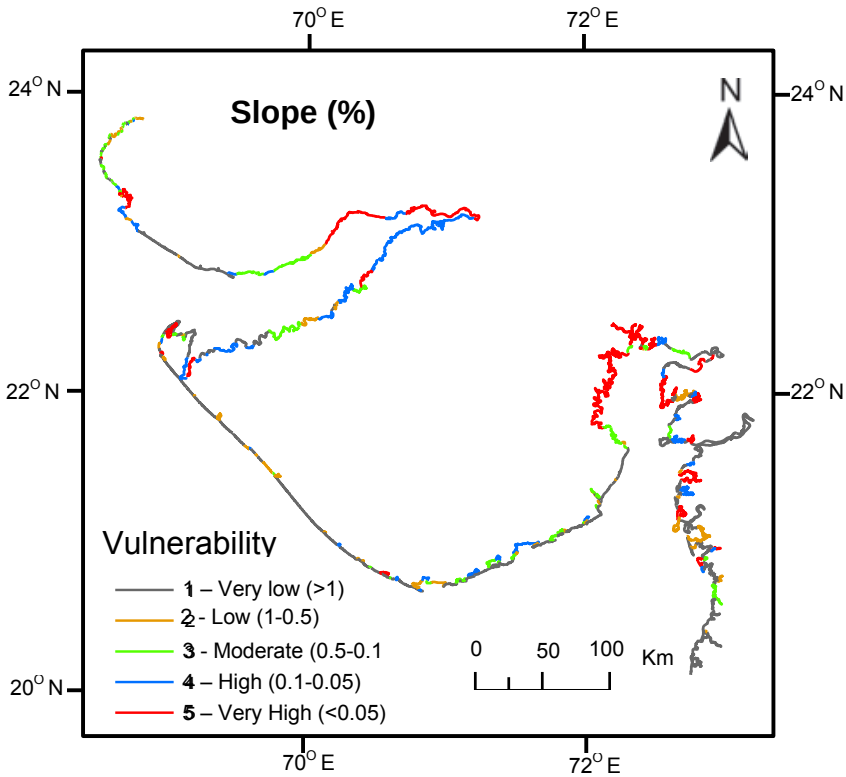


Fig. 7.47: Coastal Vulnerability on the basis of slope for the Gujarat coast

Shoreline change rate:

The High Tide line (HTL) of 1989-90 and 2004-05 time frame prepared using satellite data was utilized to quantify shoreline changes. Both data sets were

brought to same projection system and shore line changes were demarcated and computed. Horizontal displacement of shoreline which indicates the zones of erosion and accretion was extracted by overlaying technique in GIS, and the shift in shoreline during the 16-year period from 1989-90 to 2004-5 was computed. Annual shore line change rate was calculated and based on the rate of shoreline changes vulnerability map was generated (Figure 7.48).

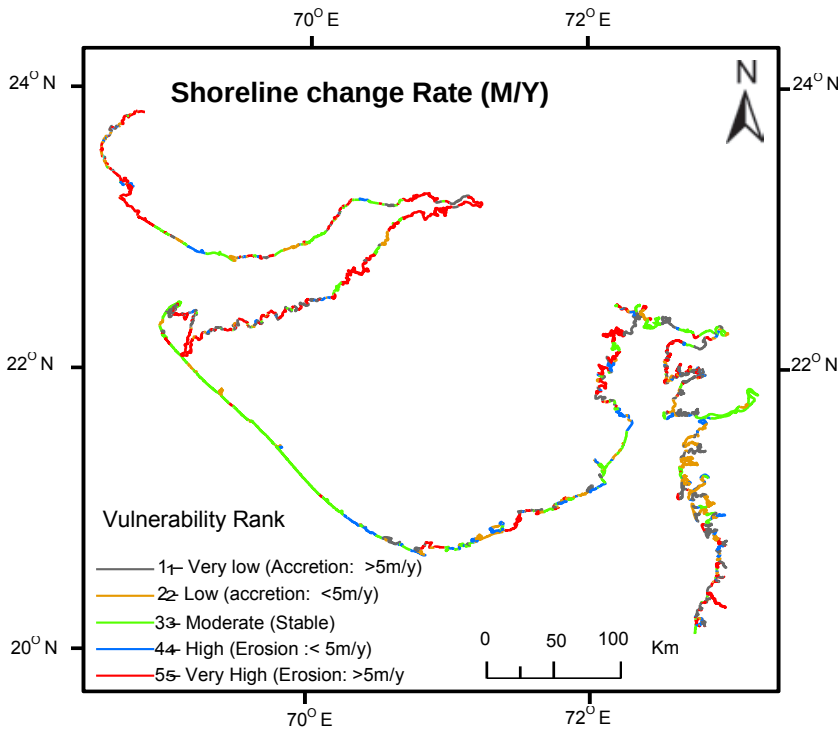


Fig. 7.48: Coastal Vulnerability on the basis of shoreline change rate for the Gujarat coast

The total land gained by accretion is about 651.04 km² and total land lost by erosion was about 1035.23 km². According the high erosional area were found north east of Kori creeks, (Lakhpat, Koteswar), near Godia creeks, and North West of Khambhat coast, and patches of south Gujarat coast. The accretional areas were found north east of khambhat and south Gujarat coast. Stable Shoreline were found mainly along south Saurashtra coast due to hard rock, linear ridge along the coast, south of Bhuj, and south Gujarat coast etc. Based

on the erosion and accretion pattern, the coastline was divided into five vulnerability classes /rank. There were very high (erosion $>5\text{m/year}$), high (erosion $<5\text{m/year}$), moderate (no change/stable), and low (accretion $<5\text{m/year}$), very Low (accretion $>5\text{m/year}$). In terms of shoreline change rate (m/y), shoreline of very high vulnerable to high are 44.12 %, moderate vulnerable are 21.71% and low to very low vulnerable are 28.16%.

Mean Spring Tide Range

Semi-diurnal tide with large diurnal inequality and varying amplitude dominates all along the Gujarat coast. The maximum spring tide recorded at Bhavnagar is 12.5 m, which is second only to the highest recorded anywhere in the world (around 17 m at the Bay of Fundy on the Newfoundland coast of Canada). In the Gulf of Khambhat, the mean high water spring of 4.7 m at Mahuva rises to 6.5 m at Gopnath and further to 10.2 m at Bhavnagar on its west coast, and decreases from 8.8 m at Dahej to 5.4 m at Umbbargaon on its east coast. In the Gulf of Kachchh, the mean high water spring increases from 3 m at Kori Creek to 5.6 m at Mundra and further to 7.3 m at Navlakhi on its northern coast, gradually decreasing to 5.4 m at Sikka and finally to 3.5 m at Okha on its southern coast. On the open coast, the tides are around 3 m at Veraval.

The predicted tide along the Gujarat coast line was used to classify the coastal vulnerability on the basis of tidal range. Tide prediction tool of MIKE-CMAP is used to obtain the predicted tidal elevation of the 23 tidal stations along the Gujarat coast for the year 2005. The spring tide range is calculated for each station from the predicted tide data. This was an ASCII data. In order to bring to the GIS this ASCII data were converted in to point data and reprojected into Transverse Mercator Projection. Coastal vulnerability ranking layer of Mean Spring Tide Range was prepared based on coastal vulnerability classification table (Fig. 7.49).

Very High mean tide is found in Bhavnagar (6.52 m), high mean tide are found in Kandla Harbour (4.84 m), Navlakhi (5.175 m), Sultanpur, Ambheta (5.67 m), Dahej Bandar etc. Moderate vulnerable area are found in Cori creek entrance (2.059 m), Koteswar, lakhpat, mandvi, Sikka, Okha, Valsad (3.88 m),

Dahanu etc. Very mean tide range is found in Godia creek (1.81 m), Porbandar, Veraval etc and very low vulnerable is found in Miyani (0.98 m). Very Low vulnerable area is 2.84%, Low vulnerable area is 28.34%, Moderate vulnerable area is 31.96% and high to very high vulnerable area is 36.86%.

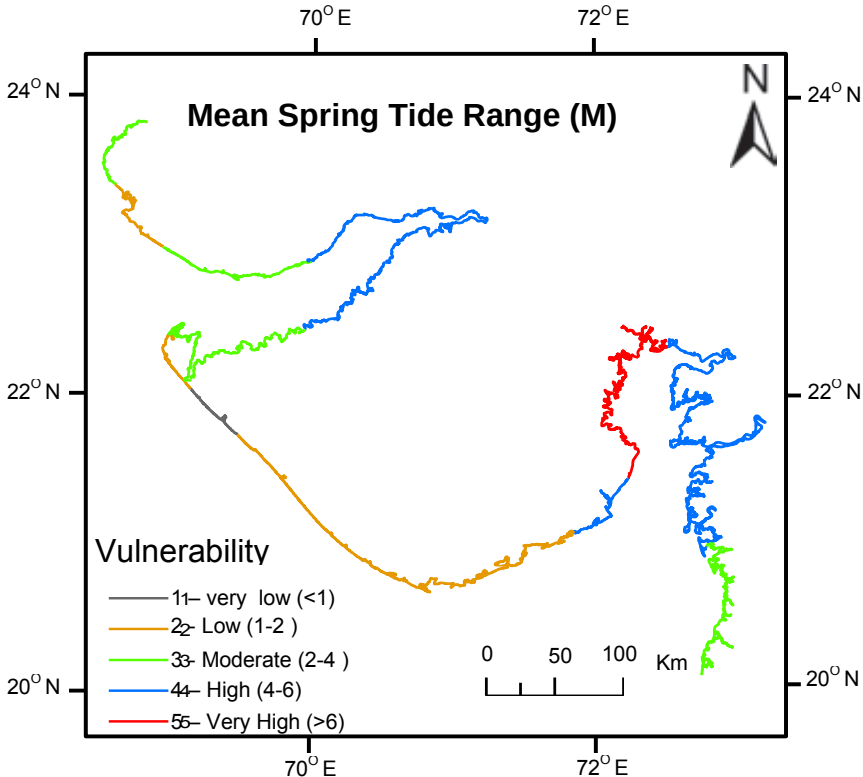


Fig. 7.49: Coastal Vulnerability on the basis of mean spring tide range for the Gujarat coast

Significant wave height:

In the absence of in situ wave data for the Gujarat coast, computer simulated wave models were used in the study. The Wave simulations have been performed using SW module of MIKE-21. MIKE 21 developed by the Danish Hydraulic Institute, Denmark, is a software package containing a comprehensive modeling system for 2D free-surface flows which is applicable to the simulation of hydraulic and related phenomena in lakes, estuaries, bays,

coastal areas and seas where stratification can be neglected. Spectral Wave (SW) model of MIKE-21 was used for the simulation of the wave. MIKE 21 SW is spectral wind-wave model based on unstructured meshes. The model simulates the growth, decay and transformation of wind-generated waves and swells in offshore and coastal areas. The model comprises phenomenon like wind induced wave growth, nonlinear wave interaction, wave breaking, bottom friction, shoaling and refraction. The governing equation is wave action balance equation formulated in Cartesian coordinate. The conservation of equation of wave is

$$\frac{\partial N}{\partial t} + \nabla \cdot (\vec{v}N) = \frac{S}{\sigma}$$

Where $N(\vec{x}, \sigma, \theta, t)$ is the action density, t is the time, $\vec{x} = (x, y)$ is the Cartesian coordinate, $\vec{v} = (C_x, C_y, C_\sigma, C_\theta)$ is the propagation velocity of a wave group in the four-dimensional phase space. Winds are the major force responsible for the generation of waves in the ocean. Wind wave generation is the process by which wind transfer energy into the water body for generating wave. Wind field are specified as wind velocity component along the grid axis. ECMWF (European Center for Medium Range Weather Forecast) assimilated wind with remotely sensed retrievals have been used as the wind force. The remotely sensed wind observations are derived from near real time measurements performed by Seawinds scatterometer onboard QuikSCAT satellite and by the three Special Sensor Microwave Imager (SSM/I) onboard DMSP satellites F13, F14, and F15. This was an ASCII data. In order to bring to the GIS this ASCII data were converted in to point data and reprojected into Transverse Mercator Projection. Coastal vulnerability ranking layer of significant wave height was prepared based on coastal vulnerability classification table (Fig. 7.50). Very Low vulnerable area is 6.99%, Low vulnerable area is 28.13%, Moderate vulnerable area is 21.52% and high to very high vulnerable area is 43.36%.

Table 7.7 summarises the length of shoreline in each of the vulnerability class of the five variables covering the Gujarat coast.

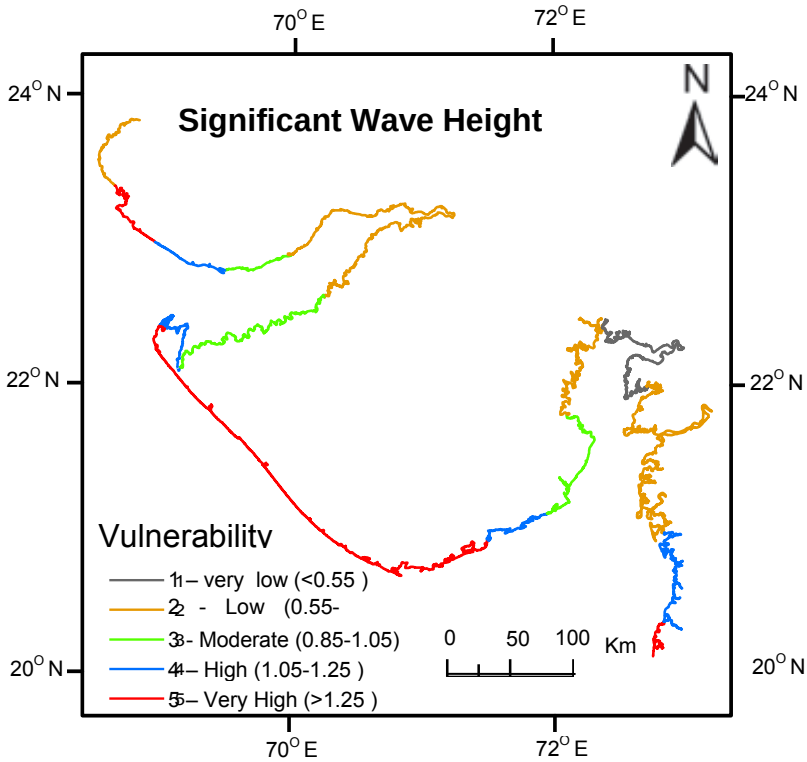


Fig. 7.50: Coastal Vulnerability on the basis of significant wave height for the Gujarat coast

Table 7.7: Length of the shoreline in each of the vulnerability class of the five variables covering the Gujarat coast

Variable	Shoreline length in km (% share)				
	Vulnerability Rank				
	Very Low	Low	Moderate	High	Very High
Geomorphology	467.68 (27%)	38.48 (2.24%)	619.74 (36.04%)	70.02 (4.07%)	523.80 (30.46%)
Slope	843.04 (49.02%)	152.80 (8.88%)	276.36 (16.06%)	172.25 (10.01%)	275.29 (16.00%)
Shoreline Change	230.71 (13.41%)	253.65 (14.75%)	476.59 (27.71%)	178.33 (10.37%)	580.47 (33.75%)

Wave height	120.22 (6.99)	483.78 (28.13%)	370.06 (21.52%)	248.28 (14.44%)	497.40 (28.92%)
Tide	48.84 (2.84%)	487.33 (28.34%)	549.58 (31.96%)	517.17 (30.07%)	116.81 (6.79%)

Coastal Vulnerability Index (CVI)

The coastal vulnerability index used in the present work is given below. The weight has been given in each of the Coastal vulnerability ranking layer based on their significance and response to sea level rise.

$$CVI = 4G + 4S + 2C + 4T + 3W$$

Where G refers to vulnerability ranking of geomorphology, S refers to the coastal slope, C refers to the shoreline change, T refers to the Mean Spring Tide Range and W refers to the significant Wave Height. The coastal vulnerability ranking layer of Geomorphology (G) (which indicates the dominant coastal processes and their susceptibility to inundation), has been assigned weightage 4. The coastal vulnerability ranking layer of slope (S) (steepness or flatness of the coastal region, which is linked to the susceptibility of a coast to inundation by flooding and to the rapidity of shoreline retreat or advance) has given weightage 4. The coastal vulnerability ranking layer Shoreline Change Rate (m/y) (C) (which indicate how fast a section of shoreline has been eroding or accreting) has given weight age 2. The coastal vulnerability ranking layer of Mean Spring Tide range (T) (which contributes to inundation hazards) has been given weight age 4 due to the high tidal influence in the Gujarat coast. The coastal vulnerability ranking layer of significant wave height (W) (which is linked to inundation hazards) has given weightage 3. A Coastal Vulnerability index (CVI) map was prepared by integrating the five weighted Coastal vulnerability ranking layers (Fig. 7.51).

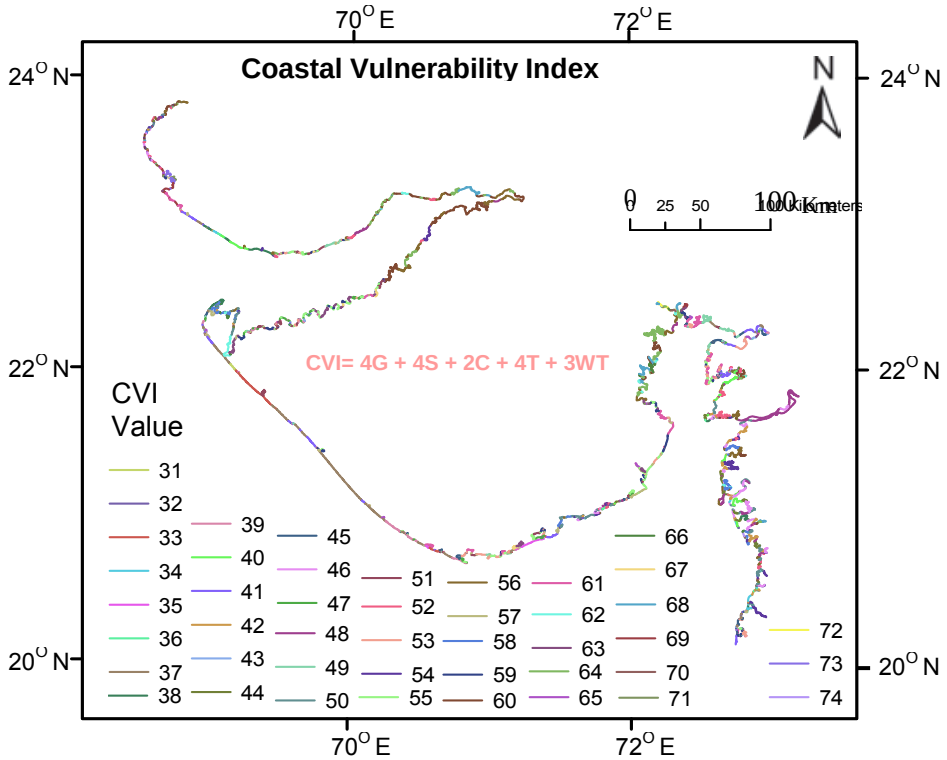


Fig. 7.51: Coastal Vulnerability Index (CVI) map for the Gujarat coast

Risk Map for the Gujarat coast

Considering the IPCC predicted sea level rise of about 59 cm by the 2100, the areas likely to be affected along the Gujarat coast were mapped and the loss of different land use and cover/geomorphological feature are quantitatively estimated.

The CVI map showed 1240 segments of the Gujarat coast each having a unique identity number in its corresponding attribute table. The CVI values thus obtained ranged from 31 to 74. The entire range of CVI values are divided into four equal parts each indicating certain risk level of the coastline to sea-level rise (Fig. 7.52). It is supposed that the lower range of CVI values indicate low-risk, followed by moderate-risk, high-risk and finally the upper range of values indicating the coast at very high-risk level.

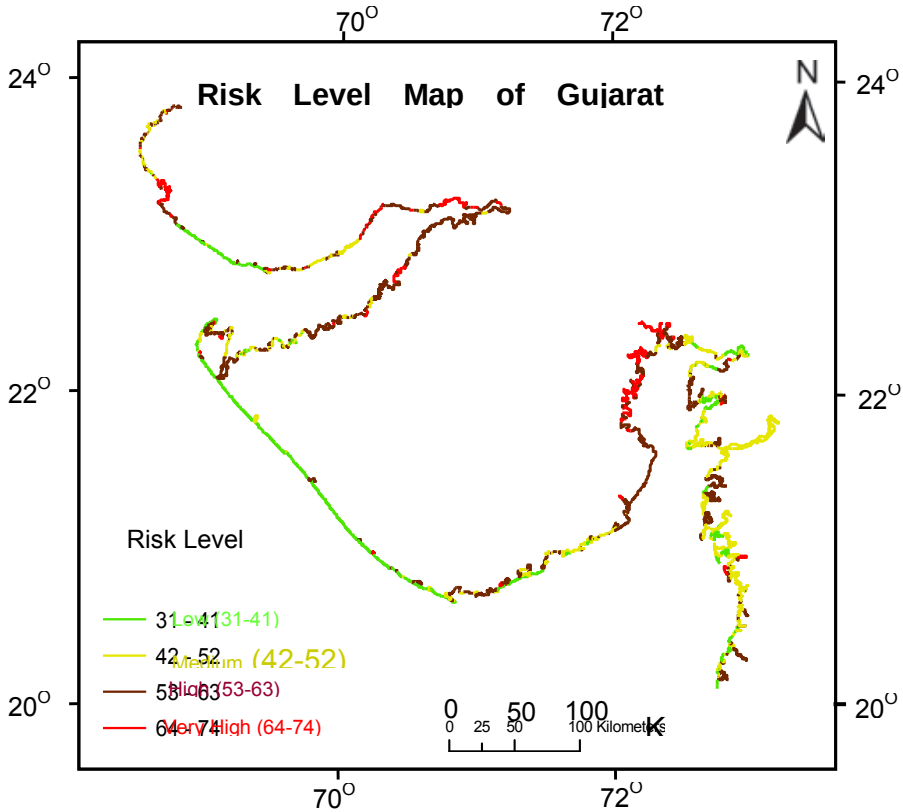


Fig. 7.52: Coastal Vulnerability Index (CVI) map for the Gujarat coast

Impact of Predicted MSL & HTL on the Resources

Andhra Pradesh Coast

The risk classification indicates that 43% of the AP coast over a length of 442.4 km (Fig. 7.53) is under very high-risk category mostly along the Krishna, Godavari and Penner delta front coastal zones, which are very low-lying and almost flat with mudflats, mangrove swamps, and lagoons/backwaters. Moreover, these coastal sections are experiencing sustained erosion for the last three decades. Even the small tidal range in these areas can reach far inland since the gradient is extremely gentle.

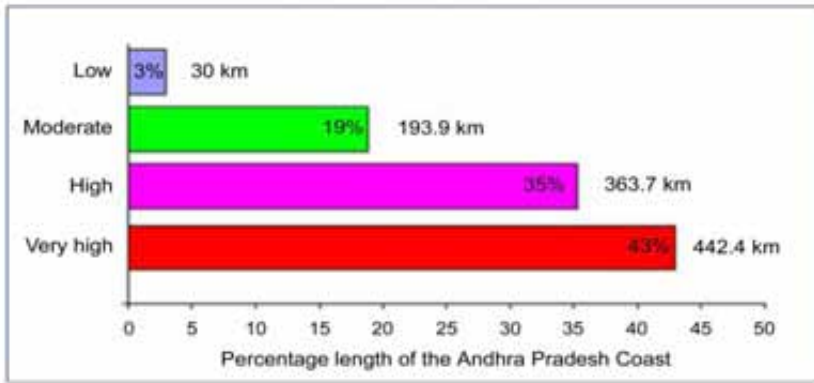


Fig. 7.53: Relative vulnerability of AP coast. Note that as much as 442.4 km long AP coast which makes up to 43% of the total length of the coast is at very high risk followed by another 35% (363.7 km) is at high risk.

Similarly, about 363.7-km-long coastal segments which account for 35% of the total length are under high-risk category mostly in the southern part of the AP coast near Pulicat Lake, north of Penner delta, south of Krishna delta, and between Krishna and Godavari deltas in the central part of AP coast where the landforms and slopes although are of moderate category, the high rate of shoreline erosion and high-wave energy make the coast high-risk prone. In the remaining part, 193.9-km-long coast (19% of the total) mainly the non-deltaic dune-front sections, come under moderate-risk category, while the rocky coast on both sides of Visakhapatnam and some embayed/indented sectors over a combined length of 30 km (3%) are in the low-risk category.

The overall CVI map showing the risk levels of different coastal segments of AP can be scaled up to any degree of enlargement in its original GIS format. But considering the scale of the Survey of India (SOI) topographic maps which are used as base maps for registering the satellite imagery from which data on landforms, coastal slopes and shoreline change are extracted, the CVI maps may best be used up to 1:50000 scale. Therefore, the map grid representing the standard SOI topographic maps (1:50000 scale) is superimposed on the CVI map (Fig. 7.28) to extract locality-wise risk level of the coast as detailed in Table 7.8.

Table 7.8: Data on risk level of the coast in various localities represented by SOI maps in the three major sectors of the AP coast

S. No.	Coastal Sector	Map Number	Locality	Length of the coast in each risk category (km)				
				Low	Moder-ate	High	Very high	Total
1	Northern Sector (Visakhapatnam region)	74B/9	Baruva	---	1.9	32.8	2.1	36.8
2		74B/6&10	Naupada	---	4.9	32.9	0.9	38.7
3		74B/3	Vamsadhara estuary	5.7	11.0	22.3	2.2	41.2
4		65N/16	Nagavali estuary	---	13.3	12.5	3.8	29.6
5		65N/12	Konada	---	7.8	14.7	3.0	25.5
6		65O/9	Mukkam	---	11.4	---	---	11.4
7		65O/5	Vizag-Bhimili coast	4.0	16.0	5.2	1.4	26.6
8		65O/6	Visakhapatnam city	6.9	14.3	---	---	21.2
9		65O/2&3	Gangavaram	5.8	14.0	14.8	---	34.6
10		65K/15	Sarada-Varaha estuary	1.7	22.3	7.8	---	31.8
11		65K/11	Tandava estuary	---	14.8	1.2	7.7	23.7
12		65K/8&12	Uppada coast	5.9	10.4	6.5	17.0	39.8
	Total			30	142.1	150.7	38.1	360.9
13	Central Sector (Krishna-Godavari delta region)	65L/5	Kakinada	---		11.8	61.7	73.5
14		65L/6	Nilarevu estuary	---	---	---	31.5	31.5
15		65L/2	Pandi lagoon	---	---	---	11.4	11.4
16		65L/3	Surasaniyanam	---	---	4.3	14.6	18.9
17		65H/15	Vainateyam estuary	---	---	22.6	5.9	28.5
18		65H/11	Vasishta estuary	---	---	18.5	10.3	28.8
19		65H/7	Goguleru creek	---	---	22.4	9.0	31.4
20		65H/4	Manginapudi	---	---	9.9	18.8	28.7
21		66E/1&2	Krishna estuary (Divi)	---	---	---	60.2	60.2
22		66A/13&14	Krishna estuary (main)	---	---	11.9	30.1	42
23		66A/11	Nizampatnam	---	---	23.9	4.5	28.4
	Total					125.3	258	383.3
24	Southern Sector (Penner Delta)	66A/5	Vadarevu	---	---	3.4	15.9	19.3
25		66A/6	Ramperu estuary	---	15.4	2.9	---	18.3
26		66A/2	Gudlakamma	---	12.8	1.3		14.1

	and Pulicat Lake region)		estuary					
27		66A/3	Palleru-Musi estuary	---	2.7	17.8	12.9	33.4
28		66A/4	Manneru estuary	---	.08	27.4	---	27.4
29		66B/1	Upputeru estuary	---	---	2.6	26.1	28.7
30		66B/2	Penner estuary	---	---	22.6	19.7	42.3
31		66B/3	Krishnapatnam	---	20.9	0.2	7.2	28.3
32		66B/4	Swarnamukhi estuary	---	---	4.6	23.7	28.3
33		66C/1	Durgarajpatt nam	---	---	---	23.9	23.9
34		66C/2&6	Sriharikota island	---	---	4.9	16.9	21.8
	Total			---	51.8	87.7	146.3	285.8
	Grand Total			30	193.9	363.7	442.4	1030

The central sector of the AP coast, i.e., the Krishna-Godavari delta region is the most vulnerable with almost two-thirds of the total length of the coast in the very high-risk category, while the rest of the coast is also within the immediate next level of high-risk category. Notably, no part of the Krishna-Godavari delta coast is in the low or moderate risk level. Perhaps the rapid coastal retreat and habitat loss due to wide-spread erosion during the recent years in most parts of this otherwise major depocenter along the AP coast is an indication of the manifestation of the impact of the rising sea levels in the area. The southern sector of the AP coast show more or less similar conditions with one-half of the total length of 285.8 km in this sector is in very high-risk category (Table 7.8). The northern sector however has at least 30-km-long part of the coast under low risk level due to the presence of number of rock headlands.

Coastal response to predicted SLR

If the sea level rises by 0.59 m as predicted by IPCC (2007), an area of about 565 km² would be submerged under the new low-tide level along the entire AP coast of which 150 km² would be in the Krishna-Godavari delta region alone. This is estimated by superimposing the contour map (generated as explained in section on 'coastal slope') over the satellite imagery to extract the area between the zero contour (shoreline) and the 0.6 m contour. The new high tide

reaches further inland by another ~ 0.6 m above the present level of 1.5m, i.e., up to 2.1 m. In such a case an additional area of about 1233 km^2 along the AP coast including 894 km^2 in Krishna and Godavari delta region alone would go under the new intertidal zone thereby directly displacing about 1.29 million people (according to 2001 census) who live in 282 villages spread over nine coastal districts of Andhra Pradesh state. Notably, the inhabitants of these villages are mainly hut-dwelling fishing communities who are highly vulnerable in socio-economic terms as well. Further, there is every possibility of increased storm surges (Unnikrishnan et al 2006) reaching much inland than at present with the rise in sea-level.

From this study, it may therefore be concluded that in the light of the rising sea levels, assessment of coastal vulnerability is necessary in order to take appropriate measures to protect the people and property. The CVI developed for the AP coast in this study by ranking five physical variables such as coastal geomorphology, coastal slope, rate of shoreline change, mean spring tide range and significant wave height indicated the risk level of different segments of the coast. Instead of segmenting the coast into spatial grids which might generalize the conditions to different degrees (depending up on the size of the grid cell), analyzing the entire coastline as a line feature using GIS as demonstrated in this study provides a more accurate picture of the vulnerability level of any point along the coast. The CVI analysis revealed that about 43% of the AP coast is under very high-risk and 35% more under high-risk, which calls for protective measures to prevent loss of invaluable coastal land and displacement of people who, mostly being hut-dwelling seafaring community are socio-economically vulnerable as well. Objective coastal vulnerability assessments of this type are necessary for a proper coastal zone management. It may be noted that the maps generated in this study are scalable to any degree of enlargement in their original GIS format for application purposes.

Impact Assessment for Visakhapatnam City

Visakhapatnam with a population of about 1.5 million is the largest city along AP coast. This port city is a major industrial hub with about 23 different types of industries such as iron and steel, petroleum refineries, petrochemical, fertilizer, also strategic location being the Headquarters of the Eastern Naval

Command. Most part of the city is bound by two hill ranges – the northern Kailasa range and the southern Yarada range. These two hill ranges jut into the sea as headlands. The 10-km-long coastline in between these two headlands is more or less crescent shape with a bay appearance, especially at its northern side.

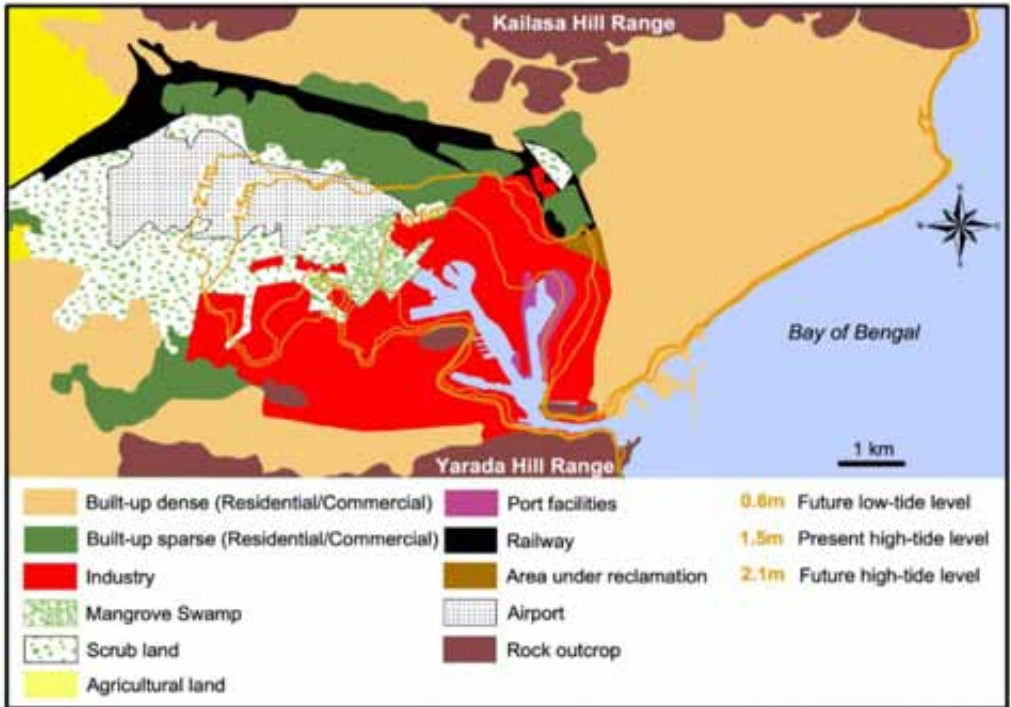


Fig. 7.54: Land use / land cover map of Visakhapatnam city, especially in the swampy area in the southwestern part of the city. Being a very low-lying zone, the area till recently was under the regular tidal influence. Large-scale reclamation led to the growth of industries (red colour) in the area. The port facilities attracted the industries like petroleum refineries, petrochemical, fertilizer, iron & steel, etc. The 0.6m, 1.5m and 2.1m contours interpolated in the area are used to response zonation for the predicated sea-level rise of about 0.6m. The average spring-high tide is 1.5m. If the sea level rises by 0.6m as predicted, the area between the present shoreline and the 0.6m contour would be submerged under the future low-tide level. Similarly, the intertidal level goes further up to 2.1m affecting more land use in the city.

Although several smaller hillocks dot the city area in between the headlands, a large tract low-lying swampy tidally submergible backwater area is to the west of the city. This swampy area which occupied about 14 km² in 1973 has been reduced to a mere 1.37 km² by 2003 by reclamation for industrial activity in this port city (Hema Malini et al 2008). In fact, the elevation of the airport built in the western side of the swampy area is just about 2 to 3 m above sea-level. Comparison of the 1990 and 2006 maps showed that some parts of the 10-km-long beach front of the city were subjected to erosion. In fact beach nourishment is being taken up regularly to combat the beach erosion in the city. The rise in sea-level will have serious impact on the urban region as number of industries, the airport and other establishments besides some residential colonies are within 3 to 4 m above sea-level at present. Moreover, the rising sea-levels, either episodic (storm surges/tsunamis) or eustatic, would have amplification effect over the city area since a part of the city area, especially the western tidal swamp is like a filled-in bay lying in between two rocky headlands. Therefore, Visakhapatnam city area is considered as one of the coastal hotspots vulnerable to sea-level rise, and hence, taken up for further study.

Land use / land cover of the city

A detailed land use / land cover map of the city area was prepared based on the interpretation of the large-scale high-resolution Cartosat-1 image of the area (Fig. 7.54). Since most of the former swampy area which notwithstanding reclamation is low-lying and hence vulnerable for sea-level rise has been considered for the study. As can be seen from the large-scale map generated from the Cartosat-1 image, many industries occupy the area. Most of them are heavy industries located close to the port facilities. The HPCL, BPCL, and other petrochemical industries, besides Essar Steel, and a host of warehouses are present in the area (Fig. 7.55).

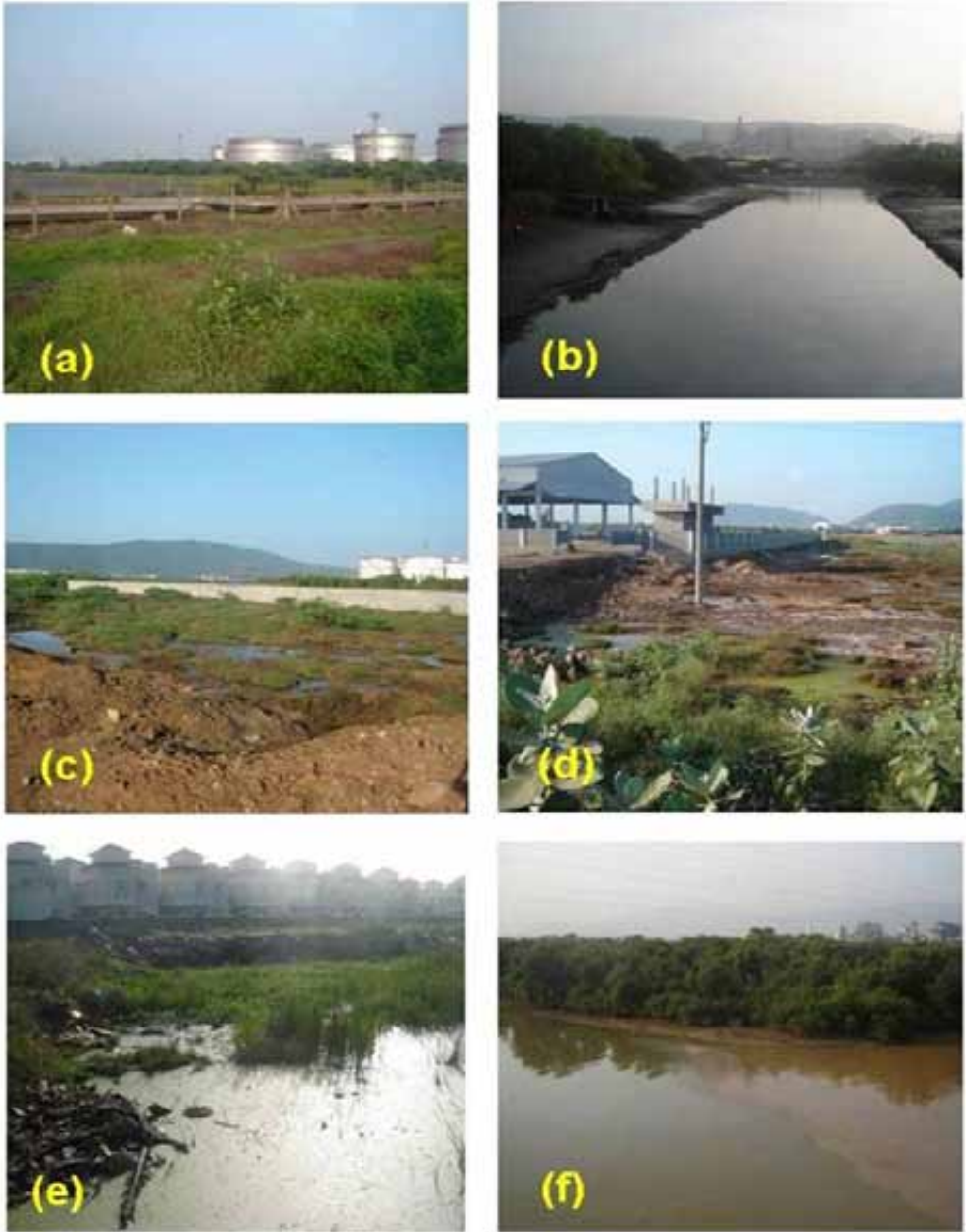


Fig. 7.55: Reclamation of extensive swampy area that used exist in the in the southwestern part of Visakhapatnam city has given rise to number of port based industries like petroleum refineries such as (a) Bharat Petroleum Corporation Ltd., (b) East India Petroleum Corporation Ltd.; petrochemical

industries like (c) Andhra Petrochemical Ltd.; and other establishments like (d) warehouses, besides (e) residential colonies. A small portion of mangrove swamp still exists in the area. The low-lying nature of the area is clearly noticeable as the tidal channels cross the area as in (c). The reclaimed scrub land is also noticeable in this area.

The present low-tide line is marked all along the shoreline and the waterfront of the harbor channel. Based on extensive corrections of the contours generated from the SRTM DEM at 10-cm-interval, three contour lines respectively representing the elevations of 0.6 m, 1.5 m and 2.1 m are overlaid on the land use / land cover map of the area (Fig. 7.54) in order to create a response zonation map for the IPCC (2007) predicted sea-level rise of 0.6 m by the 2100. Thus the 0.6 m contour line represents the future low-tide level. The 1.5 m contour line represents the present spring high-tide level. The 2.1 m contour line represents the future spring high-tide level as the high-tide line is likely to be shifted upward from its present 1.5 m level to the 2.1 m level with the rise in sea-level by 0.60 m.

The area enclosed by the 1.5 m (i.e. the present spring high-tide line) is about 1324 ha. It may be seen from the land use / land cover map (Fig. 7.54), that only about 137 ha of this intertidal zone which is occupied by mangrove swamp is only under the tidal influence at present, whereas most of the area (about 1187 ha) is already occupied by industries, residential, etc. due to land reclamation (Table 7.9).

Area inundated by SLR

Considering a rise in sea level by 0.6 m, a data on response zonation were extracted based on the area covered by each of the three contours (Fig. 9.54), especially from the reclaimed swampy land in the western part of the city. In the event of 0.6 m rise in sea level, the area between the present low-tide level and the future low-tide level (i.e. the area enclosed by the 0.6 m contour), which is about 361 ha including 50 ha of mangrove swamp and 271 ha of industrial area would be submerged under the sea (column 3 in Table 7.9), while the balance of 956 ha including 87 ha of the mangrove swamp, 410 ha of industrial zone, 58 ha of residential area, etc., would remain under the

intertidal zone in future as well (column 4 in Table 7.9). However, the future high tide would shift by another 0.6 m landward marked by the present 2.1m contour. Therefore, an additional area of about 348 ha (column 5 in Table 7.9) between the 1.5 m and 2.1 m contours would become a part of the future intertidal area. This area which is at present occupied by industrial establishments (152 ha), residential (6 ha), scrubland (70 ha), etc., would be affected by regular tidal changes.

Table 7.9: Data on response zonation in Visakhapatnam due to predicted rise in sea level by 0.6m (areas in ha)

Present Land Use / Land Cover	Present Inter-tidal zone (up to 1.5m contour)	Response zonation for sea-level rise by 0.6m			
		Area that would be submerged due to future sea-level rise (up to 0.6 m contour)	Balance area that would remain as intertidal zone (2-3)	Area added to the future intertidal zone (i.e. the area between 1.5 m and 2.1 m contours)	Total area under the future intertidal zone (between 0.6m and 2.1m contours) (4+5) (6)
(1)	(2)	(3)	(4)	(5)	(6)
Mangrove	137	50	87	----	87
Industrial establishments	681	271	410	152	562
Residential (sparsely built-up)	62	4	58	6	64
Airport zone	187	----	187	118	305
Port facilities	63	36	27	----	27
Scrubland	182	----	182	70	252
Area under reclamation	12	----	12	2	14
Total	1324	361	956	348	1311

The study highlights the impact of the predicted sea-level rise in Visakhapatnam city area which is a densely populated and highly industrialized part of the AP coast. This type of response zonation maps are necessary for proper coastal zone management plans in order to prevent disastrous effects of the impending sea-level rise.

Tamilnadu coast

Subsequent to the generation of the GIS layer showing the limits of predicted MSL (PMSL) and predicted HTL (PHTL), their probable impacts over the coastal system were analysed. The SLR impact analysis was carried out by superposing the zone of PMSL and PHTL over the geomorphology, landuse/landcover and physical resources maps.

The SLR impact analysis was done in the following two aspects:

- ➔ Natural and physical resources prone for submergences due to predicted MSL (PMSL) in next 100 years
- ➔ Natural and physical resources prone for degradation, erosion, salination, etc due to predicted high tide line (PHTL).

For the precise SLR impact analysis, the Tamil Nadu coastal region was divided into sectors from north to south such as Chennai, Mamallapuram, Chidambaram, Vedaranniyam, Ramanathapuram and Tuticorin-Kanniyakumari sectors (Fig. 7.56).

Chennai Sector

The GIS layer showing such zones prone for submergence due to PMSL and degradation due to PHTL due to predicted SLR (Fig. 7.57) of Chennai sector were superposed over the geomorphology (Fig. 7.58), landuse/ landcover (Fig. 7.59) and physical resources GIS layers of Chennai sector and damage assessment was carried out. The features to be affected by the PMSL and PHTL were identified (Fig. 7.60 - 61) and by using the GIS functions, the aerial extent of such features were independently calculated.

Such various geomorphic and landuse /landcover features were finally grouped under various categories of resources such as coastal, riverine, agricultural, water and physical resources and the same is shown in Table 7.10. The same shows that the beaches, barrier islands, spit, backwater, present swale and tidal flats are more prone for submergences. The Palaeo mudflats and beach ridges

are prone for both submergences and degradation (Fig. 7.60). As far as the riverine resources is concern, river, deltaic plain and inter lobal depressions are more prone for submergences and degradation. In the case of agricultural resources, the crop land, plantation and scrubs (Fig. 7.61) are liable to submergences and salination. While the aquifers of 18.35 sq km are prone for submergence, the 24.96 sq km of aquifers are prone for pollution. The physical resources like saltpans, industrial area, part of coastal town, roads, etc. are expected to undergo submergence and degradation in Chennai sectors due to predicted sea level rise (Table 7.10, Fig. 7.61).

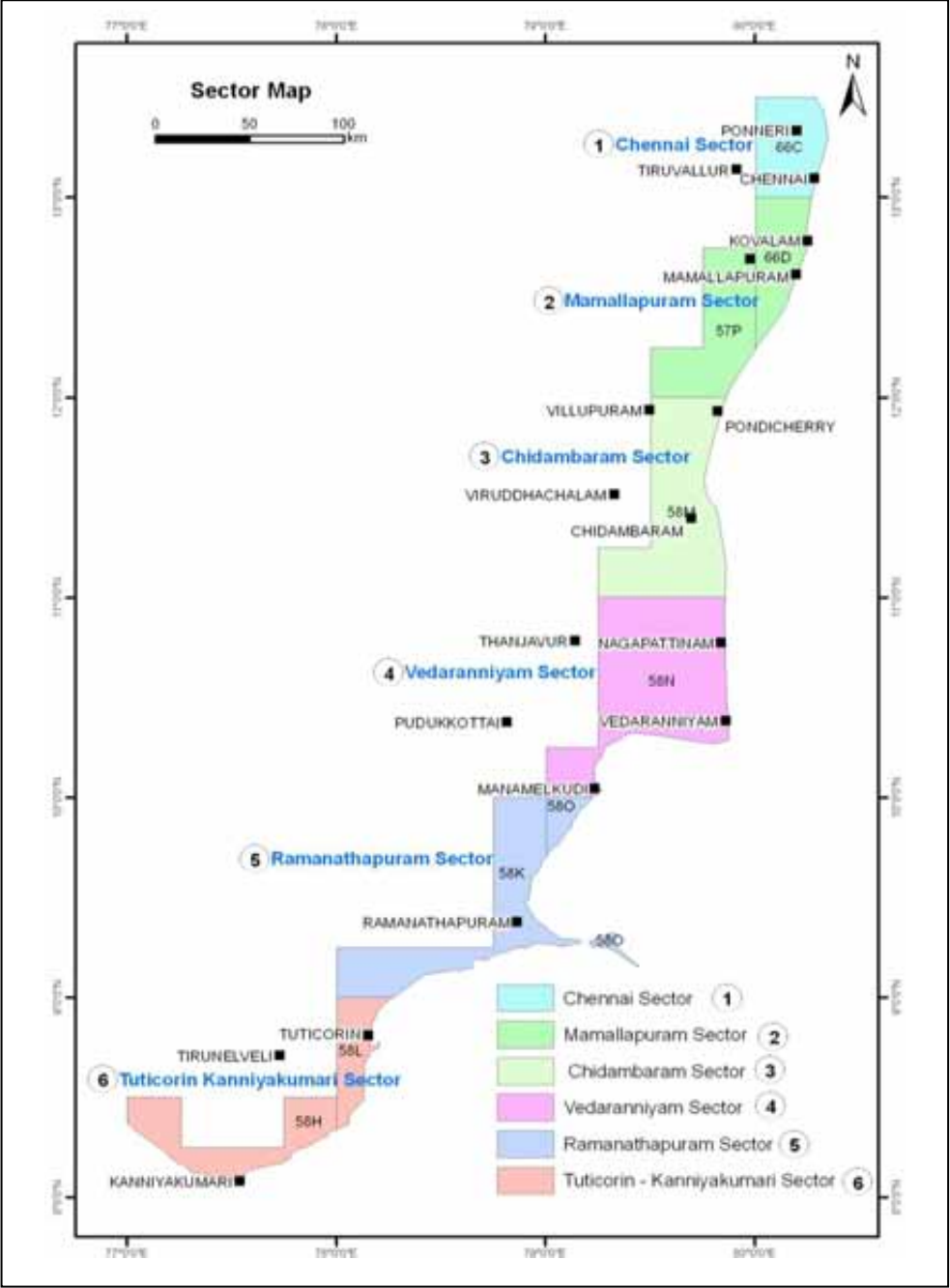


Fig. 7.56: SLR Impact analysis sectors

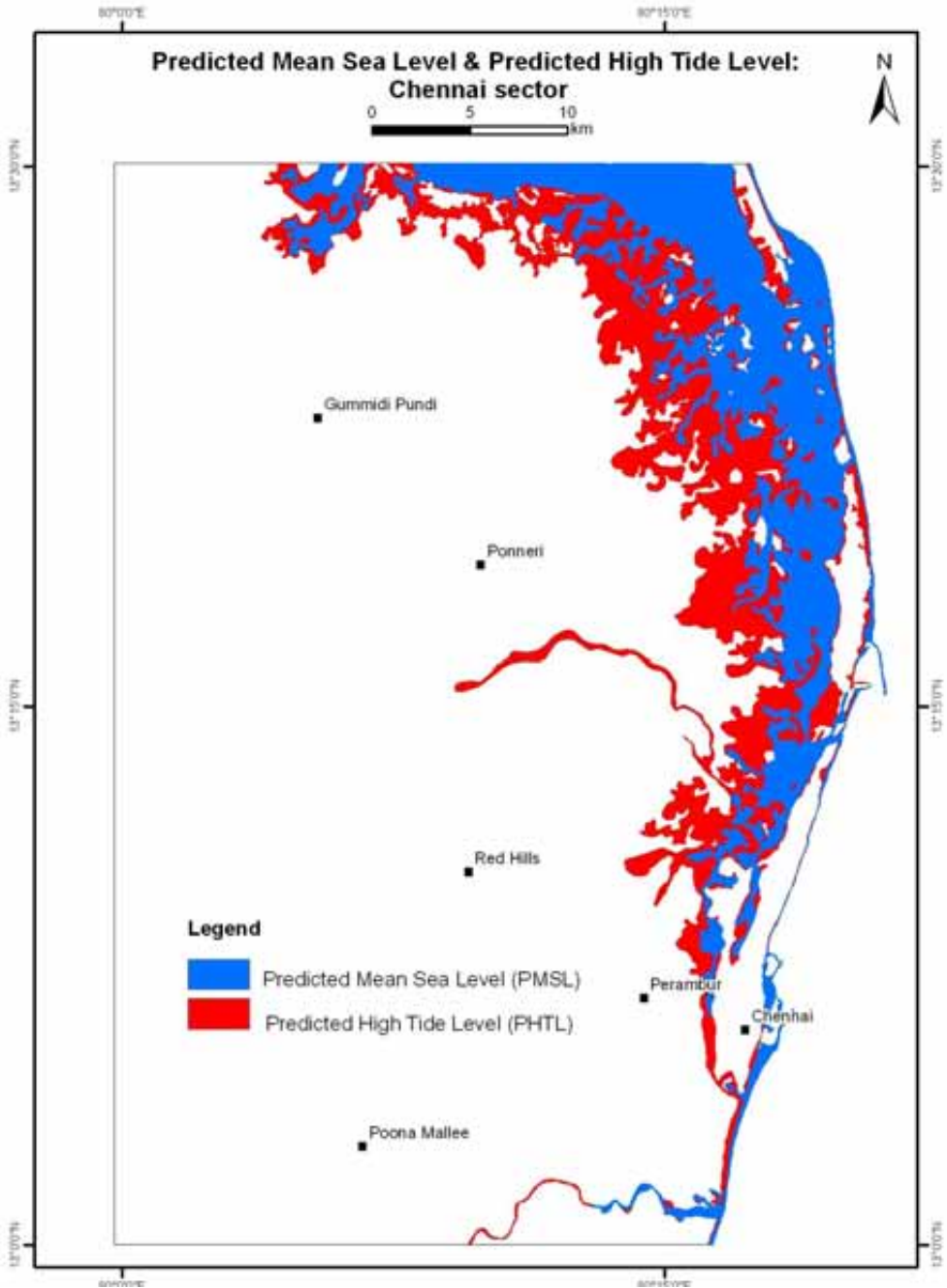


Fig. 7.57: Zone of submergence due to PMSL and degradation due to PHTL of Chennai sector

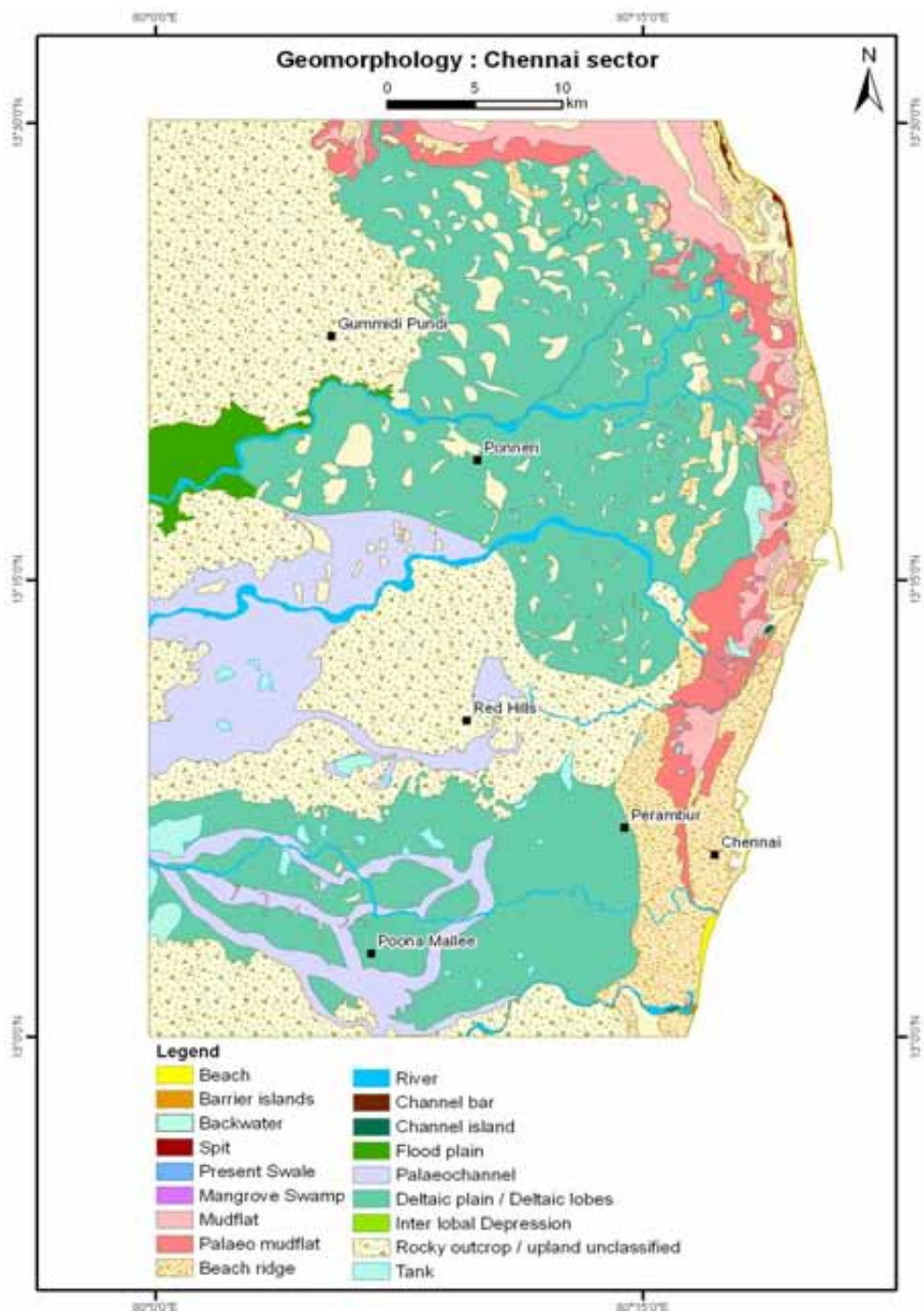


Fig. 7.58: Geomorphology of Chennai sector

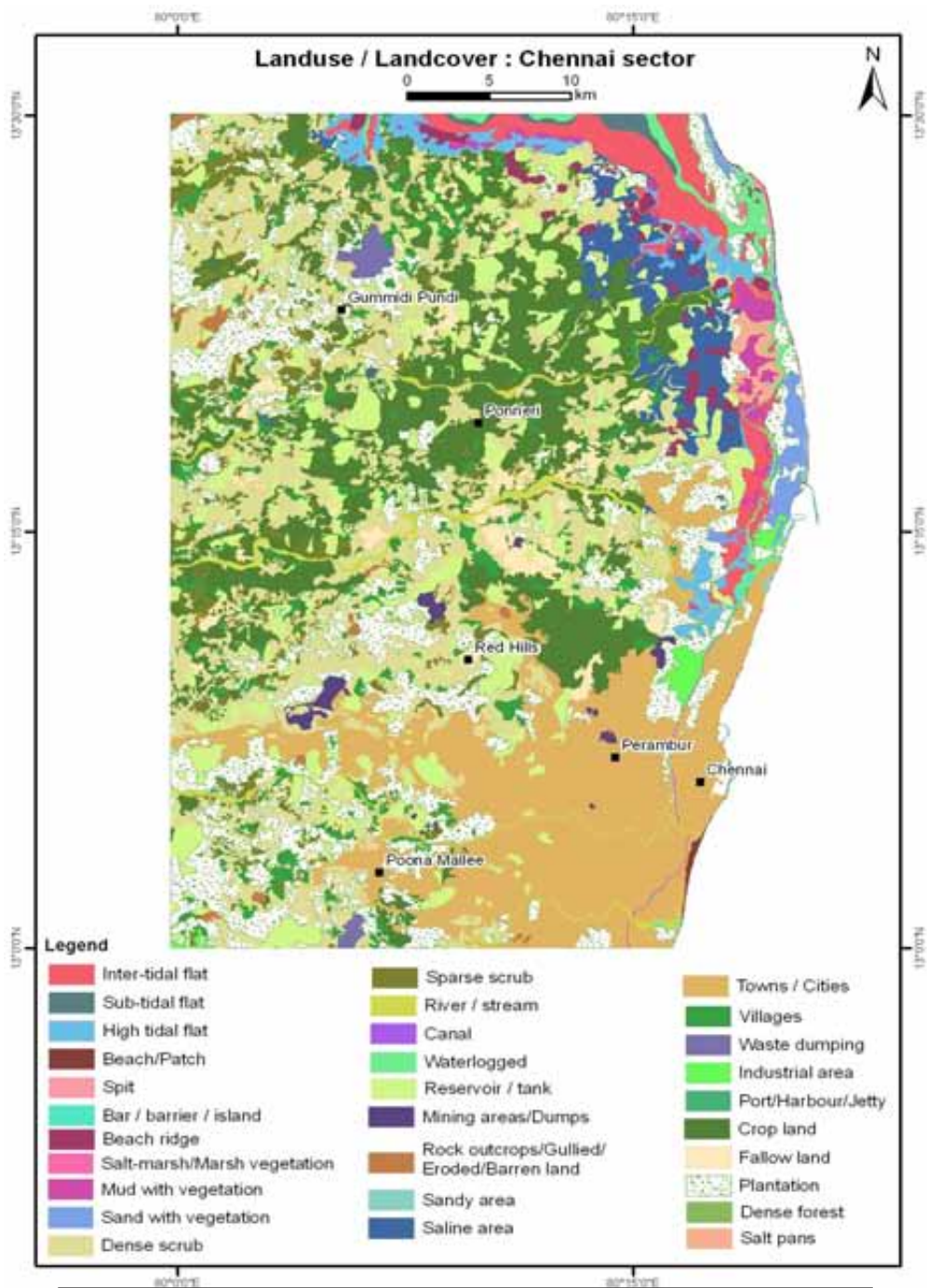


Fig. 7.59: Landuse/Landcover of Chennai sector

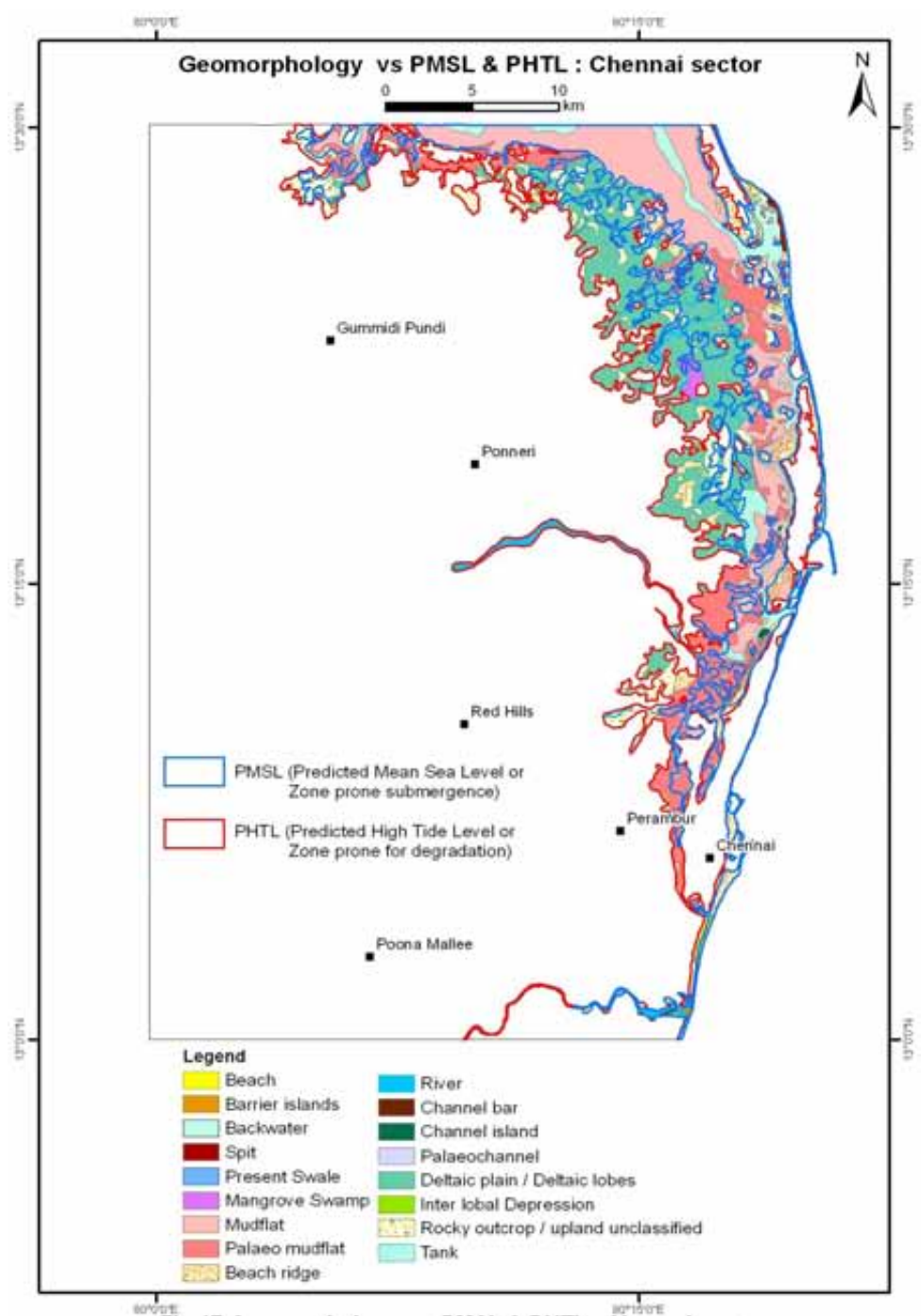


Fig. 7.60: Geomorphology vs PMSL and PHTL of Chennai sector

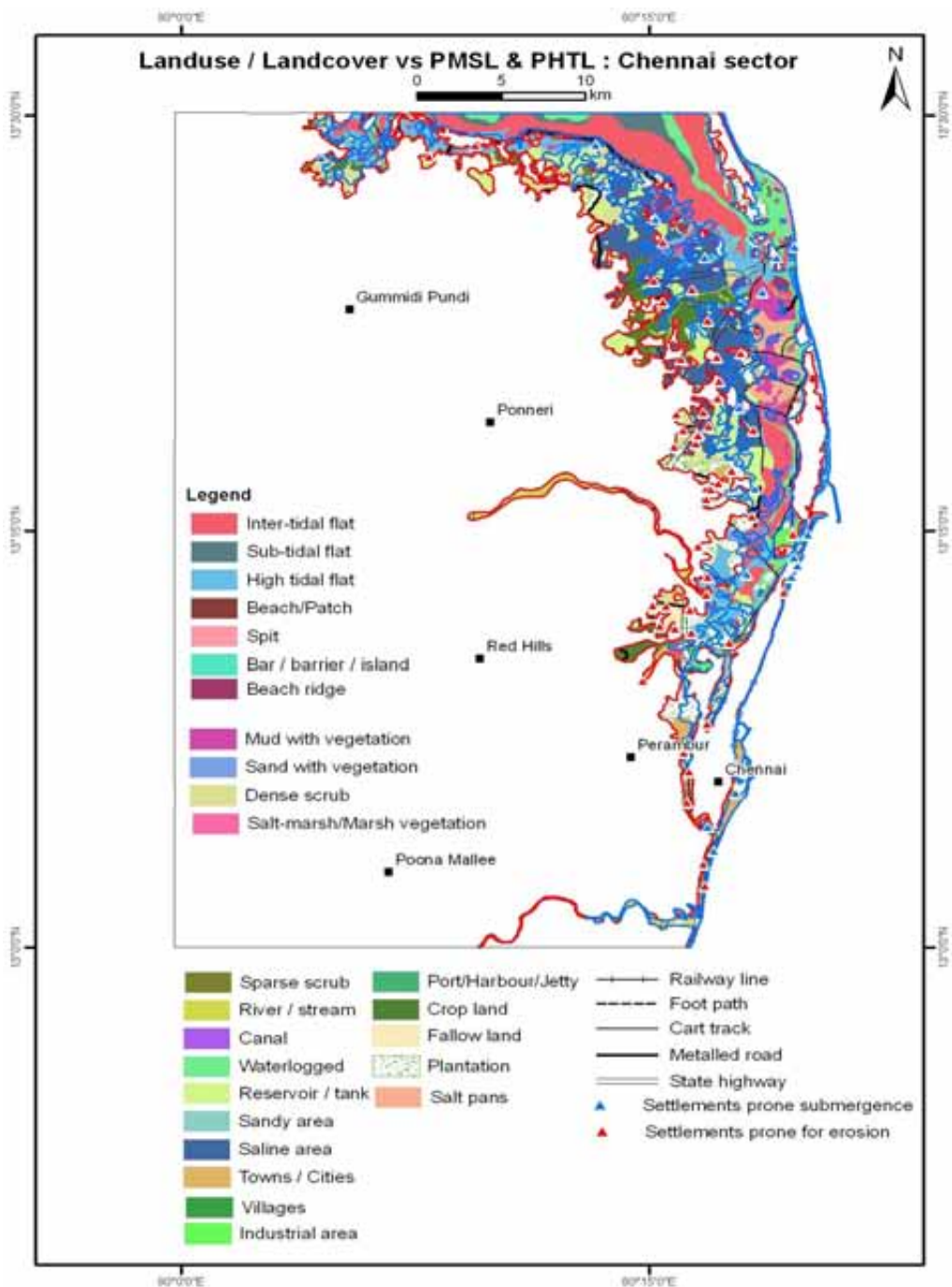


Fig. 7.61: Landuse/Landcover vs PMSL and PHTL of Chennai sector

Table 7.10: Natural and Physical Resources vs Predicted MSL and Predicted HTL – Chennai Sector

S.NO	Coastal Resources	Prone Submergences in Sq km	Prone for Degradation In Sq km
1	Beach	3.49	0.62
2	Barrier islands	0.15	0.00
3	Spit	0.76	0.00
4	Back water	19.37	0.50
5	Present swale	0.18	0.04
6	Mangrove swamp	0.49	1.71
7	Mudflat	66.53	8.31
8	Palaeo mudflat	31.13	32.94
9	Beach ridge	18.35	24.96

	Riverine Resources		
10	River	2.84	6.86
11	Channel bar	0.00	0.00
12	Channel island	0.35	0.00
13	Flood plain	0.00	0.00
14	Palaeochannel	0.00	0.03
15	Deltaic plain / Deltaic lobes	26.91	74.16
16	Inter lobal depression	4.34	11.95

	Agricultural Resources		
17	Crop land	3.86	15.93
18	Fallow land	0.18	2.75
19	Plantation	15.67	32.52
20	Dense scrub	5.08	14.40
21	Sparse scrub	0.27	0.59

	Water Resources		
23	River/Stream	2.51	5.86
24	Canal	1.59	0.36
25	Waterlogged	18.21	0.58
26	Reservoir/Tank	9.07	17.14
27	Aquifer	18.35	24.96

	Physical Resources		
28	Towns/Cities	6.13	8.81
29	Villages	0.02	1.63
30	Salt pans	7.18	0.85
31	Port/Harbour/Jetty	0.50	0.03

32	Industrial area	1.07	2.05
33	Cart track (Length in KM)	49.76	28.38
34	Foot path (Length in KM)	1.75	0.91
35	Metalled road (Length in KM)	9.65	50.97
36	State highway (Length in KM)	44.63	87.44
37	Railway (Length in KM)	28.28	17.40

Mamallapuram Sector

Similarly, the GIS layer showing such zones prone for submergence due to PMSL and degradation due to PHTL due to predicted SLR (Fig. 7.62) of Mamallapuram sector was integrated in GIS environment over the geomorphology (Fig. 7.63), landuse/landcover (Fig. 7.64) and physical resources layers of Mamallapuram sector and SLR impact analysis was carried out. The coastal landforms (Fig. 7.65), coastal landuse / landcover and physical resources (Fig. 7.66) fall in the zone of submergences and degradation were separated out using the GIS and the aerial extent of such affected resources were calculated and tabulated (Table 7.11).

The SLR impact analysis of this sector shows that the beaches, backwater, tidal flats, palaeo mudflats are more prone for submergences and degradation. It has also revealed that the possibility of tidal activities in the palaeochannels and meander plains. In the case of agricultural resources, plantation and scrub lands are seems to be affected more due to SLR in next 100 years. The physical resources like saltpans, Aquaculture ponds, state highway, etc. are expected to submergence and degradation in Mamallapuram sector due to predicted sea level rise and its related shifting of HTL (Table 7.8, Fig. 7.65 - 7.66)

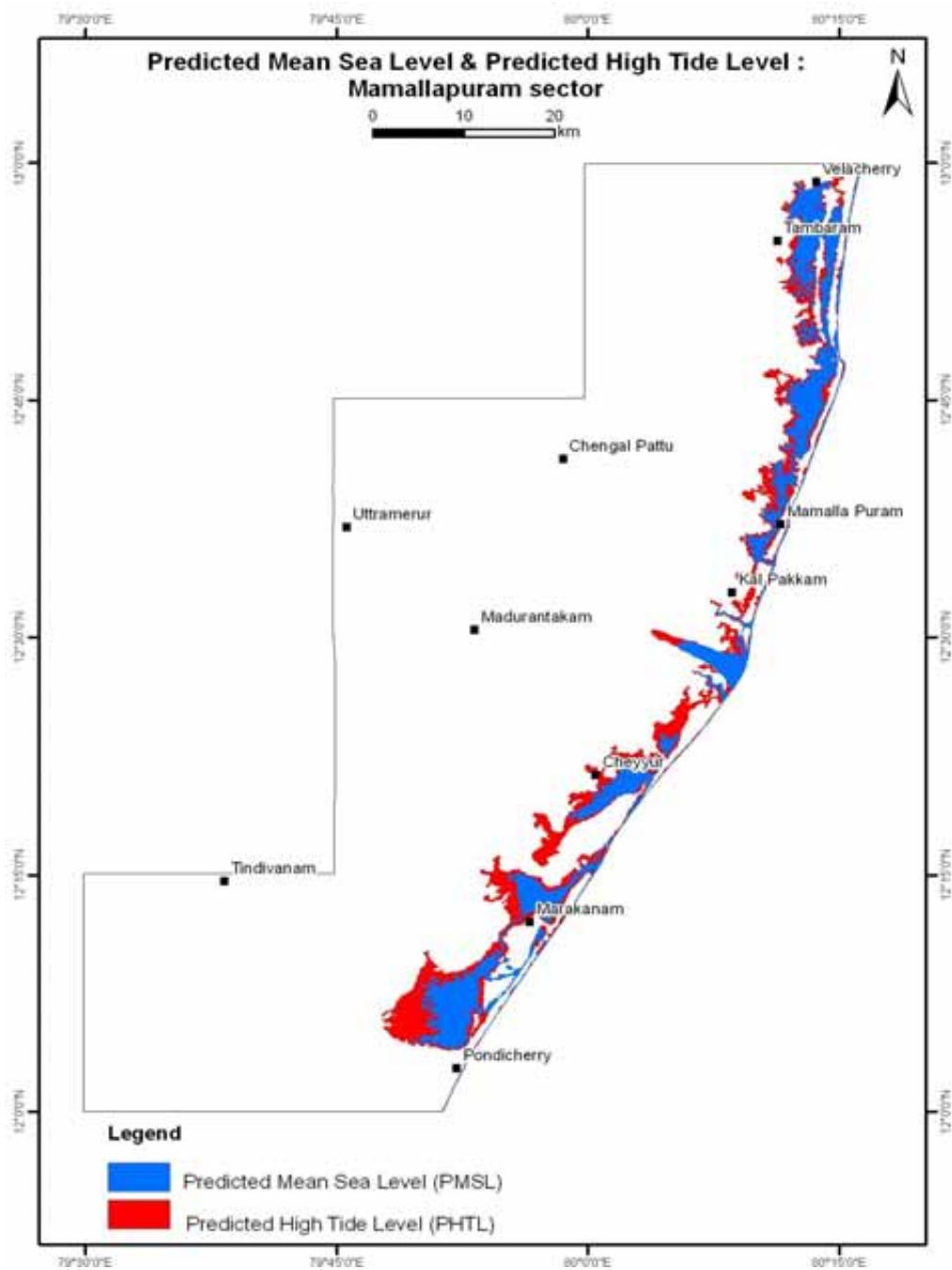


Fig. 7.62: Zone of submergence due to PMSL and degradation due to PHTL of Mamallapuram sector

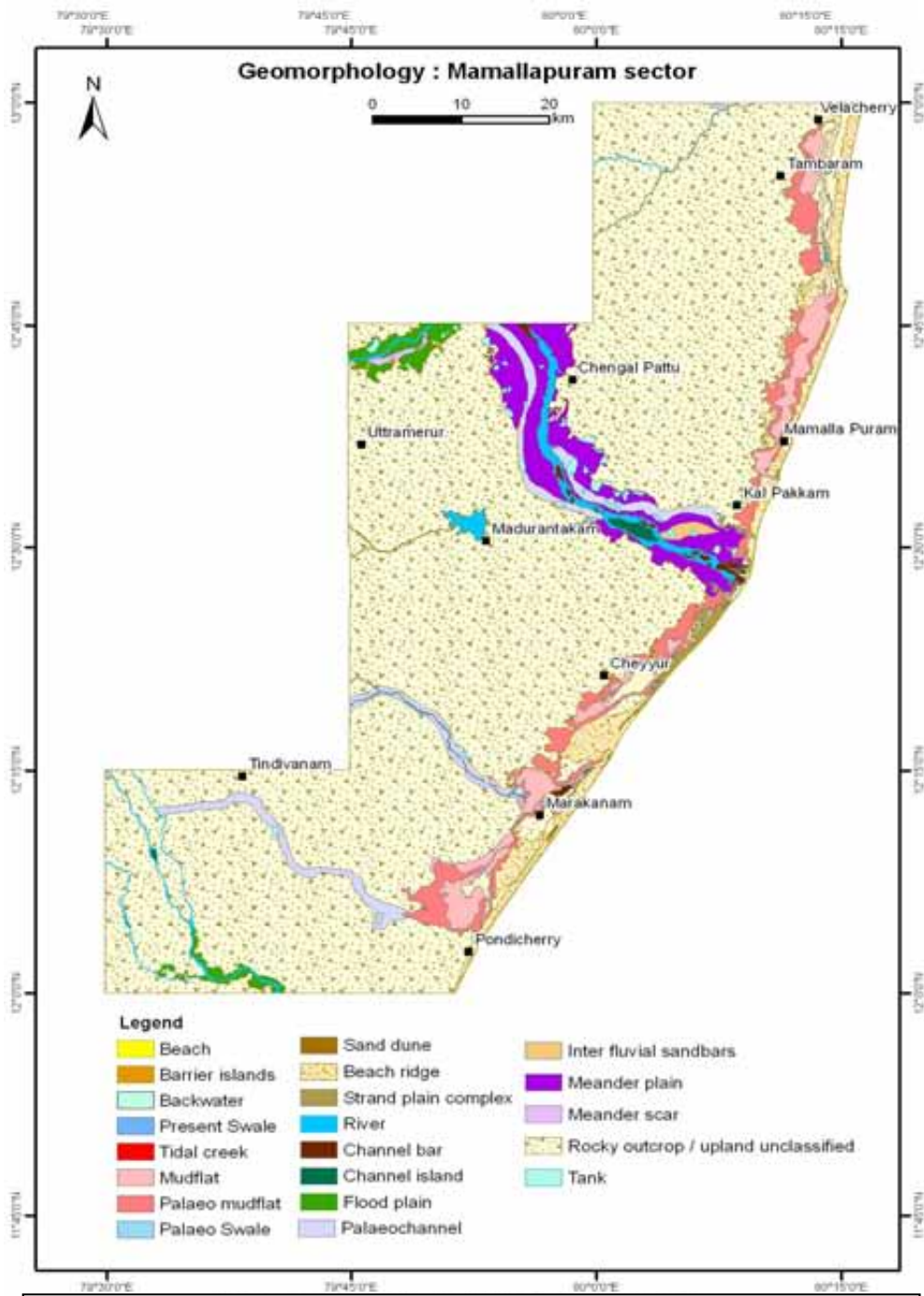


Fig. 7.63: Geomorphology of Mamallapuram sector

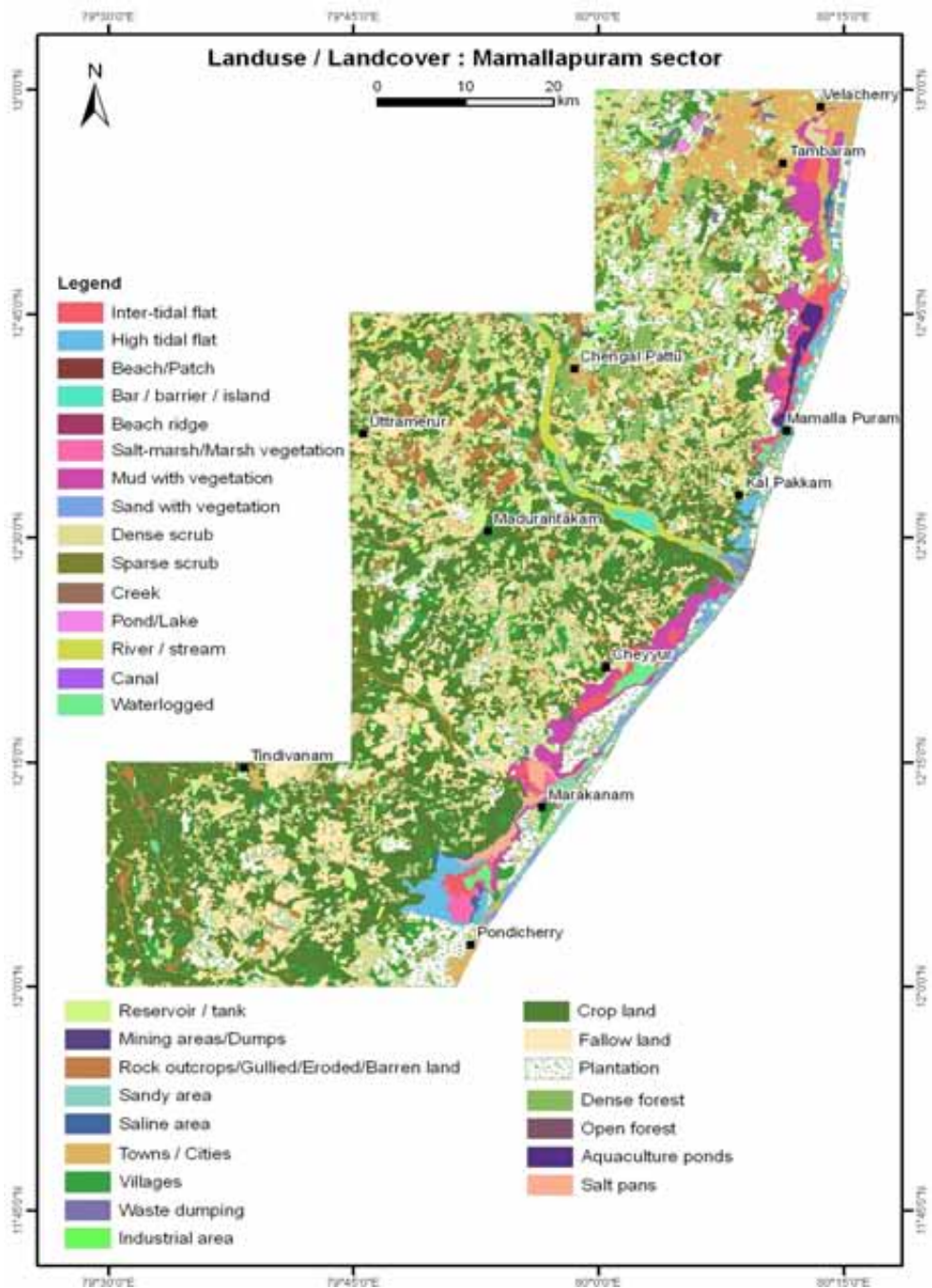


Fig. 7.64: Landuse/landcover of Mamallapuram sector

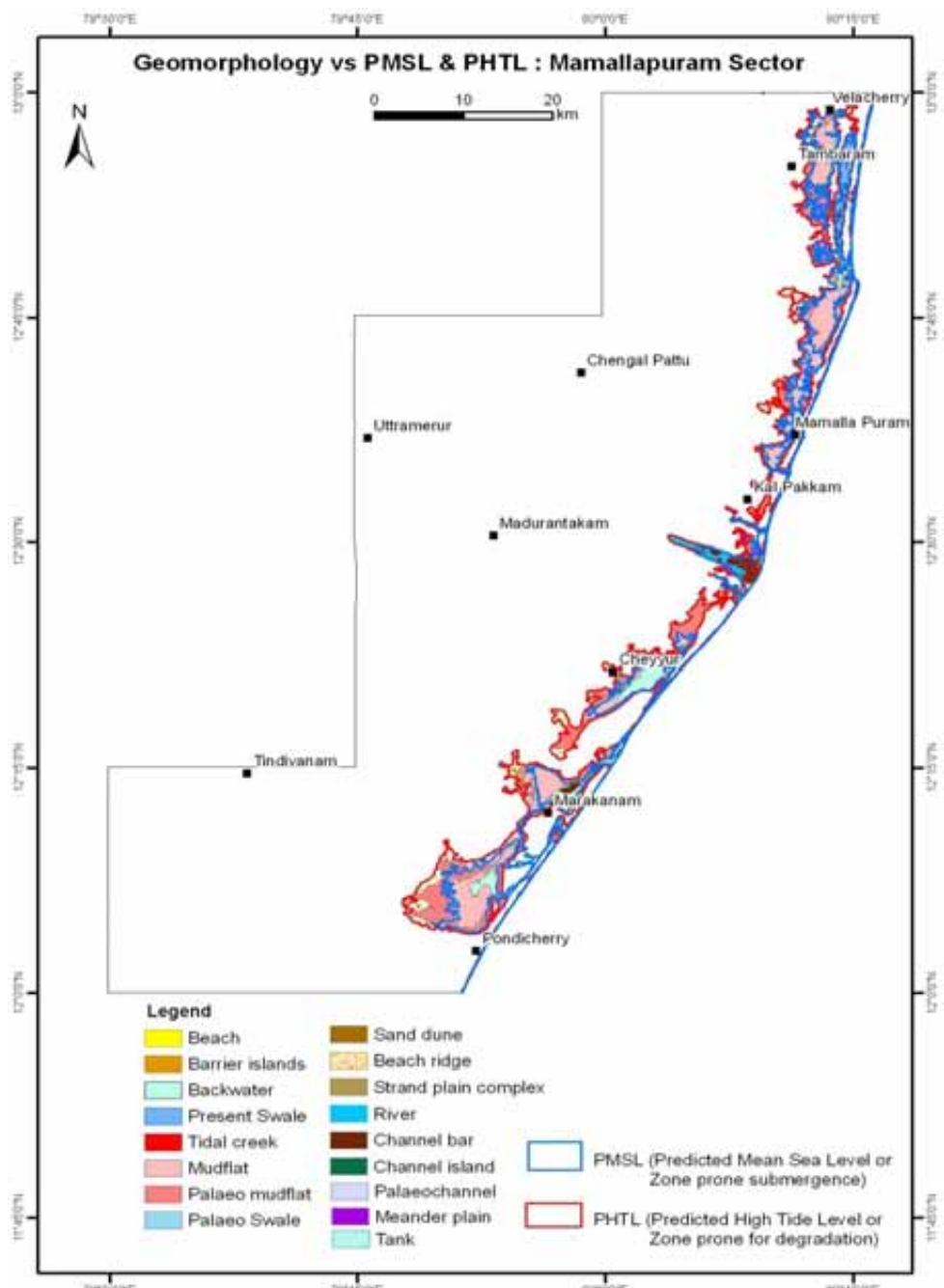


Fig. 7.65: Geomorphology vs PMSL & PHTL of Mamallapuram sector

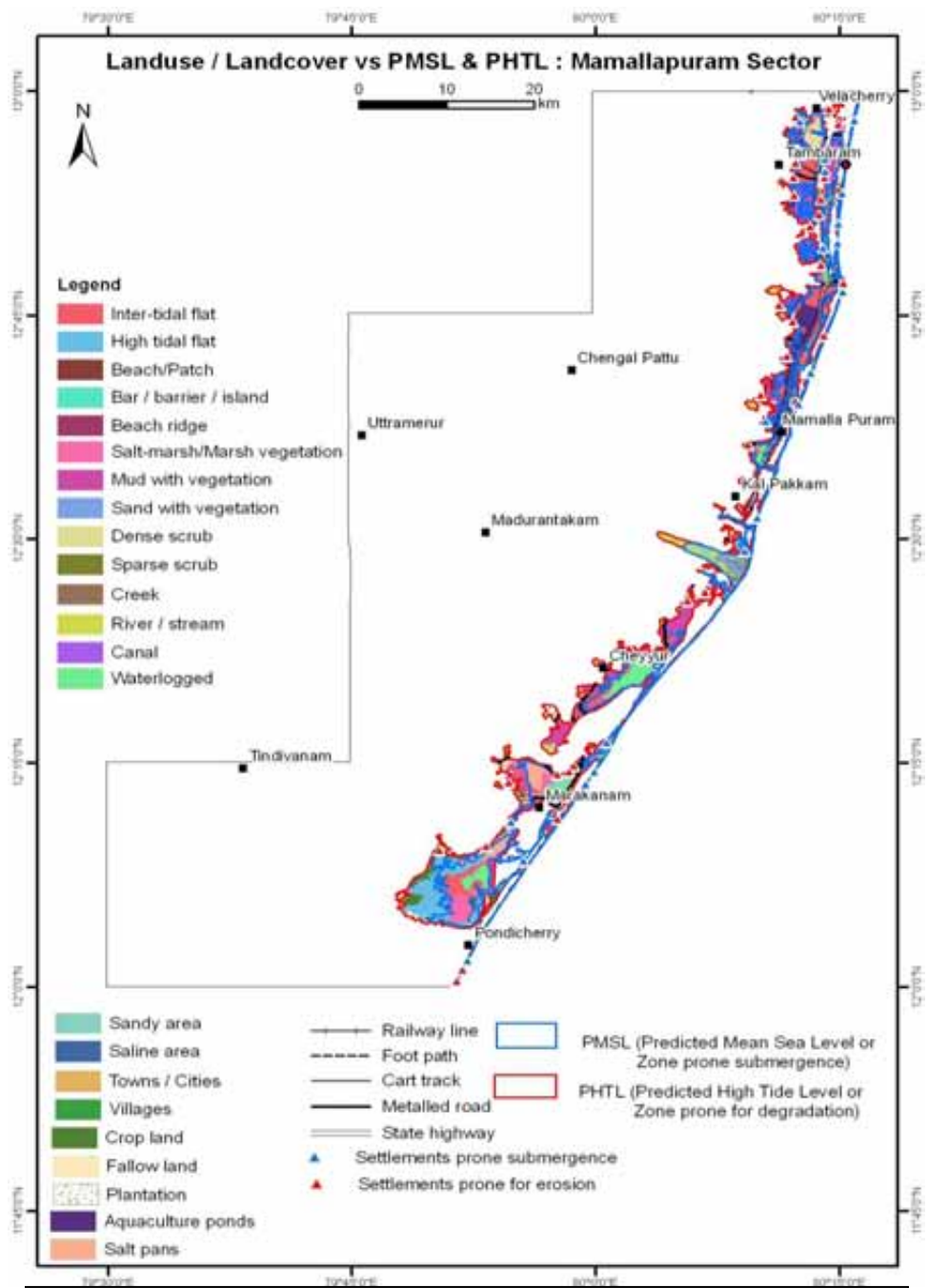


Fig. 7.66: Landuse/Landcover vs PMSL & PHTL of Mamallapuram sector

Table 7.11: Natural and Physical Resources vs Predicted MSL and Predicted HTL – Mamallapuram Sector

S.NO	Coastal Resources	Prone for Submergences in Sq km	Prone for Degradation In Sq km
1	Beach	5.03	1.22
2	Barrier islands	0.21	0.01
3	Back water	25.38	0.77
4	Present swale	13.49	4.95
5	Tidal Creek	3.67	0.26
6	Mudflat	89.15	28.12
7	Palaeo mudflat	34.98	84.65
8	Palaeo swale	2.42	1.09
9	Sand dune	0.06	0.19
10	Beach ridge	12.10	23.78
11	Strand plain complex	0.75	1.26

	Riverine Resources		
12	River	4.68	3.31
13	Channel bar	8.50	0.32
14	Channel island	0.49	0.20
16	Palaeo channel	0.00	2.31
17	Inter fluvial sandbars	0.00	0.00
18	Meander plain	1.49	2.94

	Agricultural Resources		
20	Crop land	1.36	13.68
21	Fallow land	2.39	5.76
22	Plantation	8.19	17.42
23	Dense scrub	7.22	3.21
24	Sparse scrub	0.00	0.15

	Water Resources		
25	Creek	3.71	0.34
26	River/Stream	3.76	2.99
27	Canal	1.18	0.57
28	Reservoir/Tank	0.99	6.69
29	Waterlogged	29.09	1.45
30	Aquifer	12.10	23.78

	Physical Resources		
31	Towns/Cities	4.00	7.26
32	Villages	0.19	1.62
33	Salt pans	12.17	6.69

34	Aquaculture ponds	12.35	3.68
35	Cart track (Length in KM)	4.34	1.51
36	Metalled road (Length in KM)	29.47	44.07
37	State highway (Length in KM)	69.23	73.61

Chidambaram Sector

The GIS overlay analysis was carried out between the GIS layer of the zones prone for submergence due to PMSL and degradation due to PHTL due to predicted SLR (Fig. 7.67) and the GIS layers of geomorphology (Fig. 7.68), landuse / landcover (Fig. 7.69) and physical resources of Chidambaram sector revealed that

- ➔ The coastal features of Chidambaram sector like Beach, Mudflat, Beach ridge, Palaeo swale overprinted by delta, etc. are more prone to submergences due to predicted MSL and also more prone for degradation, pollution, erosion, etc. due to predicted shift of high tide line (Fig. 7.70, Table 7.12)
- ➔ The rivers of this sectors are expected to have more tidal action and possibility of flooding in its banks of these rivers due to expected sea level rise in 2100 AD (Fig. 7.70, Table 7.12)
- ➔ The agricultural resources like crop lands of 38.63 sq. km are prone for submergences and crop lands of 75.68 sq km are expected to be affected by salination and degradation due to predicted high tide level (Fig. 7.70, Table 7.12)
- ➔ The beach ridges (generally stand as a good potable aquifers in the coastal region) of 56.35 sq km are prone for submergences and the beach ridges of 111.74 sq km are prone for pollution and salination due to expected sea level rise due to global warming. (Fig. 7.71, Table 7.12)

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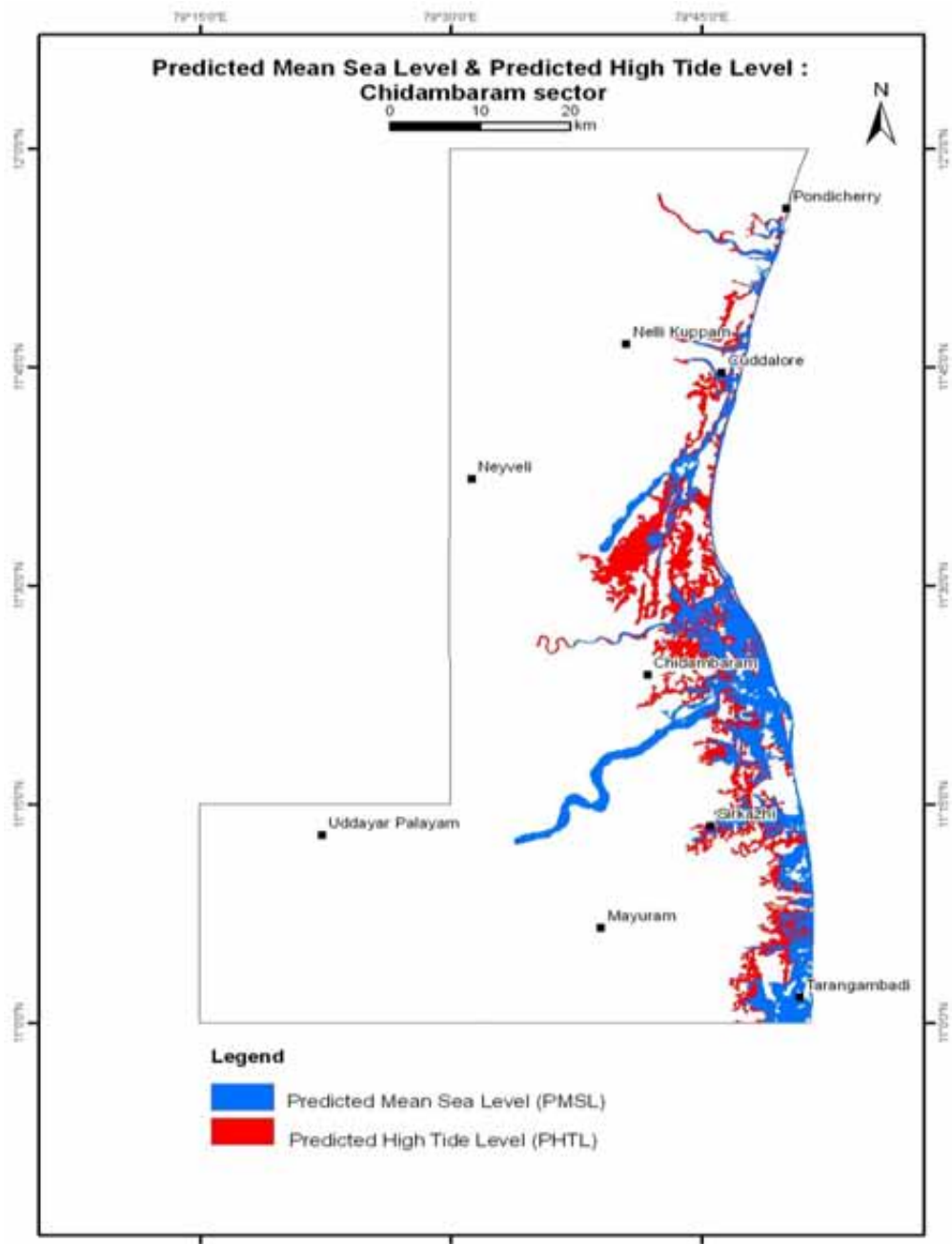


Fig. 7.67: Zone of submergence due to PMSL and degradation due to PHTL of Chindambaram setor

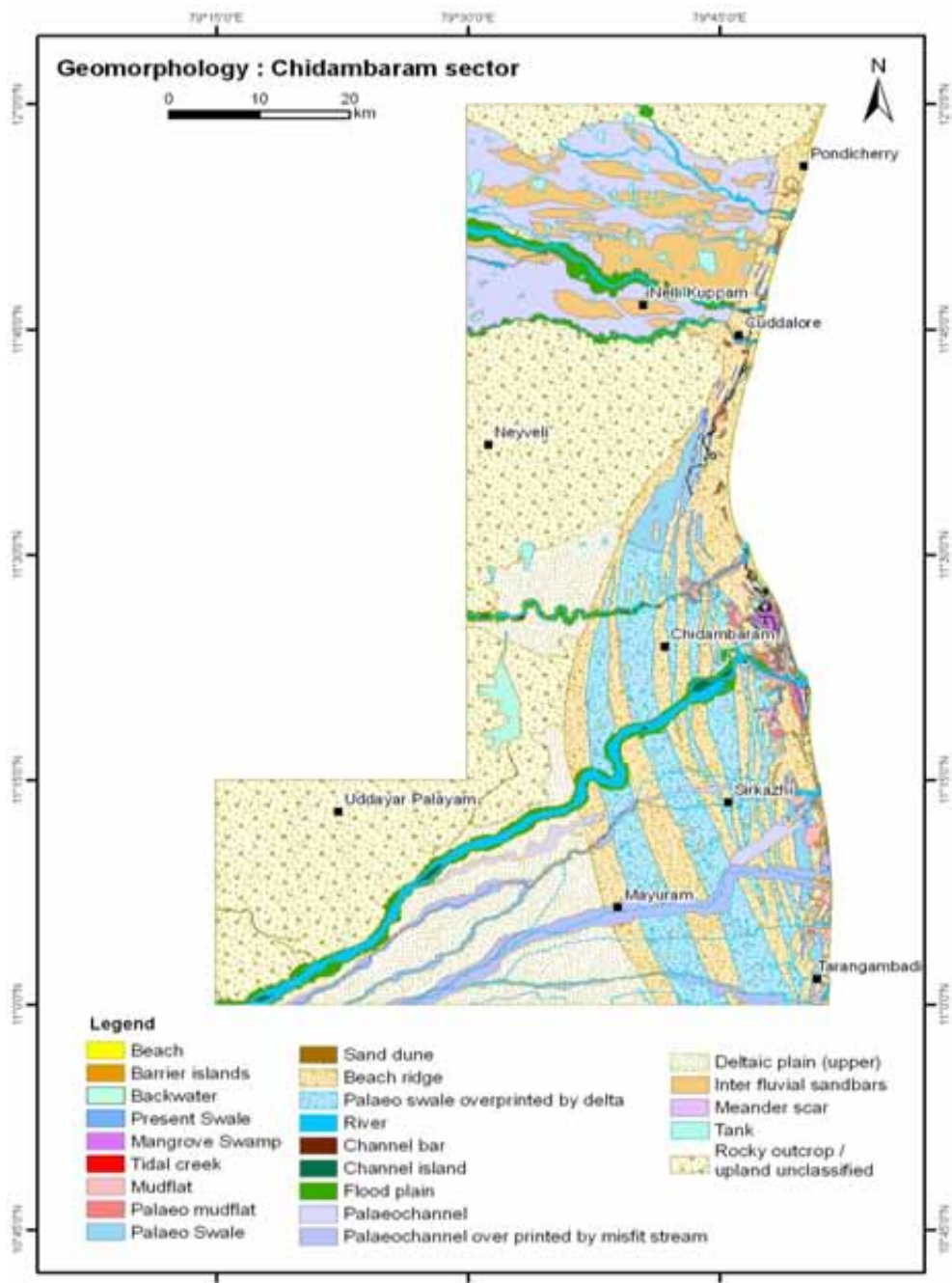


Fig. 7.68: Geomorphology of Chidambaram sector

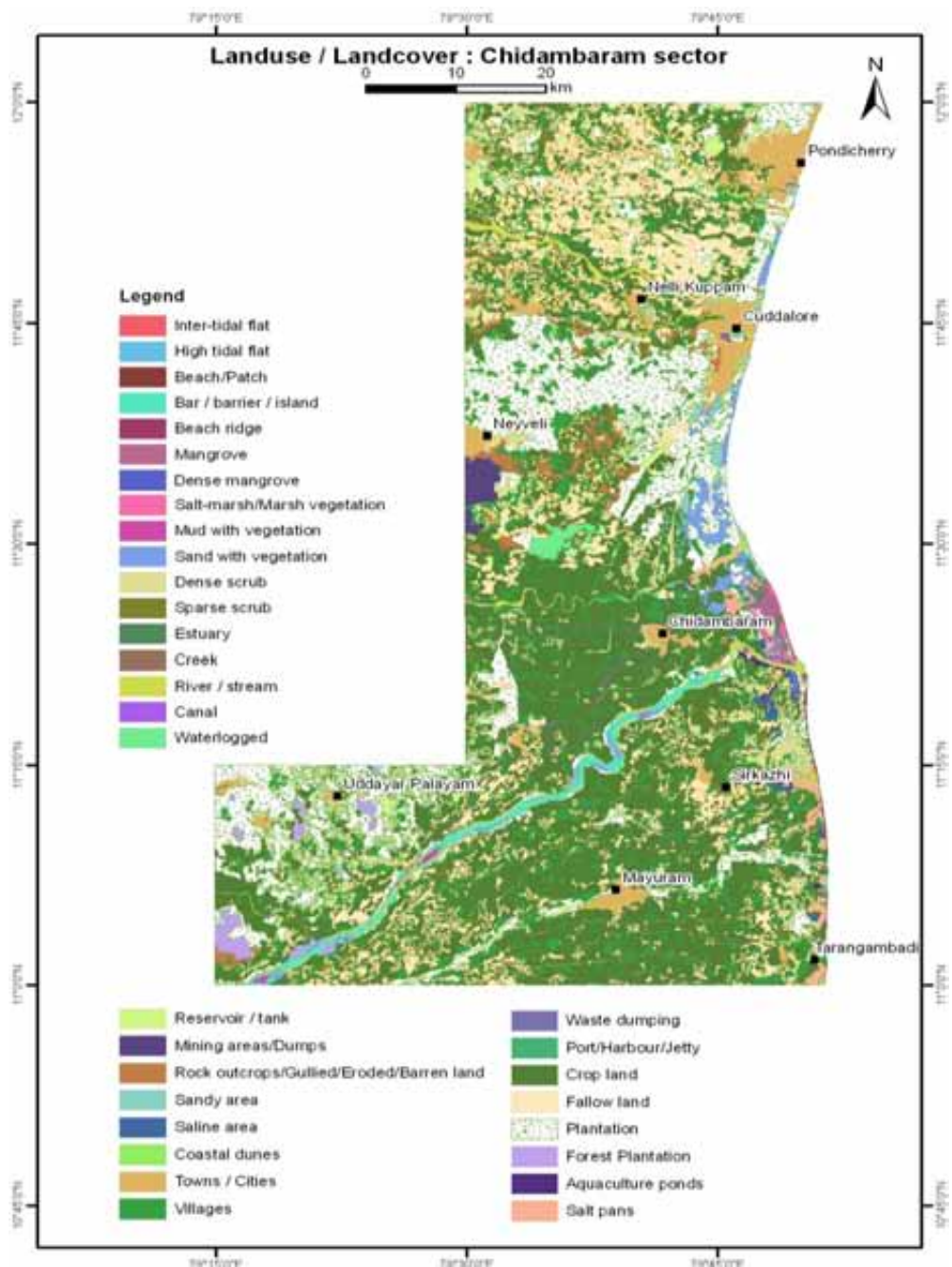


Fig. 7.69: Landuse/Landcover of Chidambaram sector

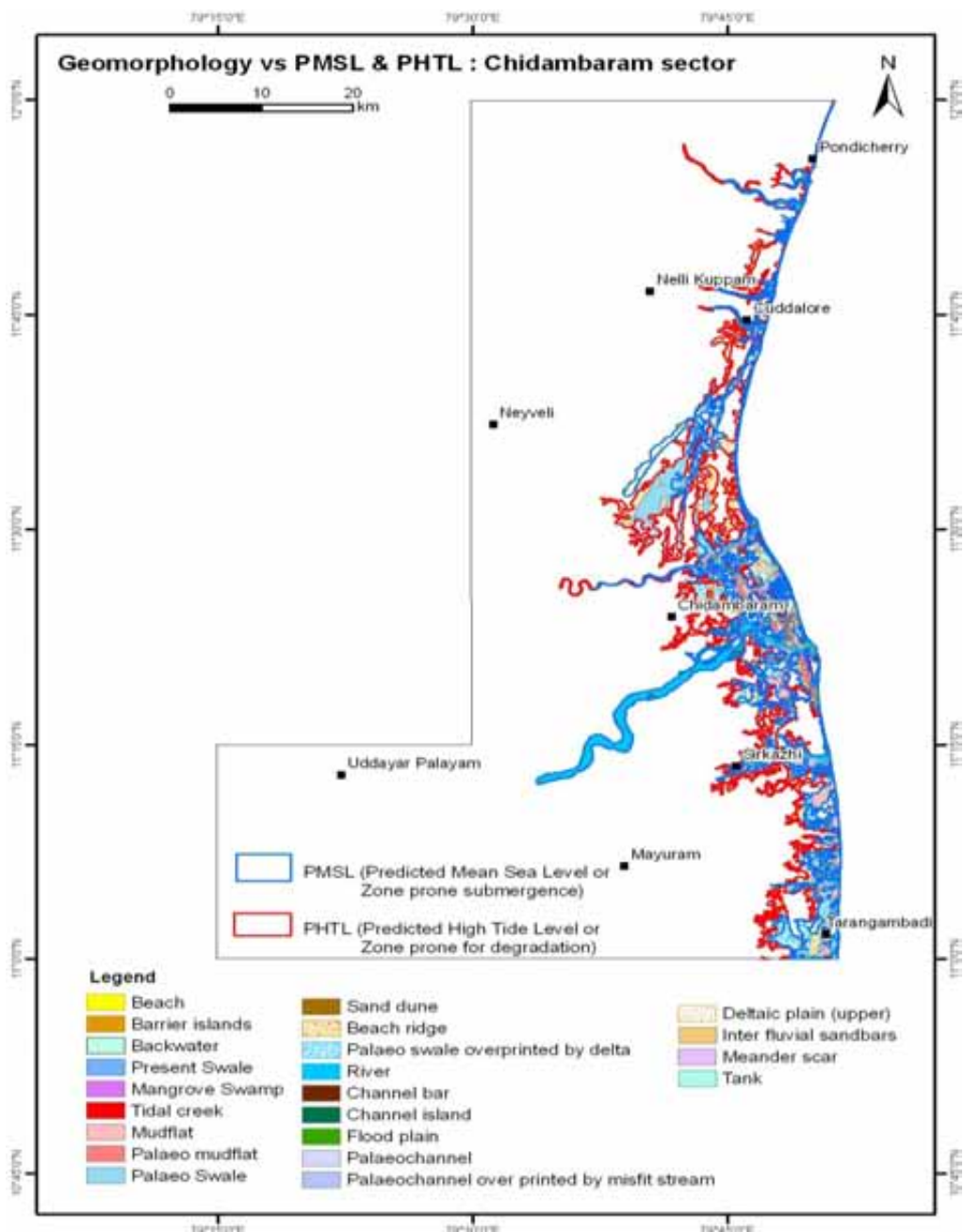


Fig. 7.70: Geomorphology vs PMSL and PHTL-Chindamaram sector

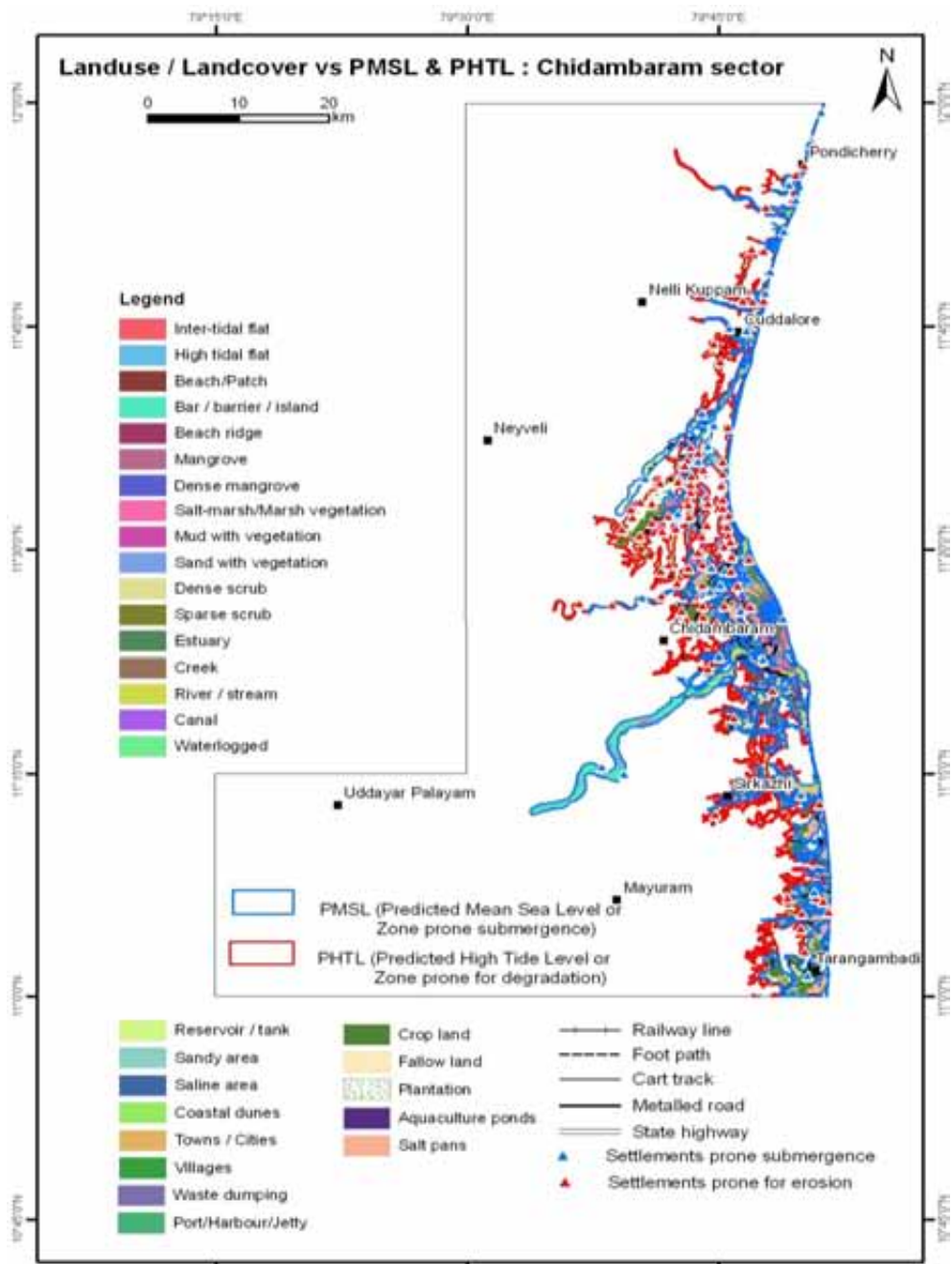


Fig. 7.71: Landuse/Land cover vs PMSL and PHTL – Chidambaram sector

Table 7.12: Natural and Physical Resources vs Predicted MSL and Predicted HTL – Chidambaram Sector

S.NO	Coastal Resources	Prone for Submergences in Sq km	Prone for Degradation in Sq km
1	Beach	6.51	0.59
2	Barrier islands	0.62	0.00
3	Back water	12.17	0.41
4	Present swale	6.07	0.55
5	Mangrove swamp	5.95	2.26
6	Mangrove	4.29	2.17
7	Mangrove-Very dense	2.27	0.33
8	Tidal Creek	1.78	0.14
9	Mudflat	43.58	4.47
10	Palaeo mudflat	13.18	3.09
11	Palaeo swale	22.82	40.40
12	Sand dune	0.02	0.71
13	Beach ridge	56.35	111.74
14	Palaeo swale overprinted by delta	25.41	56.00

	Riverine Resources		
15	River	54.58	4.78
16	Channel bar	1.48	0.59
17	Channel island	1.38	0.34
18	Flood plain	3.31	2.34
19	Palaeochannel	0.47	2.72
20	Palaeochannel over printed by misfit stream	0.32	1.16
21	Delta plain (upper)	0.00	2.36
22	Inter fluvial sandbars	0.00	3.24
23	Meander scar	0.14	1.10

	Agricultural Resources		
24	Crop land	38.63	75.68
25	Fallow land	4.75	14.35
26	Plantation	24.34	49.61
27	Dense scrub	21.72	30.34
28	Sparse scrub	1.41	3.00

	Water Resources		
29	Estuary	8.91	0.51
30	Creek	1.52	0.08

31	River/Stream	32.72	4.77
32	Canal	0.30	0.45
33	Waterlogged	1.50	0.18
34	Reservoir/Tank	3.06	0.92
35	Aquifer	56.35	111.74

	Physical Resources	Prone for Submergences in Sq km	Prone for Degradation in Sq km
36	Towns / Cities	2.87	9.38
37	Villages / habitats	5.31 (33 No.)	10.70 (89 No.)
38	Salt pans	27.76	1.81
39	Aquaculture ponds	6.02	0.18
40	Port/Harbour/Jetty	0.05	0.00
41	Cart track (Length in km)	0.92	0.20
42	Foot path (Length in km)	1.63	2.57
43	Metalled road (Length in km)	86.09	140.59
44	State highway (Length in km)	33.32	49.11
45	Railway (Length in km)	12.44	18.00

Vedaranniyam Sector

The Vedaranniyam sector is covering the southern part of the Cauvery delta and its coastal margin is vested with thick fluvio-marine and marine landforms. Same way, the SLR impact analysis was carried out by overlaying the GIS layer of the zones prone for submergence due to PMSL and degradation due to PHTL due to predicted SLR (Fig. 7.72) with the GIS layers of geomorphology (Fig. 7.73), landuse/landcover (Fig. 7.74) and physical resources of Vedaranniyam region show that

- ➔ The palaeo and present mudflats of over 400 sq km which is presently occupied by saltpans, aquaculture ponds in Vedaranniyam sector are seems to be flooded by sea water in 2100 AD (Fig. 7.75 - 7.76). The fluvio-marine geomorphic unit Palaeo swale over printed by delta of over 100 sq km mostly covered by the agricultural lands is prone for submergences due to global warming and related sea level rise. The tidal activities in rivers, creeks, backwaters, etc. are seems to be increased and flooding in the adjacent lands due to expected sea level rise

- ➔ Comparing to other coastal sectors, in Vedranniyam sector, the agricultural lands of over 600 sq km are prone for submergence and degradations (Fig. 7.76, Table 7.13)
- ➔ The beach ridges of 200 sq km presently stand as a potable water source in this sector are seem to be polluted by increase of sea level (Fig. 7.76, Table 7.13)

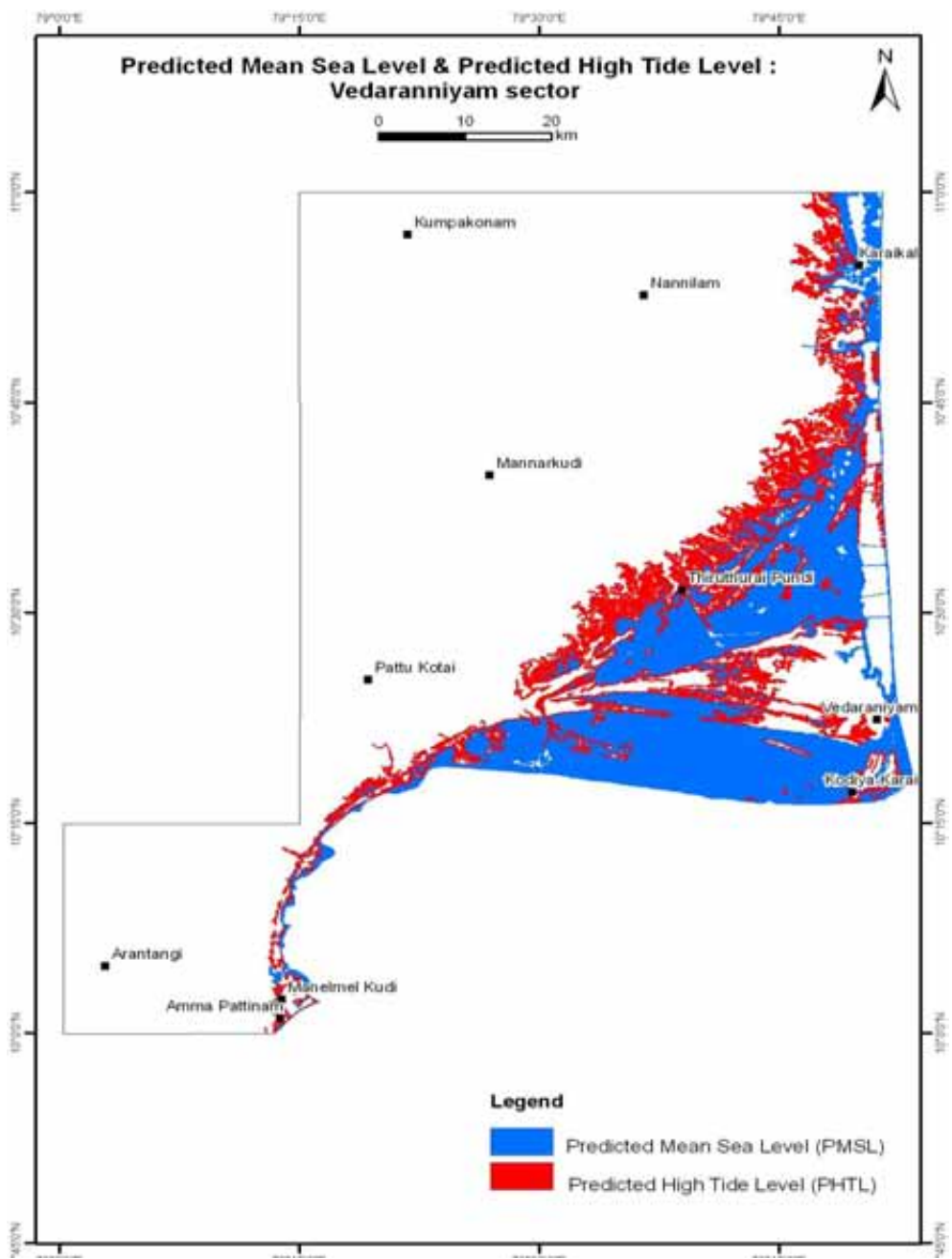


Fig. 7.72: Zone of submergence due to PMSL and degradation due to PHTL of Vedaranniyam sector

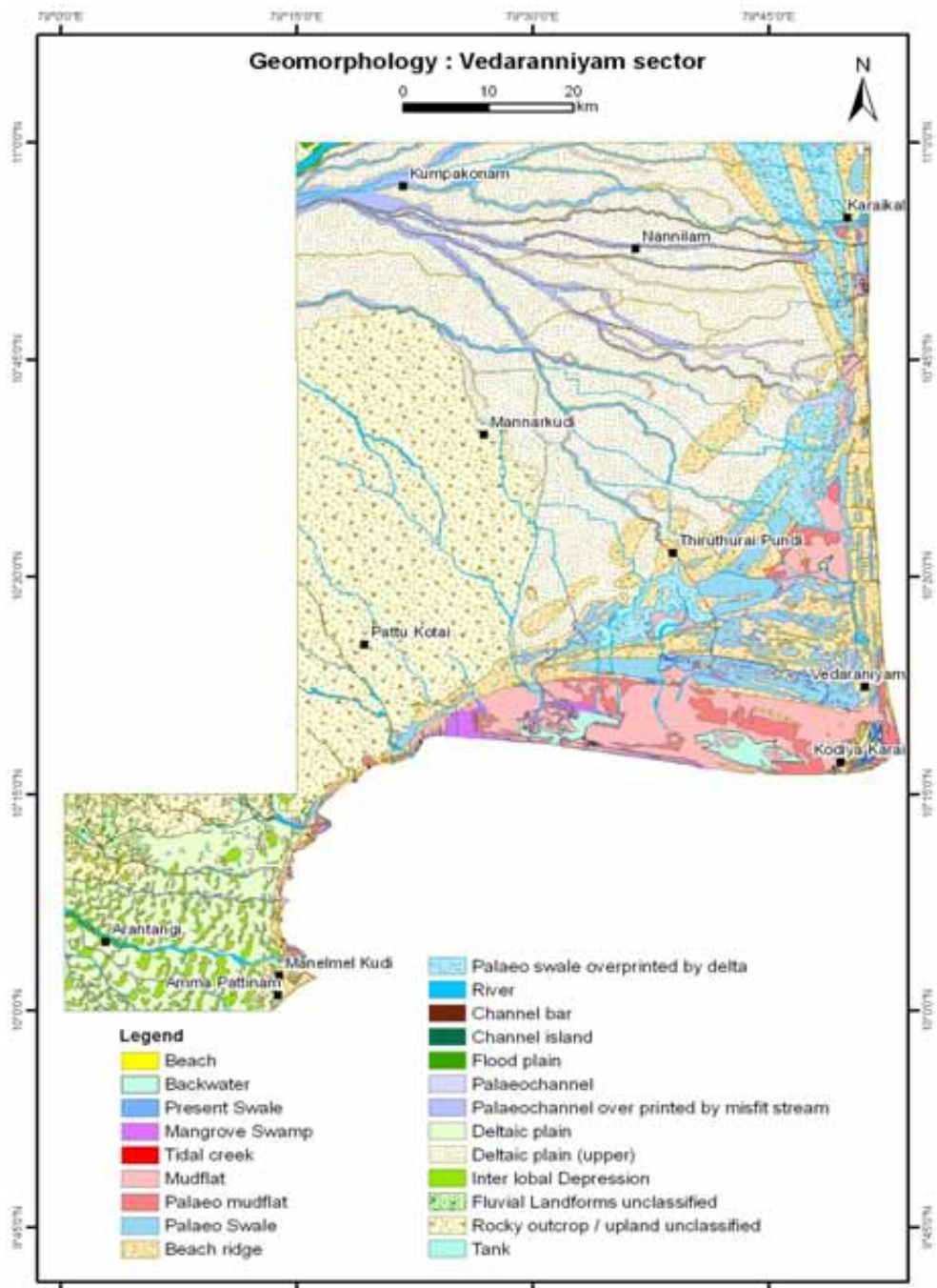


Fig. 7.73: Geomorphology of Vedaranniyam sector

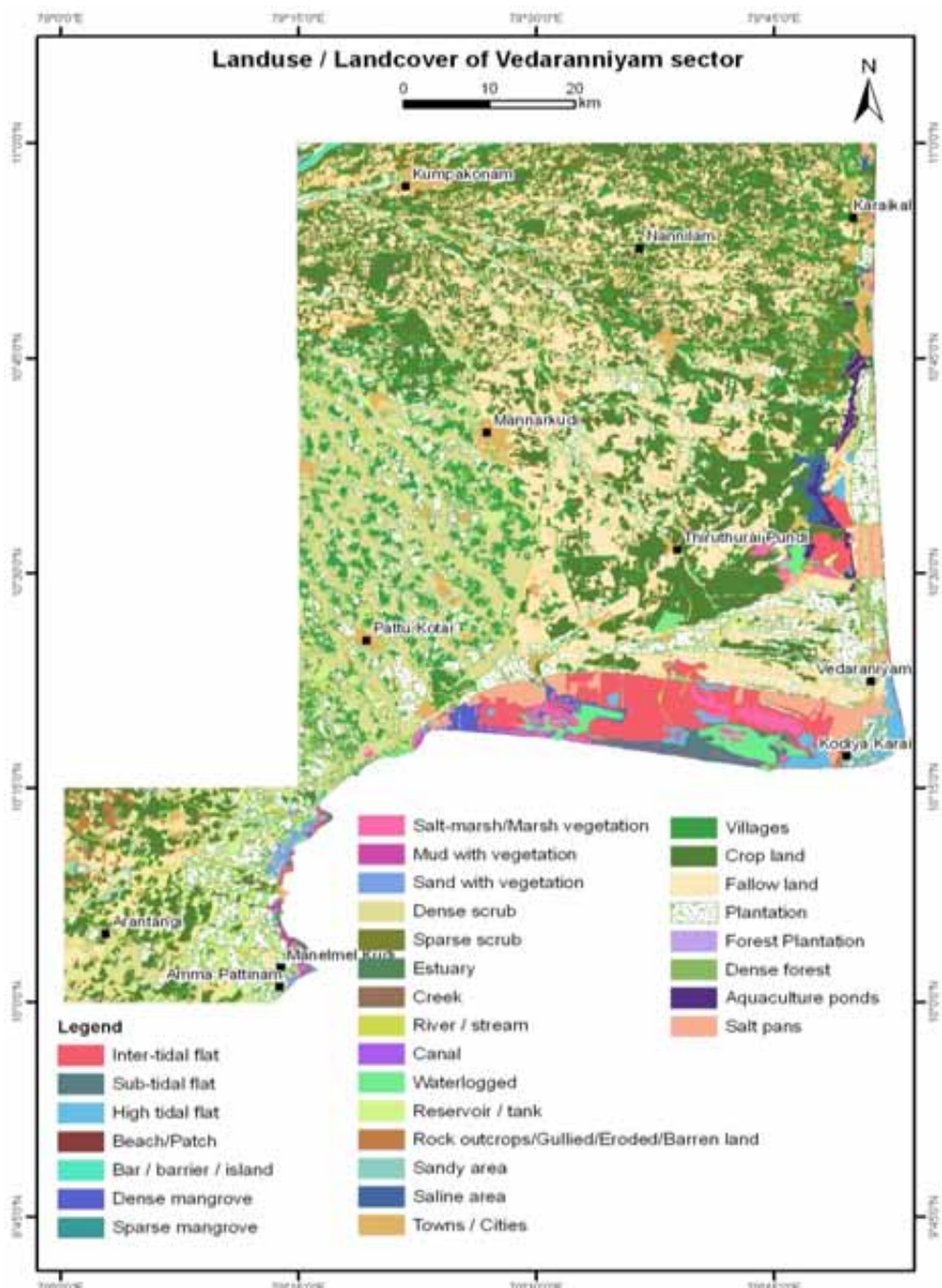


Fig. 7.74: Landuse/Landcover of Vedaranniyam sector

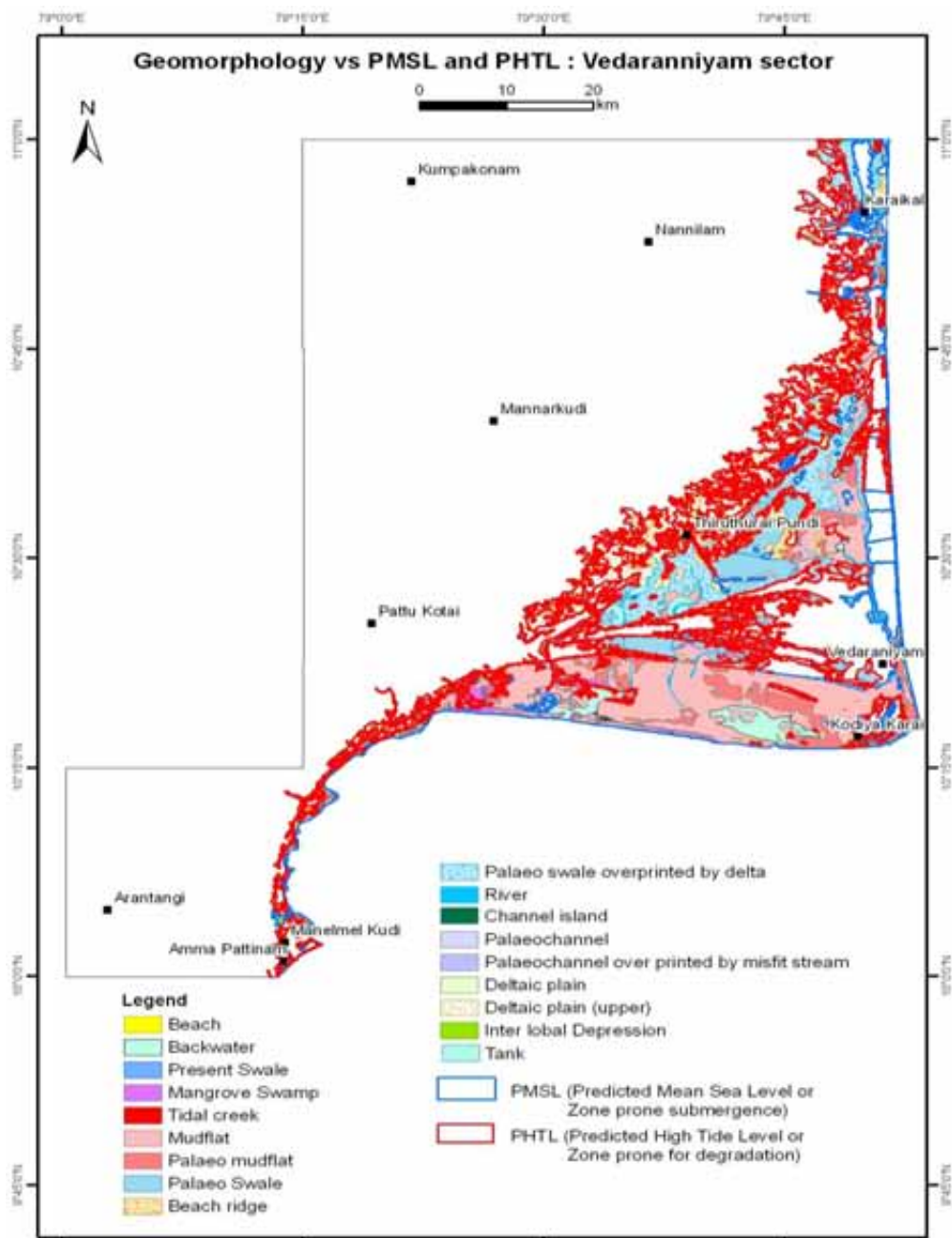


Fig. 7.75: Geomorphology vs PMSL and PHTL of Vedaranniyam sector

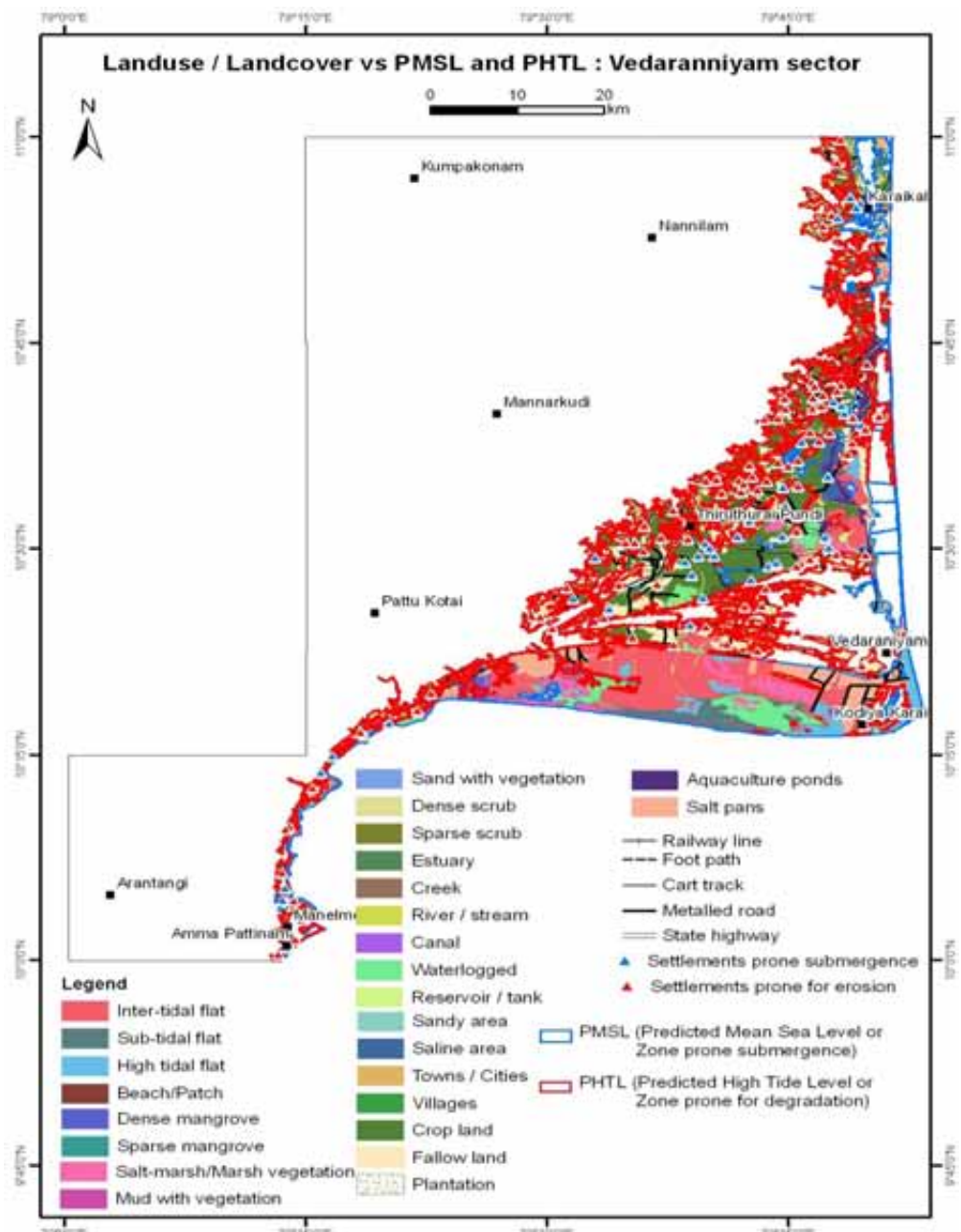


Fig. 7.76: Landuse / Landcover vs PMSL and PHTL of Vedaranniyam sector

Table 7.13: Natural and Physical Resources vs Predicted MSL and Predicted HTL – Vedaranniyam Sector

S.NO	Coastal Resources	Prone for Submergences in Sq km	Prone for Degradation In Sq km
1	Beach	7.42	0.30
2	Back water	40.58	0.93
3	Present swale	4.73	2.21
4	Mangrove swamp	25.66	6.82
6	Very Dense Mangrove	17.71	7.17
7	Dense mangrove	4.84	0.63
8	Sparse mangrove	0.17	0.05
9	Tidal Creek	4.31	0.62
10	Mudflat	347.38	11.23
11	Protuding delta	1.08	0.00
12	Palaeo mudflat	94.63	4.15
13	Palaeo Swale	139.94	65.73
14	Beach ridge	91.95	145.32
15	Palaeo swale overprinted by delta	115.43	42.82

	Riverine Resources		
16	River	20.58	6.72
17	Channel island	0.18	0.00
18	Palaeochannel	0.12	3.50
19	Palaeochannel over printed by misfit stream	1.88	3.04
20	Delta plain (upper)	37.08	112.17
21	Deltaic plain	0.99	4.49
22	Inter lobal depression	1.35	1.84

	Agricultural Resources		
23	Crop land	201.40	121.19
24	Fallow land	114.95	120.29
25	Plantation	31.18	70.83
26	Dense scrub	13.43	24.33
27	Sparse scrub	3.18	9.24

	Water Resources		
27	Estuary	0.14	0.03
28	Creek	6.95	0.55
29	River / Stream	21.21	8.48
30	Canal	0.00	0.14

31	Waterlogged	58.08	1.53
32	Reservoir / Tank	7.02	5.37

	Physical Resources	Prone for Submergences In Sq km	Prone for Degradation In Sq km
33	Towns / Cities	3.38	6.72
34	Villages / habitats	7.53 (42 No)	19.73 (83 No)
35	Salt pans	85.26	4.95
36	Aquaculture ponds	25.15	1.66
37	Aquifer	91.95	145.32
38	Metalled road (Length in KM)	171.83	120.00
39	State highway (Length in KM)	90.45	118.25
40	Railway (Length in KM)	33.77	21.67

Ramanthapuram Sector

The GIS overlay analysis was carried out between the GIS layer of the zones prone for submergence due to PMSL and degradation due to PHTL due to predicted SLR (Fig. 7.77) and the GIS layers of geomorphology (Fig. 7.78), landuse/landcover (Fig. 7.79) and physical resources of Ramanathapuram sector revealed that

- ➔ When compare to the other sectors like Chidambaram and Vedaranniyam, the SLR impact is comparatively less in Ramanathapuram sector
- ➔ In the case of coastal landforms mostly beach, mudflats, palaeo mudflats and beach ridges are more prone to submergences due to predicted MSL and also more prone for degradation, pollution, erosion, etc. due to predicted shift of high tide line. The backwaters of Sayalkudi and Vaippar coastal sectors are expected to be more swelling and flooding in the adjacent low lands due to predicted SLR in 2100 AD (Fig. 7.80, Table 7.14)
- ➔ The deltaic plains and inter lobal depressions and associated landuse /landcover features and the rivers of this sectors are expected to have

more tidal action and possibility of flooding in its banks of these rivers due to expected sea level rise in 2100 AD (Fig. 7.80, Table 7.14)

- ➔ In the case agricultural resources is concerned, plantation of 11.96 sq. km are prone for submergences and the plantation covering 17.59 sq km are expected to salination and degradation due to predicted high tide level (Fig. 7.81, Table 7.14)
- ➔ The beach ridges (potable aquifers in the coastal region) of 28.87 sq km are prone for submergences and the beach ridges of 38.99 sq km are prone pollution and salination due to expected sea level rise due to global warming. (Fig. 7.81, Table 7.14)

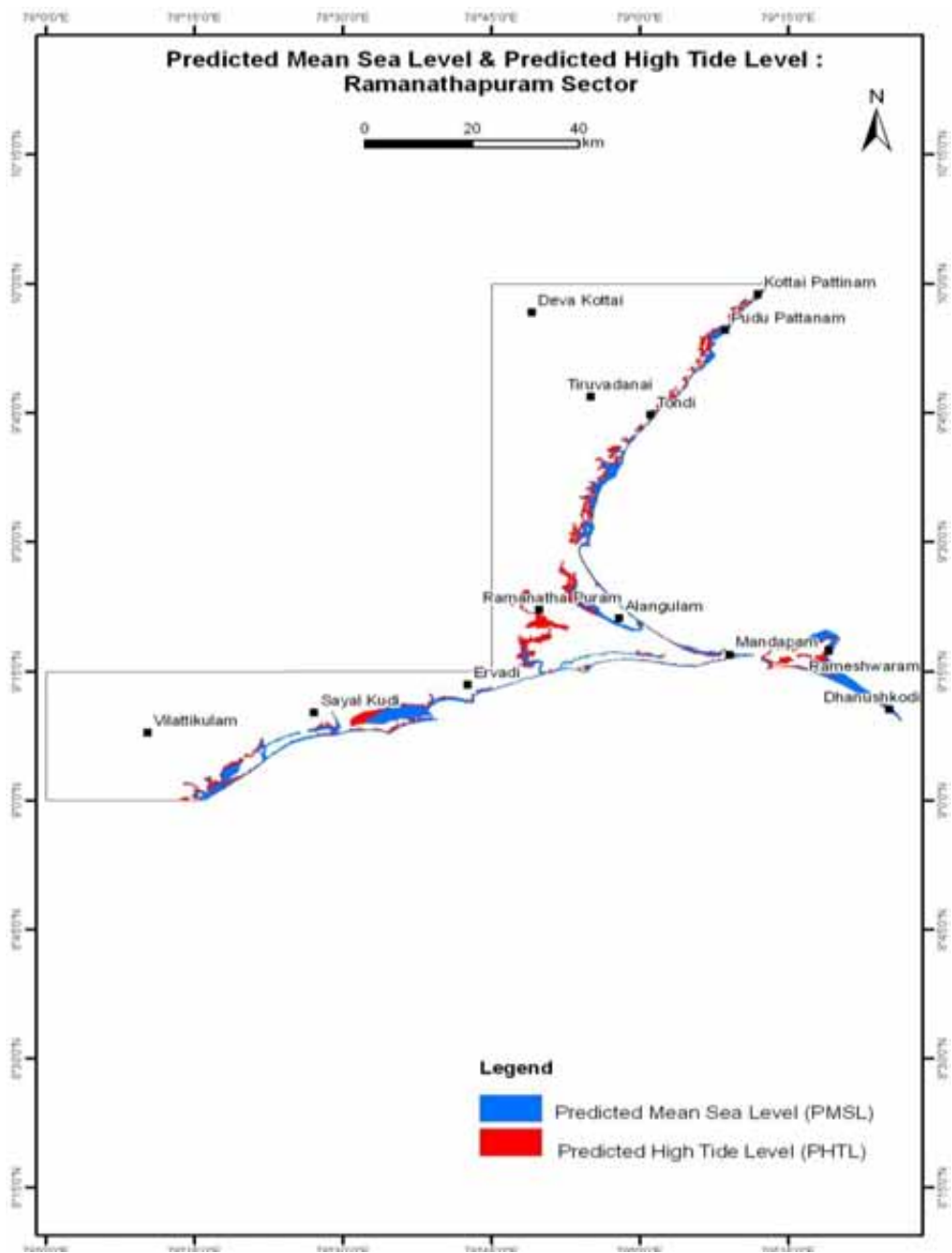


Fig. 7.77: Zone of submergence due to PMSL and degradation due to PHTL of Ramanathapuram sector

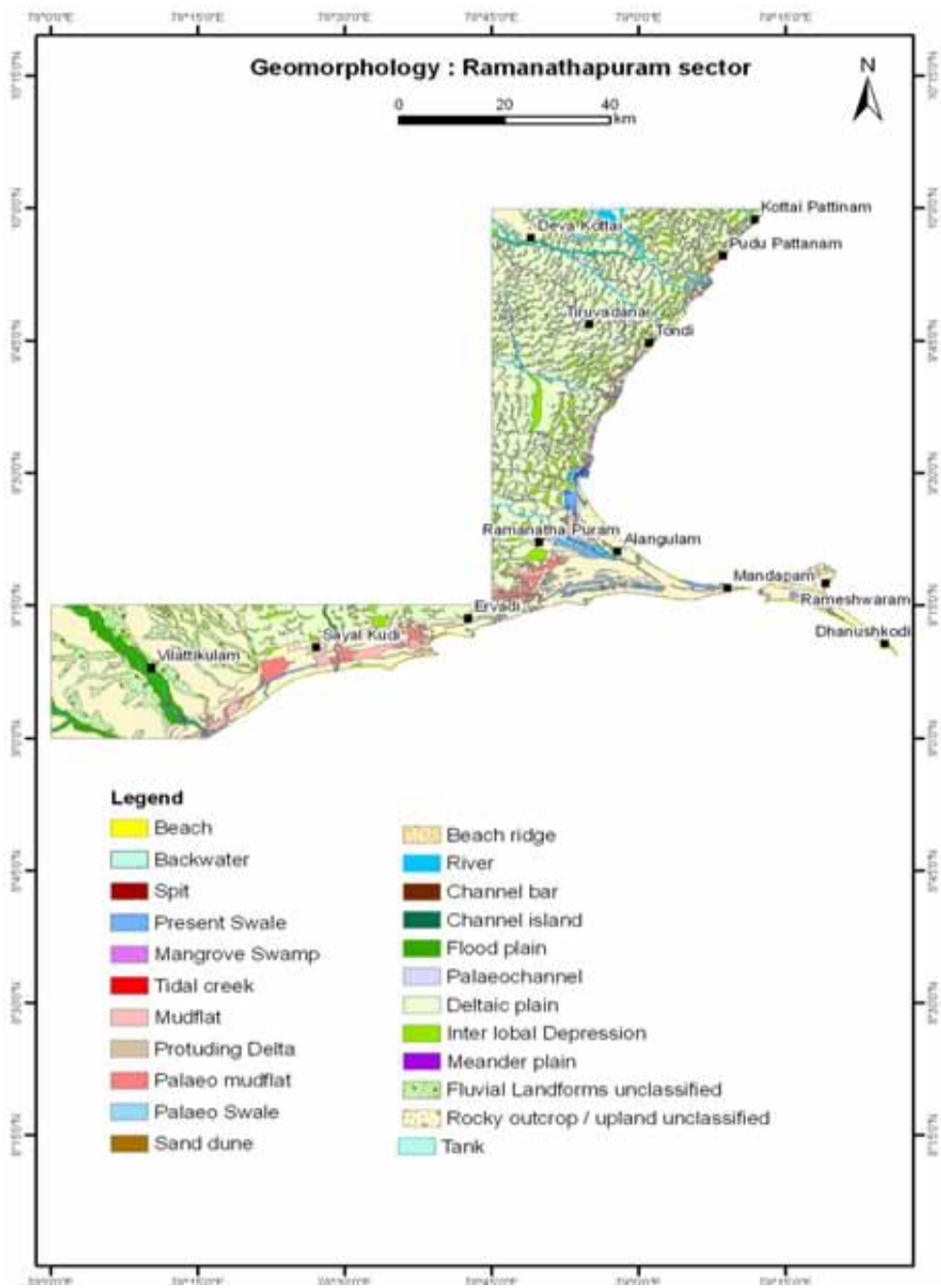
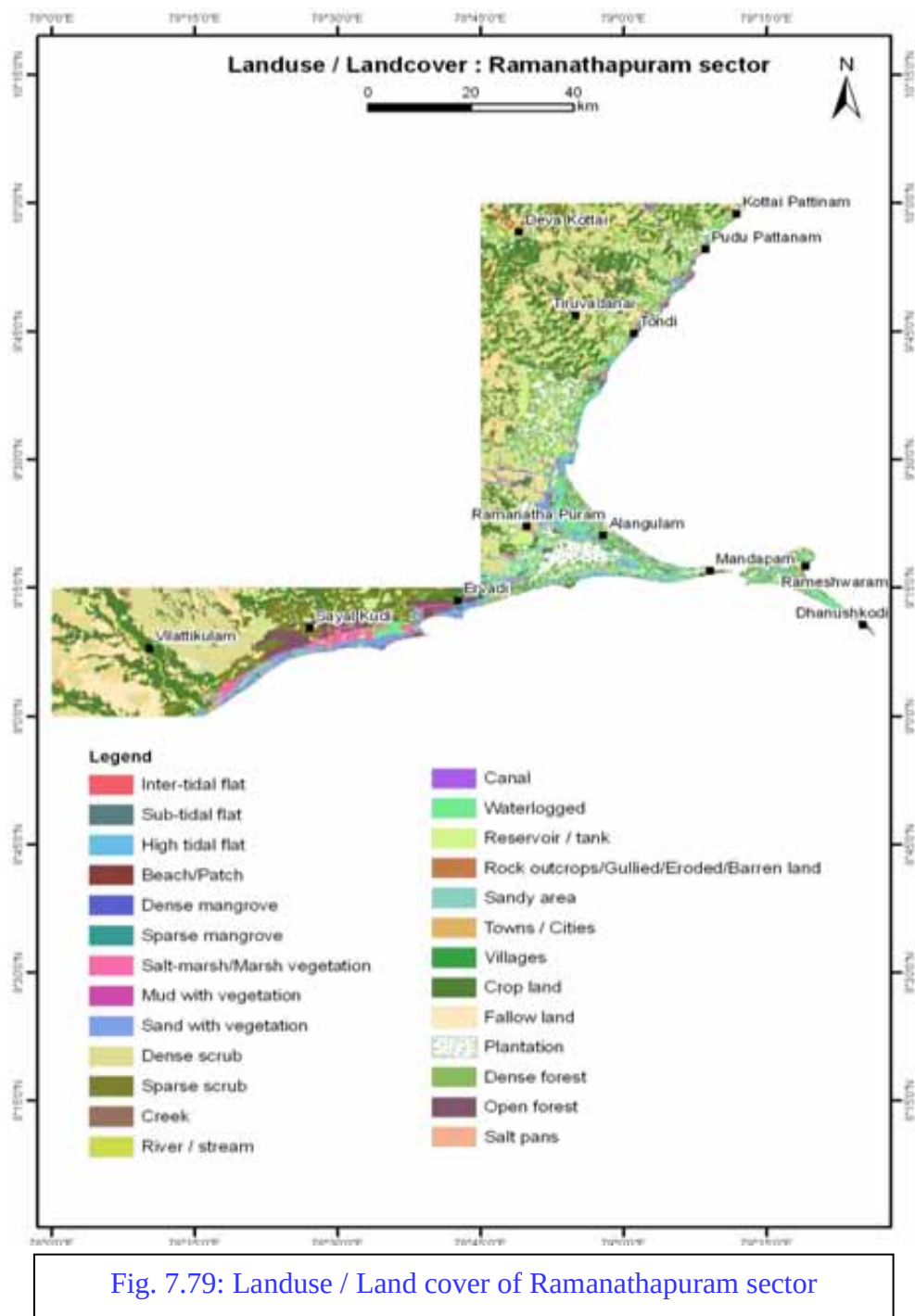


Fig. 7.78: Geomorphology of Ramanathapuram sector



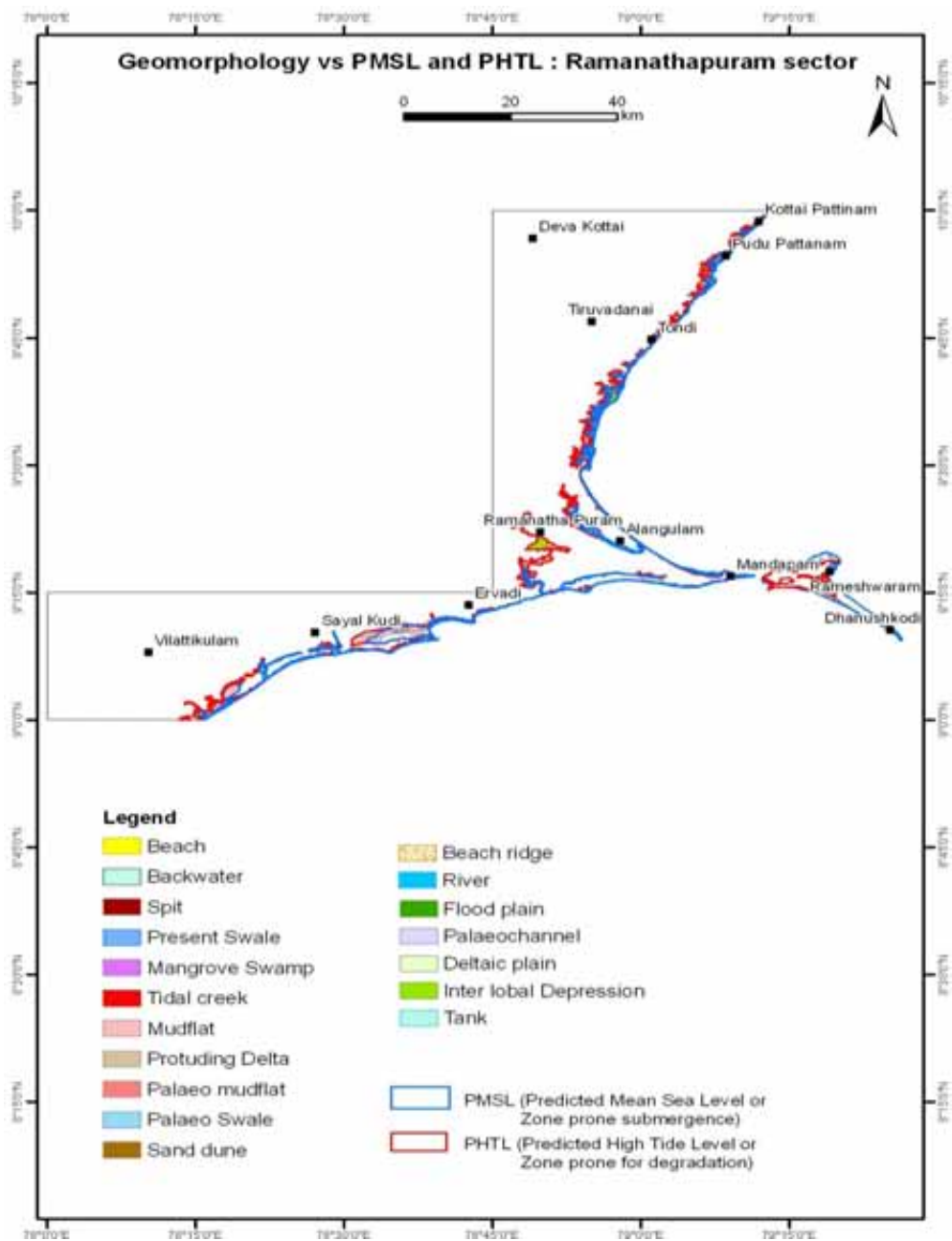


Fig. 7.80: Geomorphology vs PMSL and PHTL of Ramanathapuram sector

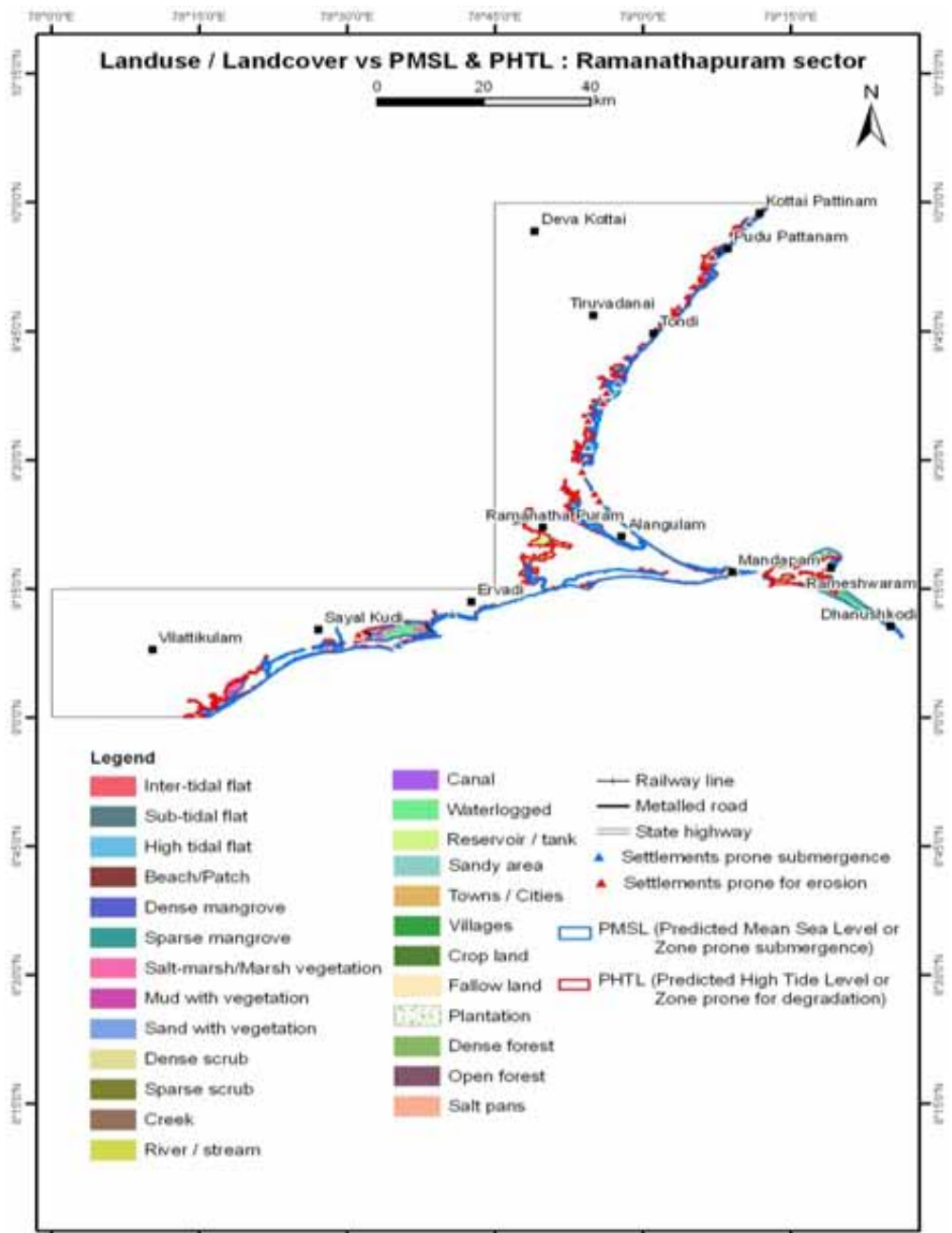


Fig. 7.81: Landuse/Land cover vs PMSL and PHTL of Ramanathapuram sector

Table 7.14: Natural and Physical Resources vs Predicted MSL and Predicted HTL – Ramanathapuram Sector

S.NO	Coastal Resources	Prone for Submergences in Sq km	Prone for Degradation In Sq km
1	Beach	20.91	3.87
2	Spit	0.14	0.00
3	Back water	23.92	0.11
4	Present Swale	7.87	6.16
6	Mangrove Swamp	1.41	0.00
7	Dense mangrove	2.66	0.86
8	Sparse mangrove	0.41	0.19
9	Tidal Creek	6.59	3.89
10	Mudflat	47.98	33.37
11	Protruding Delta	0.48	0.00
12	Palaeo mudflat	8.56	12.15
13	Paleo Swale	6.82	4.94
14	Sand Dune	1.65	0.65
15	Beach Ridge	28.87	38.99

	Riverine Resources		
16	River	4.37	2.30
17	Flood plain	0.08	0.05
18	Paleochannel	0.01	0.13
19	Deltaic plain	1.73	15.06
20	Inter lobal Depression	1.28	19.23

	Agricultural Resources		
21	Crop land	0.66	2.92
22	Fallow land	0.50	1.26
23	Plantation	11.96	17.59
24	Dense scrub	0.01	2.27
25	Sparse scrub	1.88	5.04
26	Dense forest	0.48	0.68
27	Open forest	0.65	0.90

	Water Resources		
28	Creek	6.91	3.40
29	River / Stream	3.63	1.35
30	Canal	0.06	0.17
31	Waterlogged	48.42	16.67
32	Reservoir / Tank	8.63	30.78
33	Aquifer	28.87	38.99

	Physical Resources		
34	Towns / Cities	0.75	1.57
35	Villages / habitats	0.64 (6 No)	2.61 (10 No)
36	Salt pans	5.14	1.03
37	Metalled road (length in km)	16.90	19.88
38	State highway (length in km)	35.92	35.28
39	Railway (length in km)	1.37	9.00

Tuticorin-Kanniyakumari Sector

The Tuticorin-Kanniyakumari Sector is located in the southern most coastal tip of Tamil Nadu. In this sector, more than 60% of the coastal stretch is hard rock and having marine landforms for smaller width. The Thamprabarani river coastal margin is vested with the coastal landforms for considerable width.

Similar SLR impact analysis was carried for this sector too by overlaying the GIS layer of the zones prone for submergence due to PMSL and degradation due to PHTL due to predicted SLR (Fig. 7.82) with the GIS layers of geomorphology (Fig. 7.83), landuse/landcover (Fig. 7.84) and physical resources of Tuticorin-Kanniyakumari Sector revealed that

- ➔ The beaches, mudflats located along the Tuticorin-Kayalpattinam sector and beach ridges are prone for submergence and degradation due to predicted sea level rise of 0.59 m in the next 100 years (Fig. 7.85, Table 7.15)
- ➔ The palaeochannels of Tamprabarani rivers are prone for flooding due to expected sea level rise (Fig. 7.85, Table 7.15)
- ➔ In the case agricultural resources is concerned, cropland, plantation and fallow land are prone for submergences and degradation due to SLR (Fig. 7.86, Table 7.15)
- ➔ Nearly 47 villages / habitats are vulnerable and face severe erosion and submergence due to SLR (Fig. 7.86, Table 7.15)

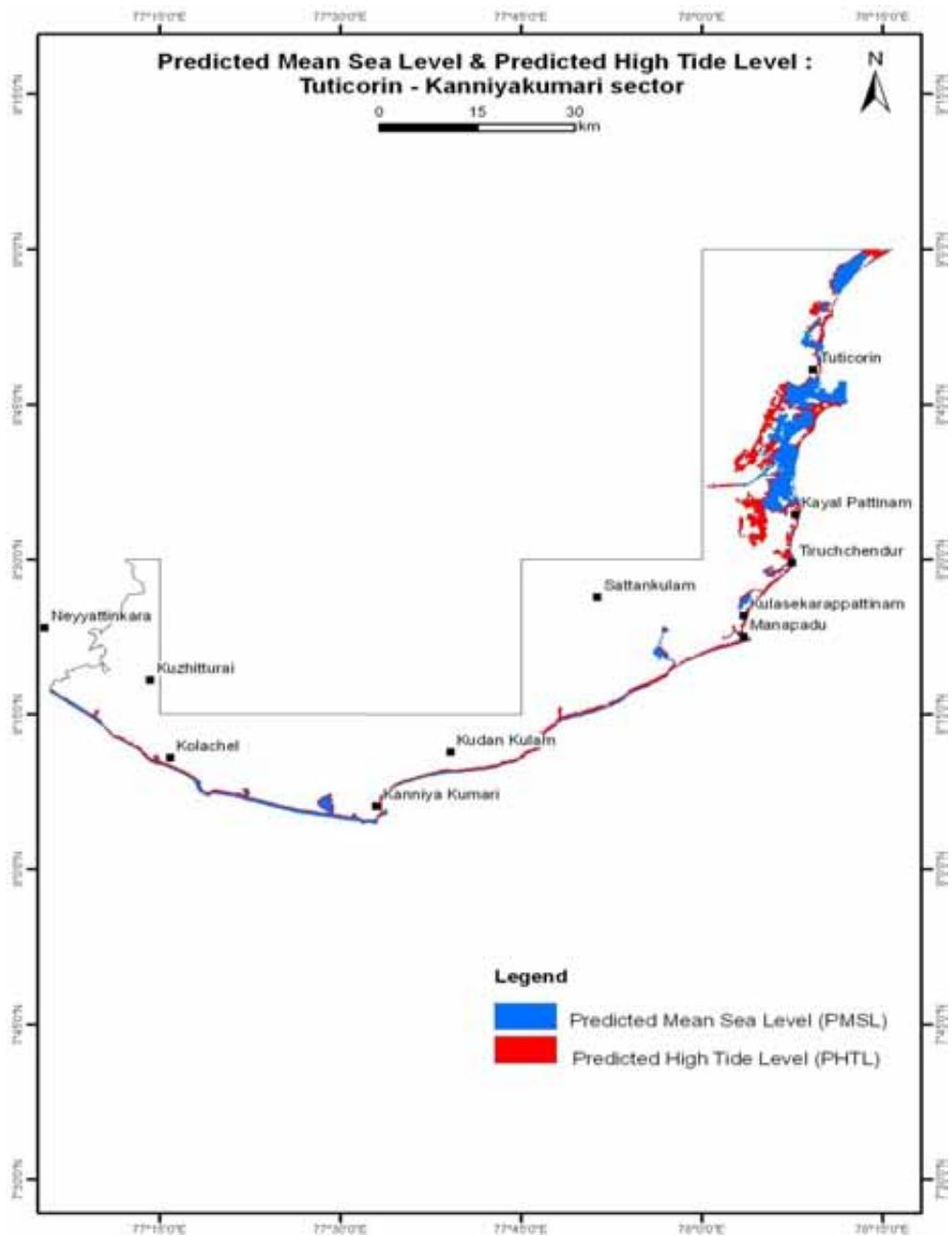


Fig. 7.82: Zone of submergence due to PMSL and degradation due to PHTL of Tuticorin-Kanniyakumari sector

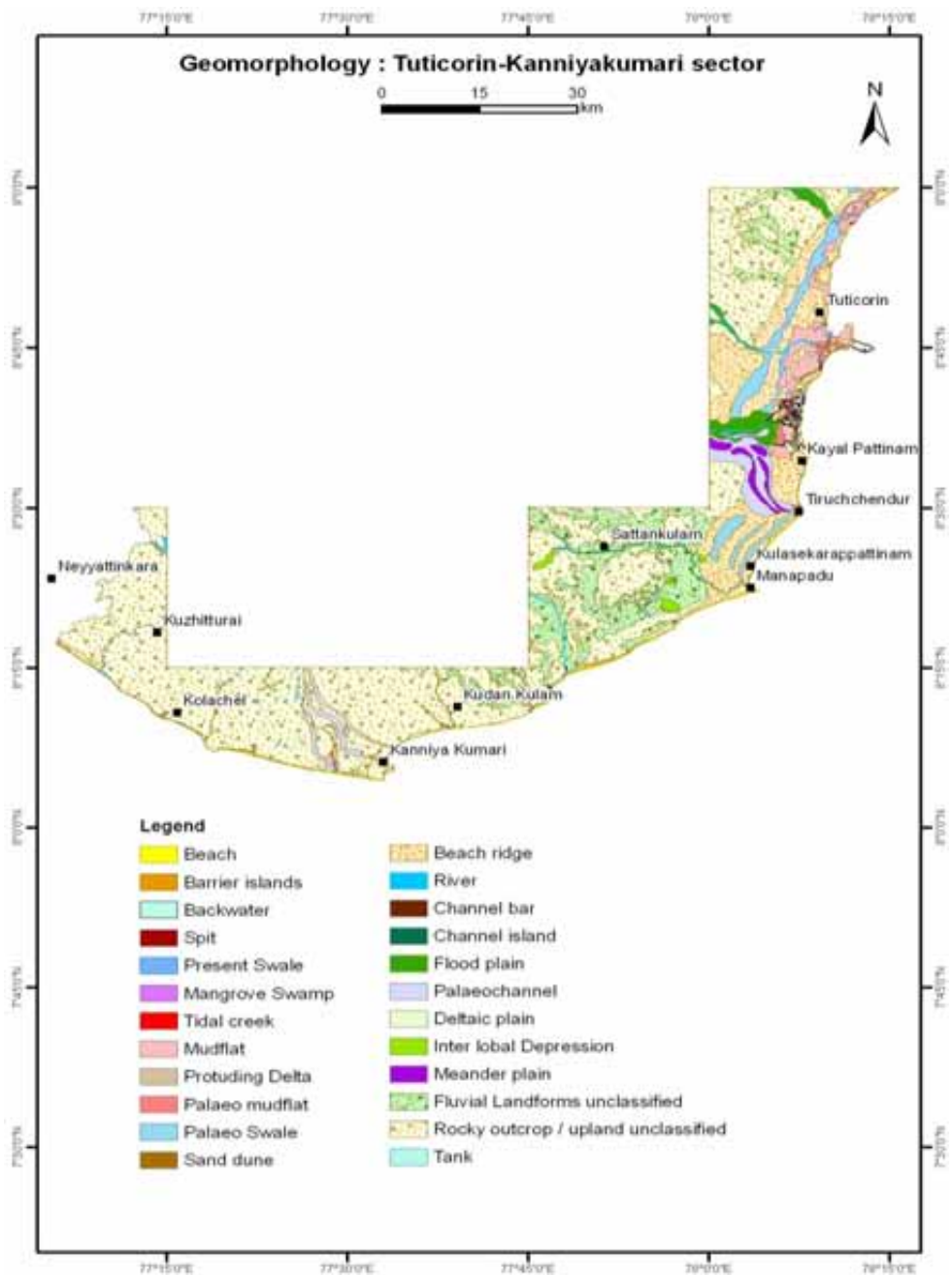


Fig. 7.83: Geomorphology of Tuticorin-Kanniyakumari sector

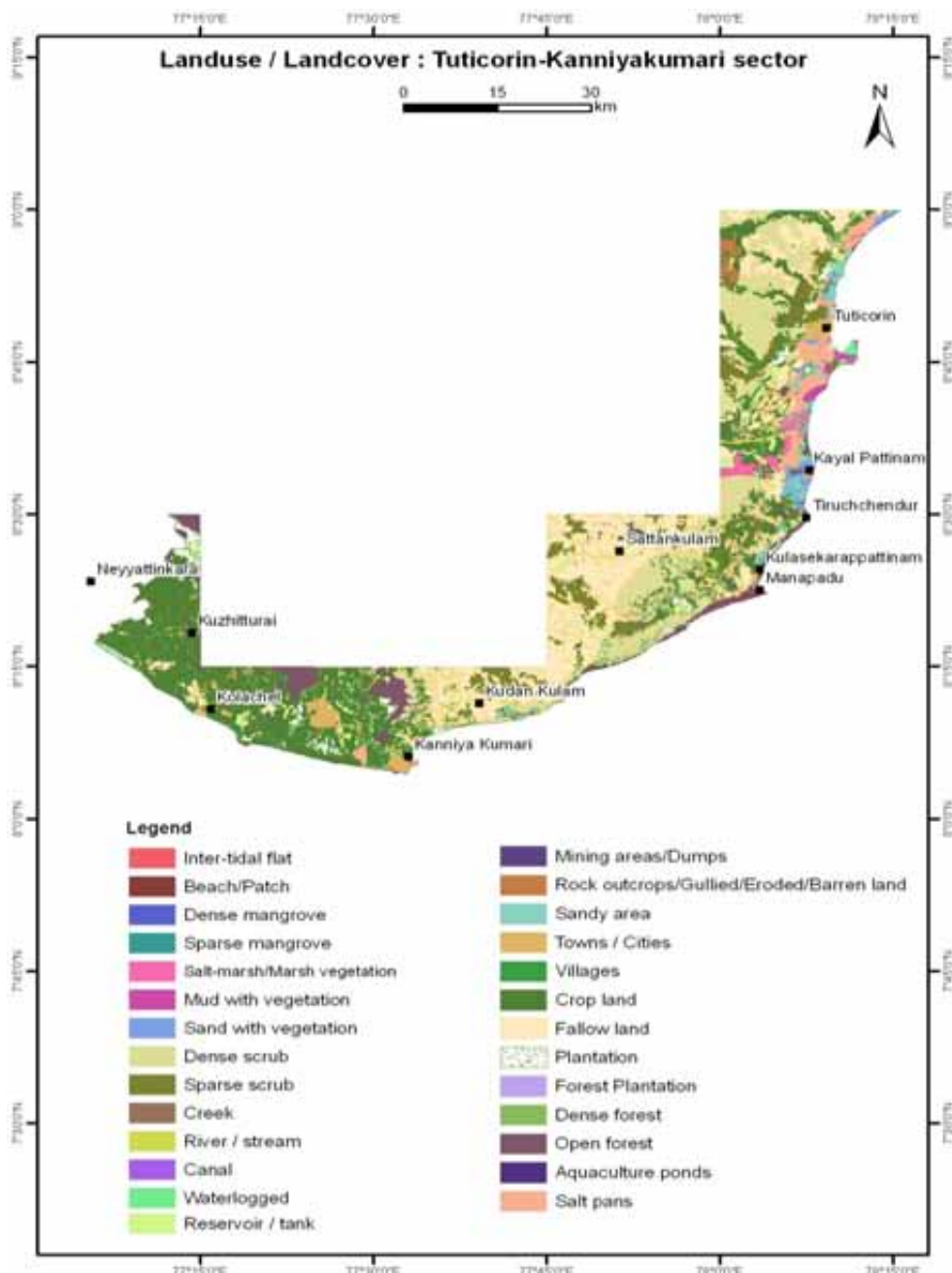


Fig. 7.84: Landuse/Landcover of Tuticorin-Kanniyakumari sector

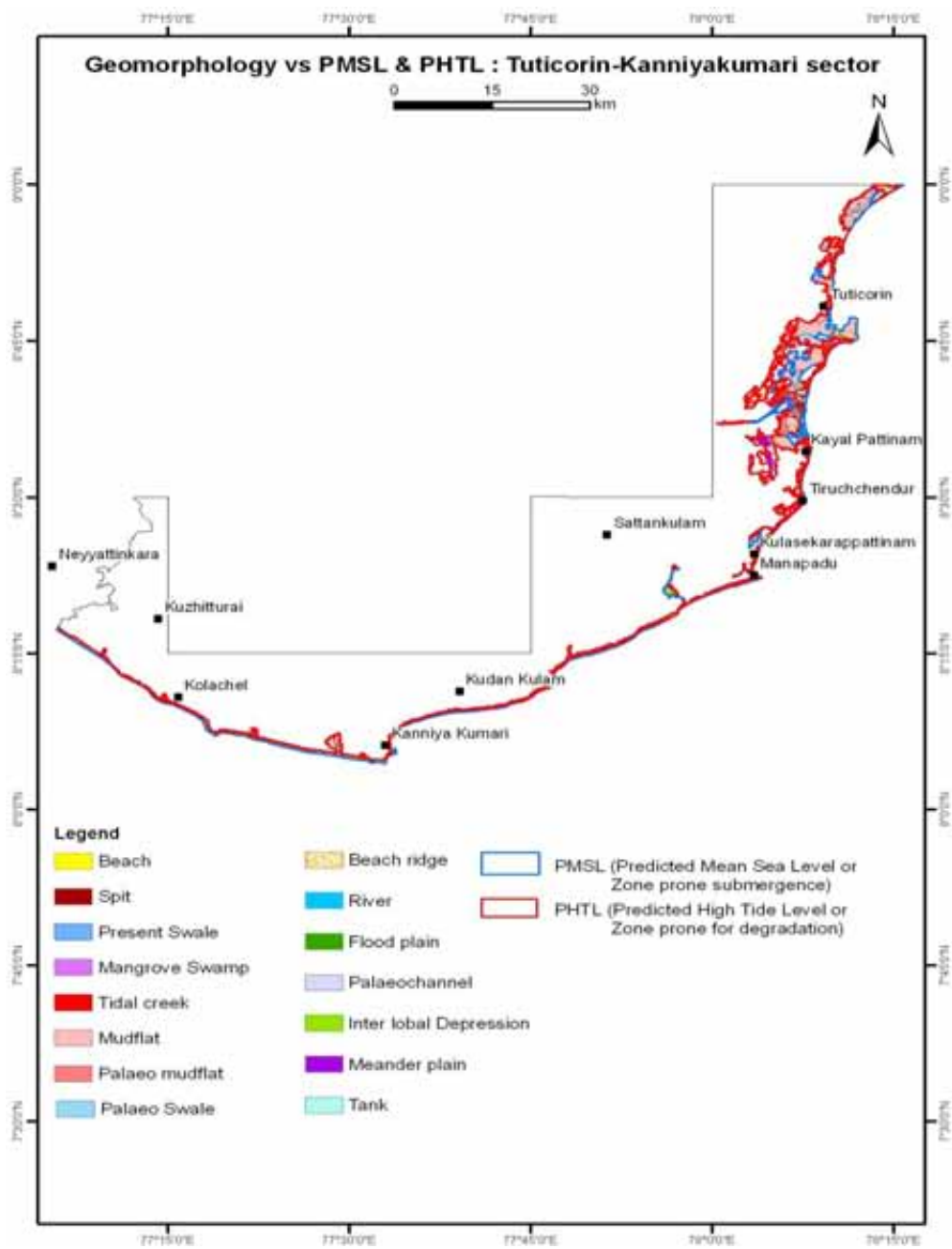


Fig. 7.85: Geomorphology vs PMSL & PHTL of Tuticorin-Kanniyakumari sector

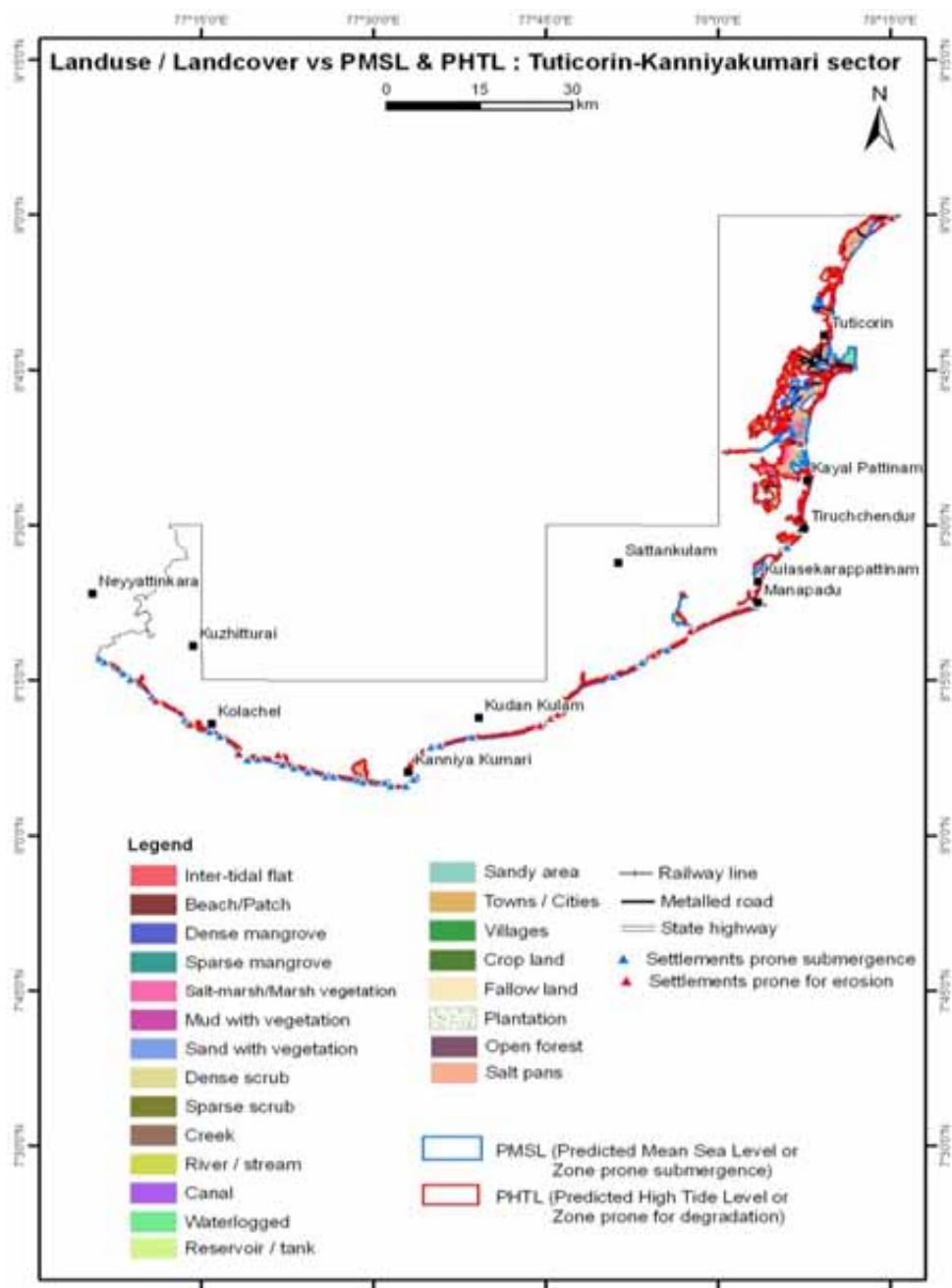


Fig. 7.86: Landuse/Landcover vs PMSL & PHTL of Tuticorin-Kanniyakumari sector

Table 7.15: Natural and Physical Resources vs Predicted MSL and Predicted HTL – Tuticorin-Kanniyakumari sector

S.NO	Coastal Resources	Prone Submergences in Sq km	Prone Degradation In Sq km
1	Beach	21.25	4.17
2	Spit	0.08	0.00
3	Present Swale	1.59	0.08
4	Mangrove Swamp	1.23	0.00
5	Dense mangrove	1.89	0.00
6	Sparse mangrove	0.23	0.00
7	Tidal Creek	10.13	0.63
8	Mudflat	86.33	4.43
9	Palaeo mudflat	8.96	2.94
10	Paleo Swale	4.28	5.46
11	Beach Ridge	28.40	45.26

	Riverine Resources		
12	River	3.63	2.05
13	Flood plain	0.43	0.91
14	Paleochannel	0.08	10.92
15	Inter lobal Depression	2.66	0.64
16	Meander plain	0.00	5.56

	Agricultural Resources		
17	Crop land	8.33	14.01
18	Fallow land	1.86	20.79
19	Plantation	5.01	6.46
20	Dense scrub	2.32	6.98
21	Sparse scrub	1.25	2.97
22	Open forest	3.61	9.41

	Water Resources		
23	Creek	1.94	0.24
24	River / Stream	4.56	2.43
25	Canal	0.33	0.35
26	Waterlogged land	16.75	0.64
27	Reservoir / Tank	2.26	3.99
28	Aquifer	28.40	45.26

	Physical Resources		
29	Towns / Cities	1.90	2.16
30	Villages / habitats	2.20 (32 Nos)	1.63 (15 Nos)

31	Salt pans	74.60	3.25
32	Metalled road	67.34	44.01
33	State highway	7.99	18.13
34	Railway	9.80	3.40

Detailed SLR Impact Analysis along Hot Spots

From the coastal vulnerability map prepared for Tamil Nadu coast, three hot spots were selected for detailed SLR impact analysis such as Chidambaram hot spot (Colleroon river mouth), Nagapattinam hot spot and Tuticorin hot spot (Tambaraparani river mouth) (Fig. 7.44b). Along such hotspots, the following detailed SLR impact studies were carried out

- ➔ Zone prone for accelerated tidal activities due to predicted high tide level (PHTL)
- ➔ Areas prone for erosion and accretion due to PHTL
- ➔ Aquifers prone for pollution
- ➔ Agricultural resources prone for salination

Accelerated Tidal Activities

The zones prone for accelerated tidal activities were mapped by superposing the GIS layer having the PMSL and the PHTL zones over the calibrated SRTM DEM and geomorphology and mapping the low lying areas, the palaeochannels and zones fringing the drainages within the zone of PHTL. These low lying zones as are going to be under the grip of inter tidal activities, these will be prone for accelerated tidal activities. The Fig. 7.87a, 7.88a and 7.89a show the zone prone for accelerated tidal activities in Chidambaram, Nagapattinam and Tuticorin sectors.

Erosion and Accretion

The zones prone for erosion and accretion was mapped by mapping the mounds, elevated zones and the projections falling within the zone of PHTL

were buffered out as zones prone for erosion and in contrast, the depressions, the embayed portions, tidal flats, mudflats and swales falling within the zone of PHTL were buffered out as the zone prone for deposition due to predicted shift of inter tidal zones. The GIS image 7.87b, 7.88b and 7.89b show the zone prone for erosion and accretion in Chidambaram, Nagapattinam and Tuticorin sectors.

Aquifers prone for pollution

In the coastal zones, the beach ridges form potential and potable aquifers. The anticipated shift of the high tide line (PHTL) is definitely going to pollute the same in the form of saltwater mixing during the course of inter tidal activity. So such zones were also mapped by the process of carrying out GIS integration between the vector GIS layer having the PMSL and PHTL and the geomorphology layer having beach ridges and buffering out such beach ridges as potable aquifer going to be polluted by the phenomenon of saltwater mixing due to such shifting high tide line. The Fig. 7.87c, 7.88c and 7.89c show the zone prone for aquifer pollution in Chidambaram, Nagapattinam and Tuticorin sectors.

Agricultural resources prone for salination

The agricultural resources are yet other important resources prone for the brunt of PMSL and PHTL. The adverse impacts will be mostly in the form of salination /salinity. So, again the vector layer with the above two PMSL and PHTL lines were superposed over the land use GIS layer and the various land use /cover categories viz: crop land, fallow land, plantations, land with scrub and land with out scrub falling within the buffer zone bounded by the above lines were mapped as zones prone for salinity. The GIS image 7.87d, 7.88d and 7.89d show the agricultural resources prone for salination/degradation in Chidambaram, Nagapattinam and Tuticorin sectors.

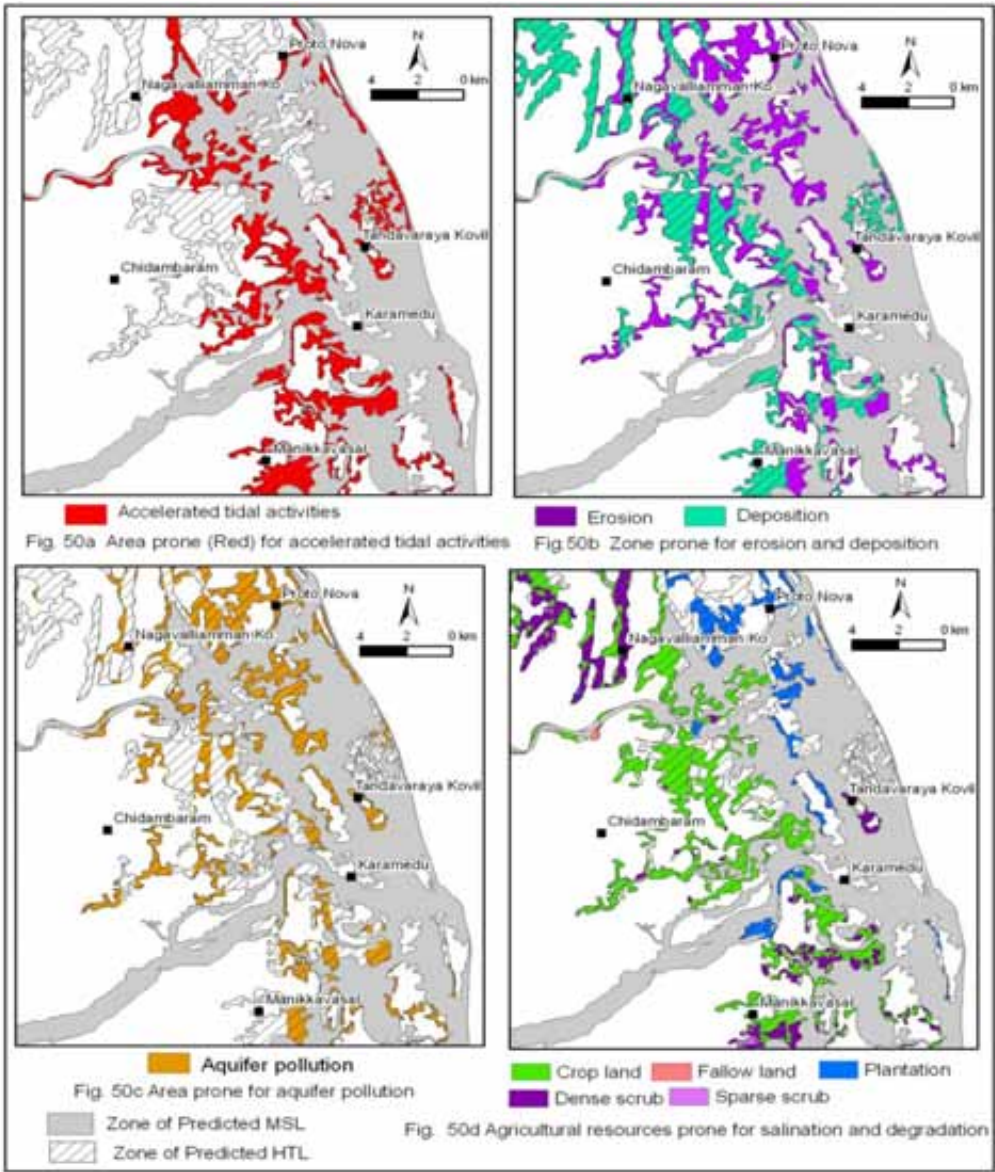


Fig. 50 Impact of sea level rise over the environment and resources - Chidambaram region

Fig. 7.87: Impact of sea level rise over the environment and resources – Chidambaram region: a) Area prone for accelerated tidal activities; b) Zone prone for erosion and deposition; c) area prone for aquifer pollution and d) Agricultural resources prone for salination and degradation

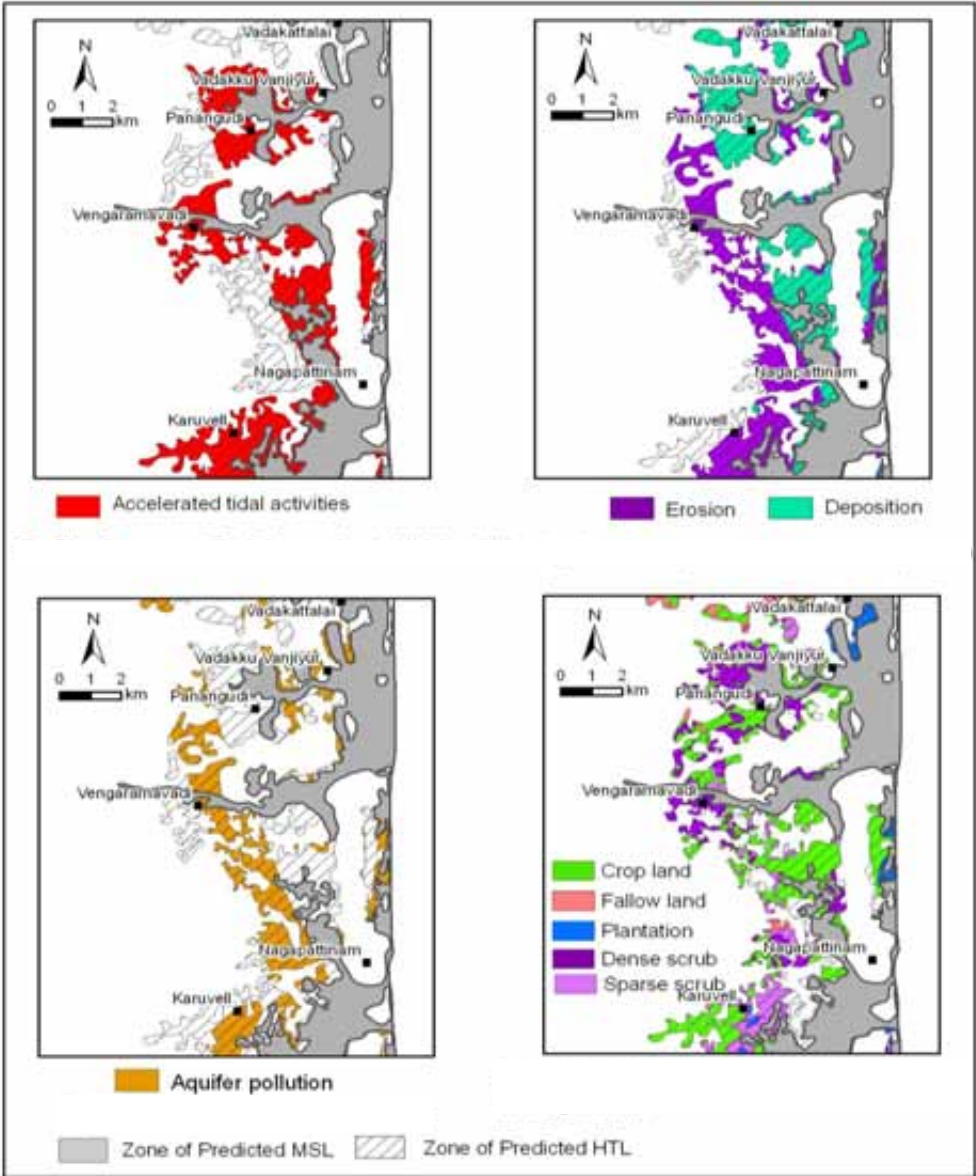


Fig. 7.88: Impact of sea level rise over the environment and resources – Nagapattinam region: a) Area prone for accelerated tidal activities; b) Zone prone for erosion and deposition; c) area prone for aquifer pollution and d) Agricultural resources prone for salination and degradation

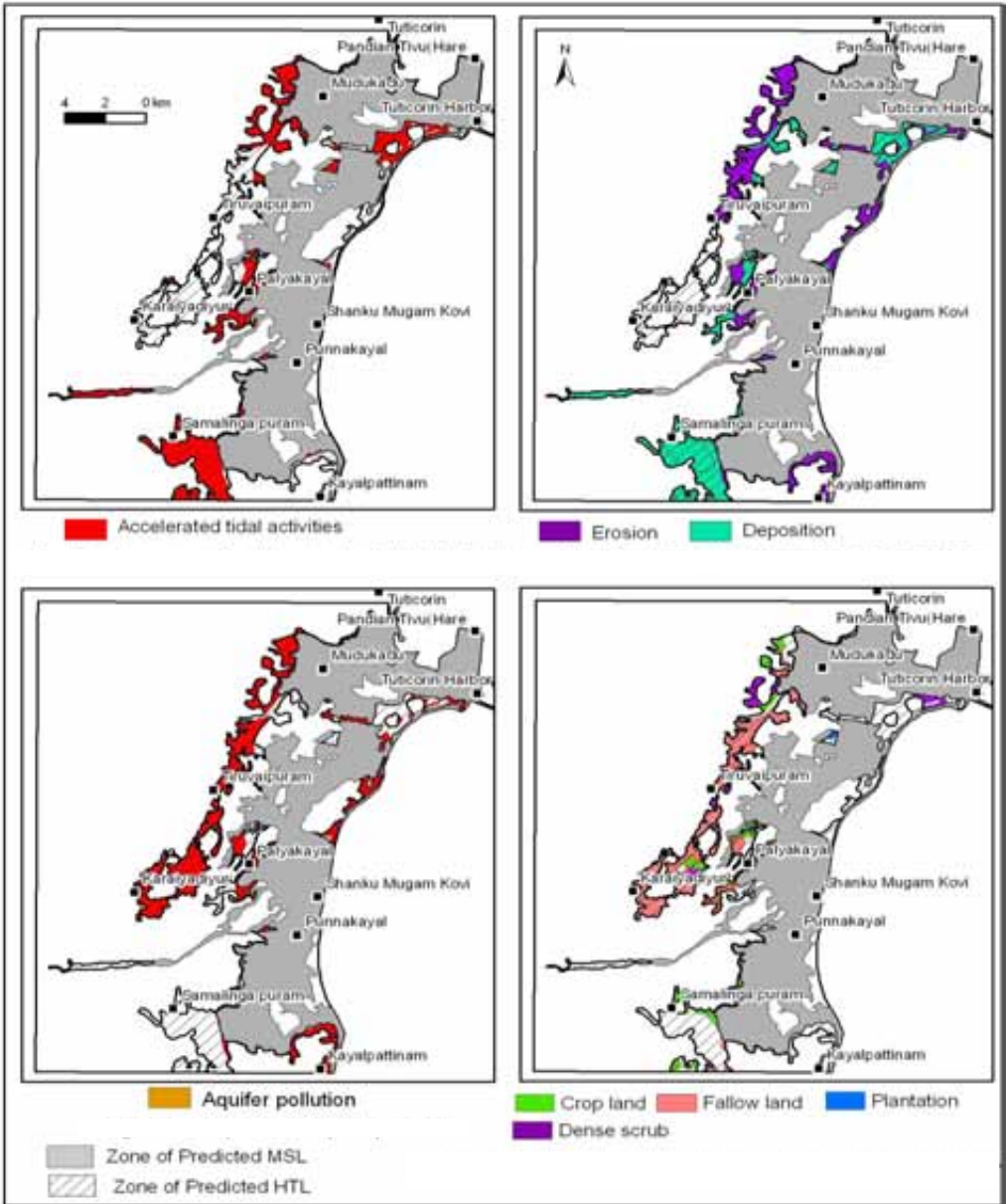


Fig. 7.89: Impact of sea level rise over the environment and resources – Tuticorin region: a) Area prone for accelerated tidal activities; b) Zone prone for erosion and deposition; c) area prone for aquifer pollution and d) Agricultural resources prone for salination and degradation

Thus the present study has brought out newer methodology to visualize and evaluate the impact of predicted SLR over the resources and environment using geomatics technology. Further, the present study revealed that the central Tamil Nadu coast (Chidambaram – Vedaranniyam sectors) is more expected to face the major threats from the IPCC predicted SLR and related intertidal activities.

However, in the case of estimating submergences and anticipated tidal activities, if still finer elevation data are available up to 20-25 cm, the impact maps can be prepared for every 25 years which would be much beneficial to the planners and administrators. This geomatics based methodology has the credits for replicating it in different parts of the world to arrive at a final picture on this issue.

Gujarat coast

Risk Level map was prepared from CVI and coastal length under different risk categories was quantified (Fig. 7.90). About 9.90 % of the total coast is under very high risk category mostly along the eastern parts of the Khambhat i.e, from Bhavnagar to Khambhat, some portion of western part of Kachchh near Naravan Sarovar, and north-eastern part of Gulf of Kachchh. The main reason of very high risk of these area are soft substrate, high tidal range (in Gulf of khambhat near Bhavnagar tidal range of about 6.52 m), and shore line erosion is large. The geomorphic features of the area are mainly intertidal and high tidal mudflat, mangroves and salt marsh. It is observed that a very small portion of south Gujarat coast is at high risk.

About 35.74 % of the total coast is under High risk and is mainly around the Gulf of Kachchh and the Gulf of Khambat. The geomorphic features are high tidal mudflats, creeks, estuaries and river mouths. The main reason of the high risk area are due to soft substrate, low to moderate slope and moderate to high shore line erosion rate.

About 28 % of the coastal segment of the Gujarat coast is under moderate risk and is found mostly along the south of Gujarat coast and eastern portion of Gulf of Khambat and distributed in the remaining area. The rocky coastal area,

low to moderate slope and less shoreline erosion are responsible of moderate risk.

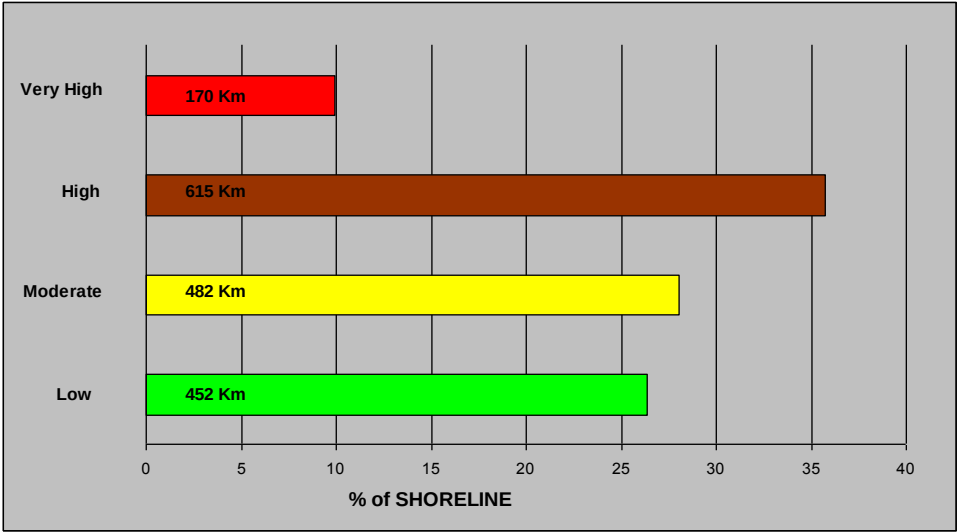


Fig. 7.90: Percentage of shore length for different risk levels of the Gujarat coast

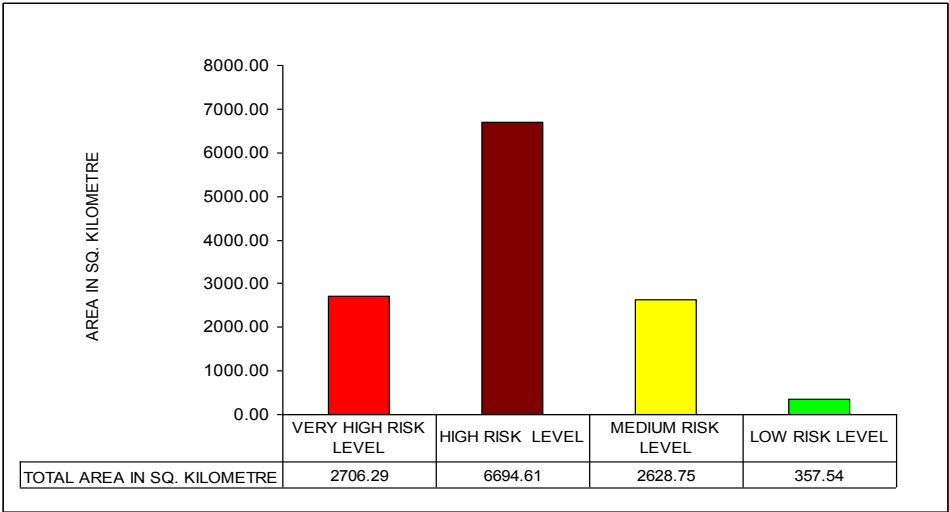


Fig. 7.91: Bar diagram showing Landuse/landcover classes between LTL and CRZ boundary under different risk levels due to predicted SLR in Gujarat State

The risk classification shows that about 26.34 % of the Gujarat coast is under the low risk category. The low risk area are Saurashtra coast, i.e. from Dwarka to Diu, south of Kachchh i.e. Mandvi to near bustard sanctuary, and distributed in length in south Gujarat and east of Khambhat coast. The main cause of low risk are rocky coast, high slope, and shoreline erosion is very less, although significant wave height is moderate to large.

Risk due to predicted SLR has been analysed for all landuse/landcover classes between LTL and CRZ boundary at 1:25, 000 scale using LISS-IV data for the period 2004-2006. Table 7.16 provides the details.

The results show that area under Very High risk level is 357.54 sq km, High risk level area is 2628.75 sq km, Moderate risk level area is 6694.61 sq km and Low risk level area is 2706.29 sq km (Fig. 7.91).

Table 7.16: Landuse/landcover classes between LTL and CRZ boundary under different risk levels due to predicted SLR in Gujarat State

(Area in square km)

	Landuse/Land Cover	Low Risk Level	Medium Risk Level	High Risk Level	Very High Risk Level
1	Dense Mangrove	1.91	68.46	561.44	74.96
2	Agricultural Land	93.24	400.27	422.83	134.85
3	Airport	0.10	0.49	0.74	0.00
4	Aquaculture Ponds	0.17	28.32	22.50	12.28
5	Beach/Patch	45.88	10.90	12.16	4.98
6	Bridge	0.00	0.00	0.04	0.00
7	Canal	0.00	0.00	0.72	0.00
8	Creek	4.23	157.64	1195.67	195.18
9	Degraded Mangrove	0.00	0.08	25.61	4.38
10	Degraded Scrub	7.51	35.78	59.01	25.05
11	Dense Salt-Marsh Vegetation	0.11	6.31	1.63	2.66
12	Dense Scrub	16.21	37.22	55.16	35.81
13	Estuary	0.35	1.07	7.24	0.44
14	Forest(Non-Tidal)/Plantation	68.79	78.18	86.38	18.49
15	Habitation	3.70	15.42	9.21	0.39
16	Habitation With Vegetation	5.96	27.66	15.42	4.37
17	High Tidal Mudflats	3.56	198.95	352.39	189.75
18	High Tidal Mudflats With Salt Enchrustation	1.08	30.99	77.83	32.03

19	Industrial Area	1.41	18.62	14.67	13.19
20	Inter Tidal Mudflats	13.12	350.08	1745.79	407.59
21	Island	0.02	0.10	0.36	0.00
22	Mining Areas/Dumps	0.91	0.09	0.05	0.00
23	Moderately Dense Salt-Marsh Vegetation	13.59	85.89	87.32	25.02
24	Mud With Vegetation	1.40	52.77	64.08	32.17
25	Open/Vacant Land	0.40	0.02	0.74	0.00
26	Pond/Lake	0.92	8.10	6.31	2.65
27	Port/Harbour/Jetty	0.00	0.44	0.33	0.00
28	Reservoir/Tank	0.42	9.24	11.22	2.21
29	River Sand	0.00	6.71	0.44	0.00
30	River/Stream	2.12	65.69	70.04	34.89
31	Rock Exposure	0.00	0.00	1.69	0.00
32	Rock Outcrops/Gullied/Eroded/Barren Land	1.07	3.27	8.54	0.42
33	Rocky Coast	0.50	0.17	3.56	0.50
34	Saline Area	2.75	27.19	126.44	126.93
35	Salt Pans	9.36	176.03	528.94	406.15
36	Sand With Vegetation	0.91	1.45	2.63	0.25
37	Sandy Area	1.60	20.92	3.86	0.29
38	Seawall/Embankment	0.00	0.02	0.02	0.00
39	Sparse Mangrove	0.06	32.38	427.18	163.55
40	Sparse Salt-Marsh Vegetation	0.45	101.53	3.11	6.97
41	Sparse Scrub	36.03	155.66	189.39	137.34
42	Sub Tidal Mudflats	16.15	357.23	705.90	285.43
43	Very Dense Mangrove	0.00	26.57	199.73	19.20
44	Waterlogged	0.36	6.01	87.02	36.74
45	Dune With Vegetation	0.23	0.00	0	0
46	Dune Without Vegetation	0.95	0.02	0	0
47	Lagoon	0.01	0.00	0	0
48	Water Treatment Plant	0.00	0.68	0	0
49	Cooling Pond	0.00	2.83	0	0
50	Coral Reefs	0	21.32	60.69	269.18
	Total Area	357.54	2628.75	6694.61	2706.29

The coastal vulnerability index (C.V.I.) of Gujarat coast shows the relative potential of coastal changes due to future sea-level rise. Coastal geomorphology and mean tide range are the most important variables in determining the C.V.I. for the Gujarat coast since both variables reflect very high vulnerabilities along nearly the entire shoreline.

8. Integrated Coastal Zone Management

The Coastal Zone in most countries is under severe and increasing pressure from rapid urbanisation, pollution, tourism development, over exploitation of coastal resources (especially biological resources) and continued development in hazard-prone areas. Resource allocation conflicts are increasing. The coast provides important locational benefits for heavy industries, energy generating facilities, fuel and raw material processing, etc. Coastal landforms have an important role in protecting the coastline from erosion and flooding. The salt marshes and mangrove swamps, if present, absorb a large portion of wave energy arriving at the coast. Besides, spit and bar perform similar role in dissipating wave energy. Coastal wetlands are home to a large variety of birds, plants and other biota and also serve the important role of filtering impurities in the water coursing through them.

With development in economy and world trade, sea route is the most economical and viable for goods transport. Coast has also become the dumping ground for sewage, various polluted and hazardous materials. Various human-induced activities are putting tremendous pressure on coastal land which is limited in area. Looking to future projection of the pressure on the coastal area, managing coastal area assumes special importance than other terrestrial land.

It becomes paramount importance to make judicious use of resources of coastal zone and development in sustainable manner. Thus, an integrated coastal zone management plan is the need of the day. Integrated coastal zone management (ICZM) is a process dealing with planning and management of development, keeping in view the interest of all stake holders and sustainability of natural resources. Main objectives of ICZM are conservation of critical habitats, maintaining biodiversity and sustainable use of coastal resources. ICZM comprise of two components, management and administration. The coastal resources like beaches, mudflats, corals, mangroves and submerged sea grass are unique and not available anywhere other than the coast. Developmental activities along the coast pose the threats to the productivity and existence of these ecosystems/habitats. ICZM should address these coastal resources issues and socio economic implications of coastal communities while going for

economic development. Thus, environmentally effective coastal zone management depends upon accurate and comprehensive scientific data on which policy decisions can be based. Remote sensing data because of its repetitive, multispectral and synoptic nature have proved to be extremely useful in providing information on various components of the coastal environment and therefore for ICZM.

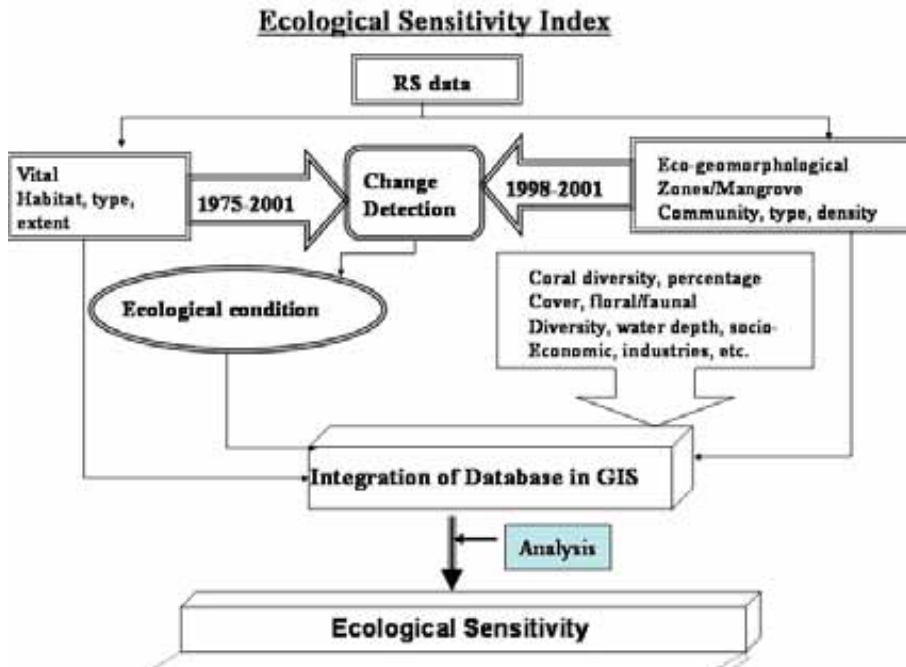


Fig. 8.1: Concept for Modeling the Vital Coastal Ecosystem for Ecological Sensitivity

The concept of integrated Coastal Zone Management, involves zoning of the coastal area in to preservation, conservation buffer, utilization and development zones. The first step towards this was to develop ecological sensitivity index for the vital coastal habitats using remote sensing data (Fig. 8.1). Satellite data of two time frames are required to prepare maps for vital coastal habitats such as coral reefs and mangrove maps at 1:25000 scale. These maps pertaining to two or more time frames are used for change detection in order to assess the ecological conditions of these important habitats. Integrating this spatial information with aspatial information like water depth,

turbidity, socioeconomic data, and industries etc., qualitative ecological sensitivity index are generated to classify the habitats in good, degrading and degraded condition. The next step is to identify the vulnerability index of these habitats using the ecological sensitivity index as input (Fig. 8.2). Anthropogenic pressure and various other related parameters like proximity of the habitation, population, approachability, existence and development of industries, port, jetty etc are considered in deriving the vulnerability index. As an outcome of this, vital habitats are qualitatively classified into high risk, medium risk and least risk. Based on information on the risk zonations of the habitats, preservation zone, conservation zone, utilization zone and development zone are suggested for coastal zone management (Fig. 8.3). The habitats at high risk should be declared as preservation zone where no further accessibility and activities to be allowed. There should be some buffer for preservation and conservation of the habitats. After exercising the site selection criteria utilization and development zone should be allowed for appropriate activities.

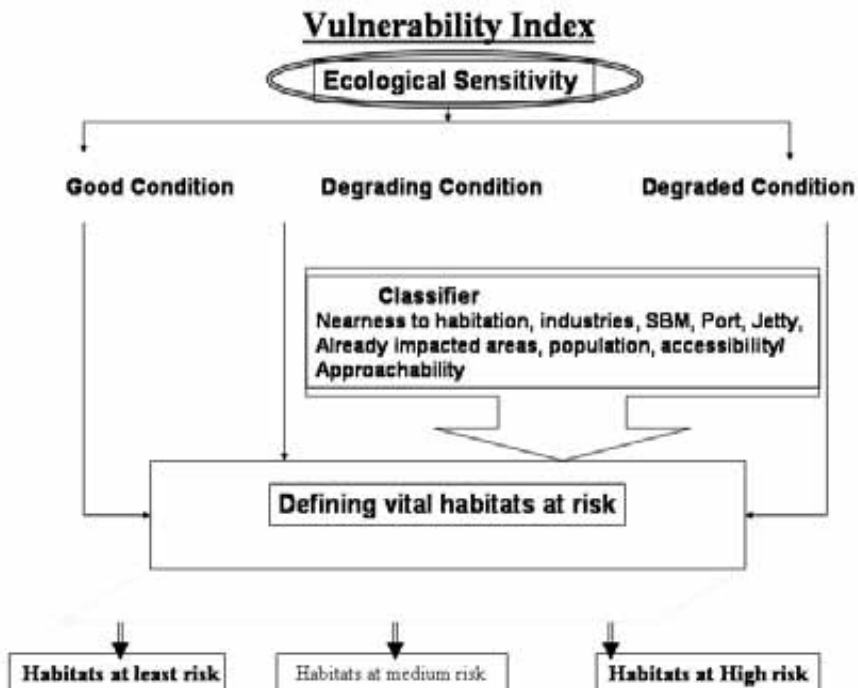


Fig. 8.2: Concept for Modeling the Vital Coastal Ecosystem for Vulnerability (to anthropogenic pressure)

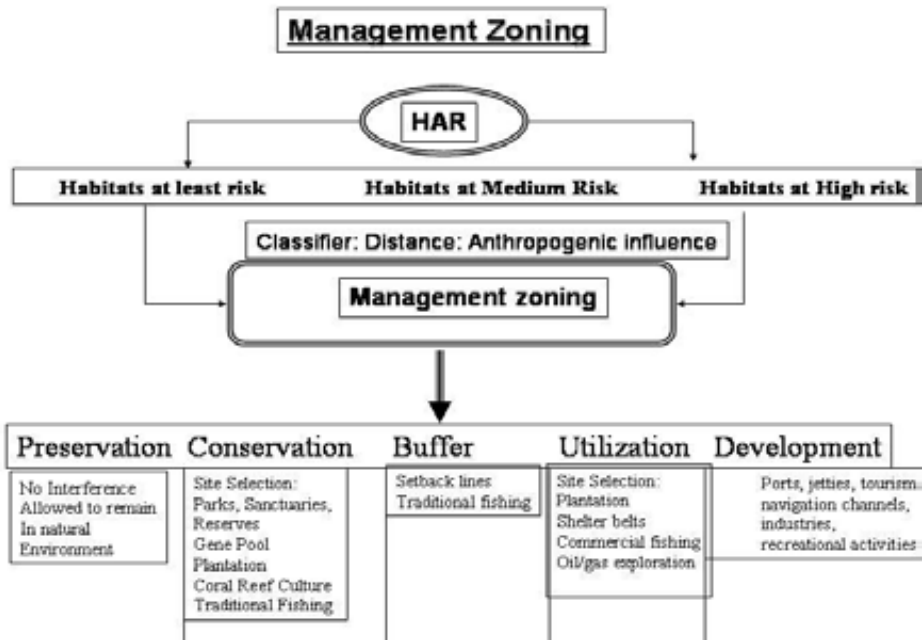


Fig. 8.3: Concept for Modeling the Vital Coastal Ecosystem for Management

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Annexure 4.1.1: Coral Reef - Definitions

Coral Reef

Corals are exclusively polypoid, marine organisms (which belong to Class: Anthozoa of Phylum: Coelenterates/Cnidarians), capable of secreting a massive calcareous skeleton. Hermatypic or reef building corals colonize suitable sea-floor substrates in tropical and sub-tropical shallow waters with appropriate ecological conditions (summer maximum mean temperature is 28°C and winter minimum mean temperature generally above 18°C, colonizing mainly photic depths, salinity 35±2‰, etc.

Concerted growths of a variety of corals in their localized habitat give rise to a Coral Reef.

Coral Reef is defined as a 'bioherm' or a complex organogenic, wave-resistant, framework of calcium carbonate (primarily of corals), which forms a rocky eminence on the sea floor and customarily grows upward to the tide limit. This ridge of limestone causes waves to break, and consequently, internal spaces in this branching framework are packed with fragments of broken reef material, coralline algae, broken-up molluscan shells, echinoid debris and foraminifera.

Fringing Reef

Fringing reef is one of the basic types of reef formation, which is adjacent to the continental or island coastline separated by a shallow channel from the mainland. These reefs are generally characterized by rough, table like surfaces exposed at low tide and their seaward edges are marked by sharp steep slopes down to the sea floor. These surfaces may extend over a width of a kilometer or more and show ecological zonation parallel to the shore. They are further classified into Platform, Patch and Pinnacles on the basis of their relative size.

Platform Reef

Platform reef is an extensive/large reef without lagoon having a rounded or ovoid shape in plane, with a flat upper surface, sometimes forming an island with shallow pools. They are found in waters of moderate depth (generally 20-40m) on the continental shelves, sometimes dotted in random manner, but more often in recognizable belts, suggesting an evolution from former (drowned) shorelines. Probably they grew on upward as the sea level continued to rise.

Patch Reef

Patch reef is less extensive than a platform reef (generally less than a kilometer) and also without a lagoon. They frequently form a larger reef complex. These mound-like, flat-topped reefs are also known as 'shelf', 'bank', 'table' and 'hummock' reefs.

Coral Pinnacle

Coral pinnacle is an isolated spire or column of small reef patch consisting of sharp vertical growth (with slopes ranging from 45° to nearly vertical) of corals, either slightly submerged or awash. Coral pinnacle also does not have a lagoon. (Coral pinnacle is shown in the satellite image of platform reef)

Atoll

An atoll is a basic type of coral reef formation, which appears annular or ring-shaped (roughly circular or elliptical or horse-shoe shaped) in its plan view. An atoll is often topped by low sand island(s), enclosing a body of water (i.e. the lagoon) and is surrounded by deep water of the open sea, either oceanic or of continental shelf.

Coral Head

Coral head refers to the massive, rounded/knobby or mushroom shaped protuberance of corals usually formed on the submerged part of a reef.

Ribbon Reef

Ribbon reef is a linear chain of reefs, emergent at low tide, commonly having inwardly curved extremities, and form a festoon along the precipitous edge of the continental shelf.

Reef Front

Reef Front refers to the upper part of the seaward slope of a reef, extending from the surf zone to a depth of approximately 100m, commonly to the depth limit of abundant living corals and coralline algae. It is the highest energy zone of the reef. Specific features of the reef front include reef slope, marginal channels, terraces, reef front/fore reef, spur and groove systems. It has coral growth of about 50% in the first 5 m. Below 15 m the coral cover gets restricted but diversity increases (Hopley 1982).

Reef Crest

The sharp break in slope at seaward margin or edge of reef flat. Reef crest is the upper portion of the reef slope. The crest has the best balance between sunlight and waves, so coral grows fastest here. The base of the slope receives the least sunlight and has the least growth out of the whole slope.

Reef Slope

Reef slope refers to the reef face/flank that rise from the sea floor to the reef crest.

Algal Ridge

Algal ridge is a prominent, wave resistant, slightly elevated seaward (outer) margin of the reef flat, which rises from the reef edge and culminates into the steep sea-facing side of the reef crest or the reef front zone. This ridge is mainly composed of the calcium carbonate secretions of actively growing calcareous algae. The algal pavement of encrusting coralline algae provides a hard, resistant surface which bears the main force of the breaking waves and

reduces their destructive power before they sweep into reef flat behind the rim. Very little fine sediments are retained on the algal ridge because of their exposure to the breaking waves.

Moat

Long narrow pool, which occurs in the intervening area between ridges of shingle and rubble and that retain water (Hopley, 1982) is known as moat. Moats are rich in coral diversity and are ideal locations for micro atolls. Apart from corals, clams are also found in moats. Seagrass *Thalassia* may also colonize the sandy moat floors.

Reef Flat

The nearly flat surface that gets exposed as the summit level of the reef at low tide is known as reef flat. Under low tide condition, water depth on reef flat is extremely shallow, at the most a few meters. Reef flat is commonly composed of loosely cemented coralline sand or coarser reef debris and may consist of shallow pools, irregular gullies, low islands or cays of sand or rubble, vegetated and widely scattered colonies of hardy species of coral.

Outer Reef Flat

The seaward or basin ward part of the reef flat or a larger reef tract / reef complex is known as the outer reef flat. This part is generally better developed in terms of substrate diversity than that of the inner reef of the same region.

Inner Reef Flat

The landward or shelf ward part of the reef flat or a larger reef tract / reef complex is known as the outer reef flat. Inner reef flat is often smaller and less developed in terms of substrate diversity than the outer reef flat of the same region.

Sanded Reef Flat

The lee side/inward part/portions of the reef flat where fine coralline sand and broken molluscan shells get deposited are known as the sanded reef flat. However, the deposition may be migratory in nature and may have a seasonal cover of algae or sea grass. The sand is mainly coralline in nature, consisting of fine sand and broken molluscan shells.

Muddy Reef Flat

The part or portions of the reef flat where either thin or thick veneer of silt and mud gets deposited on the reef is the muddy reef flat.

Boulder Zone

Boulder zone is commonly identified with large blocks of dead corals or consolidated reef rock commonly lying on the windward side of the algal pavement/ridge or in the reef crest zone.

Sand Cay

Sand cays are small, low, flat, lens-shaped, crescentic, triangular or near-circular accumulations of loose coralline sand, reef debris, dead corals and beach rock material, commonly situated on the leeward side of the reef where intersecting waves have minimum energy. Sand cays initially develop as concentric or parallel ridges of such constituent materials under the refraction action of the waves. The thickness of sand accumulation varies with tidal range, but many of these islands are only 1m high spring tides. Sand cays may be vegetated or non-vegetated.

Beach

The shore parallel, linear deposition of sand, shingle or gravel by the waves is commonly known as beach. Beach is a gently sloping zone of unconsolidated material, typically with a concave profile, that extends landward from the low

water line to the place where there is a definite change in material or physiographic form or the line of permanent vegetation.

Mudflat

Mudflat is a relatively level area along the coast where fine-grained sediments (silt and clay), ooze etc. accumulate over time. Mudflats are subjected to alternate tidal inundations and may be barren or colonized by mangroves.

According to the effective tidal range mudflats can be again classified into *sub-tidal mudflat*, *inter-tidal mudflat* and *high tidal mudflats*.

Lagoon

Lagoon is a relatively shallow water body situated in a coastal environment and has restricted connection with the open ocean/sea. Lagoon can be partially or completely separated from the sea by a narrow, elongated strip of land, viz. spit, barrier, sand bank, island or a coral reef. Lagoon is a characteristic feature of an atoll. The lagoon floor is composed mainly of sediment derived from erosion of the windward reef and this becomes colonized by a variety of macrophytes and invertebrates. Lagoon may be of varying water depths. The shallowest portion of the lagoon may be 5-10 m depth and the floor is exclusively sandy. The lagoonal patch reefs are located in the deeper part of the lagoon and they grow up to the lagoon water level (Hopley, 1982). They have rich coral assemblages.

Lagoonal Patch Reef / Reef Patch

Independent, commonly mushroom shaped growth of coral colonies in lagoon, varying in extents, is known as lagoonal reef patch. They have rich coral assemblages.

Coralline Shelf

The deposits on the continental shelf around India are mostly those supplied from the sub-aerial erosion of inland areas and from coastal erosion (sand,

gravels, silt and mud). However, there are two regions where the deposits are not terrigenous but of marine origin consisting of coral sand and mud and are thus called as coralline shelf, e.g. Lakshadweep and Andaman and Nicobar islands (Ahmad, 1972). The zone between seaward edges of the fore reef to the beginning of the escarpment where the insular shelf drops off into deep oceanic water is termed as coralline shelf (Ahmed, 1972). It is the flattened platform between the fore reef/reef front and deep open ocean waters.

Coral Knoll

An isolated, rounded, massive, often knobby or mushroom shaped protuberance or growth/structure of coral colonies, which develop locally and upward rather than outward or laterally are commonly termed as coral knolls. These isolated mounds are commonly associated with lagoons of the atoll reefs. The term was first used by Tiddeman for a reef feature that originated as a knoll. The term was used by Emery in 1948 to differentiate a coral head from a coral pinnacle. The size of knolls may vary from very small (<10 feet across and 3 feet high) to several hundred feet or more than a mile but are characterized by the gentle slope.

Live Coral (Platform)

Reef growth generally irregular in shape, developed over submerged rock and more or less completely surrounded by water, with or without island. Live coral platform harbours living coral growth.

Algae / Seaweeds

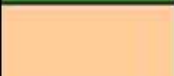
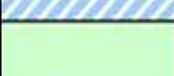
Algae refer to the exclusively aquatic, photosynthetic plants of *Thallophytic* division, which grow on hard substrate (like rock, coral reefs, etc.) by means of a holdfast. They lack proper vascular and root systems. They are non-flowering and their plant body (thallid) is not differentiated into root, stem and leaves they colonize the reef flat. They are broadly classified into marine and freshwater type.

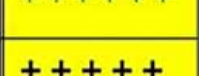
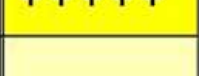
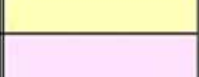
Sea Grass

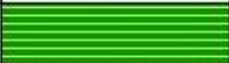
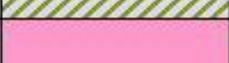
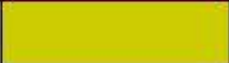
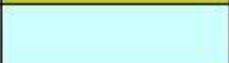
Advanced flowering plants complete with both vascular and root systems. The root rhizome system anchors sea grasses on to soft sediments of low energy environment. (Fine sand mixed with silt and shell debris below which lies fine black sediments/sands rich in decomposing organic matter.

Annexure 4.1.2

Symbols used for the Eco-morphological zones

Classes	Symbol
Windward Reef Front/Reef Front	
Reef Slope	
Reef Crest	
Reef Flat (Outer)	
Algal Ridge	
Moat	
Reef Flat	
Sparse Algae on Reef Flat	
Dense Algae (all the classes associated with dense algae)	
Sparse Algae	
Live Corals	
Mixed Coral Zone	
Dense Algae and Live Corals	

Sand Sheet	
Lagoonal Reef Patch	
Coral Knoll	
Rock	
Submerged Rock	
Boulder Zone	
Sparse Algae on Boulder Zone	
Submerged Reef	
Channel	
Coral Heads	
Sand Cays	
Sand Vegetation	
Sand Deposit	
Beach/Sand Patch	
Coralline Shelf	
Mudflat	
Shallow Turbid Water	
Polluted Water	
Shore Protection Structure	

Seagrass	*****
Microalgae	*****
Algae and Seagrass	
Algae on ERF	
Sand on ERF	
Exposed Reef Flat (ERF)	
Sparse Algae on SMRF	
Reef Flat (Inner)	
Sanded Reef Flat (Deeper Sanded Reef Flat)	
Sparse Algae on SRF	
Muddy Reef flat	
Sparse Algae on Muddy Reef flat	
Sandy Muddy RF (SMRF)	
Reef Flat (Degraded)	
DIRF (Deeper Inner reef Flat)	
Deeper Reef Flat	
Shallow Pools	
Lagoon	
Deep Lagoon	
Intermediate Lagoon	
Shallow Lagoon	

Colour Plates



Plate 2.1: A large Inter tidal mudflat



Plate 2.2: Dense Inter tidal mudflat



Plate 2.3: Sparse mangrove patch



Plate 2.4: A patch of salt marsh



Plate 2.5: A patch of dense scrub



Plate 3.1.1: *Avicennia marina* pure patch along seaward channels towards south eastern part of Corringa Wildlife Sanctuary.



Plate 3.1.2: *Sonneratia apetala* bordered with *Myriostachya wightiana* and *Fimbristylis ferruginea*.



Plate 3.1.3: Pure patch of *A. alba* growing on islands near Coringa creek.



Plate 3.1.4: Mangroves like *Avicennia* sp. and *Excoecaria agallocha* on saline marshes covered with *Suaeda*, *Salicornia* etc.



Plate 3.1.5: Community of 'Mixed mangroves' comprising of *A. marina*, *A. officinalis*, *Bruguiera gymnorhiza*, *E. agallocha* etc.



Plate 3.1.6: *Rhizophora apiculata* with fruits along the eastern side of Gaderu river.



Plate 3.1.7: *R. apiculata* along the creek in Rathikalava RF.



Plate 3.1.8: Pure patch of *A. marina* in Rathikaluva RF.



Plate 3.1.9: *Clerodendrum inerme* – Kottapalem R.F.



Plate 3.1.10: *R. mucronata* along the river bank – Kottapalem R.F.



Plate 3.1.11: Extensive patch of *Avicennia* sp. in Yelichetlidibba RF.



Plate 3.1.12: *R. mucronata* along the creeks in Nachgunta RF.



Plate 3.1.13: Degradation of mangroves due to hyper salinity – Soralagondi R.F.



Plate 3.1.14: Moderately dense patch of *A. alba* on the coastal side of Kendrapatia.



Plate 3.1.15: A small patch of moderately dense *E. agallocha* at Jambu forest block.



Plate 3.1.16: Degraded patch of *E. agallocha*, *Acanthus* and *Suaeda* in Jambu forest block.



Plate 3.1.17: Moderately dense patch of *A. marina*, *S. apetala* and *A. officinalis* along the creek in Bhitari Kharnasi Forest Block.



Plate 3.1.18: Pure patch of Moderately dense *E. agallocha* in Bhitari Kharnasi Forest Block.



Plate 3.1.19: *B. gymnorrhiza* with mangrove associates like *Brownlowia tersa* in Bahar Kharnasi Forest Block.



Plate 3.1.20: *Aegialitis rotundifolia* in Kansardia Forest Block.



Plate 3.1.21: *Ceriops decandra* in Kansardia Forest Block.



Plate 3.1.22: Fruit bearing *Xylocarpus granatum* in Hatamundia Forest Block



Plate 3.1.23: Mangrove forest along with non-littoral vegetation in Hukitola Forest Block.



Plate 3.1.24: A sparsely dense pure patch of *Phoenix paludosa* facing degradation problem because of overgrazing by cattle.



Plate 3.1.25: A moderately dense patch of *Tamarix troupii* in front of very dense *Heritiera fomes* patch in Bhitarkanika Reserved Forest.



Plate 3.1.26: A moderately dense patch of *Lumnitzera racemosa* and *C. decandra* in Bhitarkanika Reserved Forest.



Plate 3.1.27: *E. agallocha* and *A. ilicifolius* in Bandar Forest Block.



Plate 3.1.28: Stumps of degraded mangrove trees on the coastal side of Chandrabali area.



Plate 3.1.29: A pure patch of sparsely dense *A. marina* facing degradation because of anthropogenic pressure in Huppalam area in Puducherry district.



Plate 3.1.30: A pure patch of moderately dense *A. officinalis* near to Gaderu river area in Yanam district.



Plate 3.1.31: A pure patch of moderately dense *E. agallocha* along Nula river in Karaikal district.



Plate 3.1.32: Moderately dense patch of *A. marina* – *E. agallocha* near Gaderu river area.



Plate 3.1.33: 'Mixed mangrove' community consisting of *A. marina*, *A. officinalis*, *R. apiculata*, *E. agallocha*, *S. alba* etc.



Plate 3.1.34: *A. marina* and *S. alba* at Chorao Sanctuary.



Plate 3.1.35: *S. alba* - pure patch along the Chorao Sanctuary.



Plate 3.1.36: *Rhizophora* plantation in Dr Salim Ali Bird Sanctuary (Chorao).



Plate 3.1.37: ‘Mixed mangrove’ community consisting of *A. officinalis*, *A. alba*, *S. alba*, *A. ilicifolius* etc along Talpona canal.



Plate 3.1.38: Mangrove plantation near Katuli by Forest Department of Goa.



Plate 3.1.39: *Myriostachya wightiana* (mangrove associate) with mixed mangrove patch in the background at Pattuvam river area.



Plate 3.1.40: Pure patch of *R. apiculata* with 40-70% density in Kottiyur range.



Plate 3.1.41: *A. officinalis*, *A. marina* with mangrove associate *A. ilicifolius* in Kanhangad range.



Plate 3.1.42: A mixed patch of *A. officinalis* and *A. marina* with 40 to 70% density in Kadalundi area.



Plate 3.1.43: Degradation of mangroves because of lack of availability of tidal flux in Puthuvypin area.



Plate 3.1.44: Large trees of *A. officinalis* and other mangrove species in Mangalvanam Bird Sanctuary.



Plate 3.1.45: *B. Sexangula* in Kundannur area.



Plate 3.1.46: *A. marina* with *A. ilicifolius* (mangrove associate) in Kumarakom area.



Plate 3.1.47: Sparsely dense patch of *E. agallocha* and *Acrostyrium aureum* in Munroturuttu area.



Plate 3.1.48: *E. agallocha* in regenerating stage at Kumbalam area.



Plate 3.1.49: Mixed mangrove.



Plate 3.1.50: *Avicennia alba*.



Plate 3.1.51: *Avicennia marina* (Degraded).



Plate 3.1.52: Mixed mangrove.



Plate 3.1.53: *Sonneratia alba*.



Plate 3.1.54: *Sonneratia apetala*.



Plate 3.1.55: *I Sonneratia alba*.



Plate 3.1.56 *Avicennia marina*.



Plate 3.1.57: *Avicennia marina* with pneumatophores.



Plate 3.1.58: Isolated *Rhizophora* plants.



Plate 3.1.59: *Avicennia* – *Suaeda* zone.



Plate 3.1.60: A view of mangroves in Manoli island.



Plate 3.1.61: *Exoecaria agallocha*.



Plate 3.1.62: Flowers of *Pemphis acidula*.



Plate 3.1.63: Severe soil erosion in the non-mangrove areas of Anipar island.



Plate 3.1.64: *A. alba* preceded by *Porteresia* at the front of Ajmalmari Reserve Forest (at low tide condition).



Plate 3.1.65: Planted *Bruguiera* near Curzoon creek, upstream of Saptamukhi river.



Plate 3.1.66: *Ceriops–Avicennia* assemblage near Kalchara creek, upstream of Saptamukhi river.



Plate 3.1.67: *Phoenix–Ceriops* south-eastern corner of Herobhanga RF.



Plate 3.1.68: Few single stands of *Rhizophora* at Kalchara creek, upstream of Saptamukhi river.



Plate 3.1.69: Few single stands of *Rhizophora* at Kalchara creek, upstream of Saptamukhi river.



Plate 3.1.70: Mangrove assemblages with *Acrostichum* along Tugapur Nala, Middle Andaman.



Plate 3.1.71: *Nypa* backed by terrestrial vegetation at the junction of Betapur Nala near Padmanabhapuram, Middle Andaman.



Plate 3.1.72: A closer view of *Rhizophora stylosa*, along Betapur Nala, Betapur, Middle Andaman



Plate 3.1.73: *Rhizophora* uprooted due to huge tsunami waves with very few *Ceriops* along Homfrays strait, Middle Andaman.



Plate 3.1.74: Pure patch of *Phoenix* with *Acrostichum* in the outer zone of mangrove near Bharatpur, Middle Andaman.



Plate 3.1.75: *Bruguiera* plantation near Sabari, Middle Andaman.



Plate 3.1.76: *Rhizophora*, *Xylocarpus*, *Ceriops* assemblages exposed due to erosion of bank of Austen channel, North Andaman.



Plate 3.1.77: *Rhizophora* tops at the mouth of Austen strait, boundary of North & Middle Andaman.



Plate 3.1.78: *Xylocarpus* near Jirkatang side of Shoal Bay, South Andaman.



Plate 3.1.79: One of the survivor of devastated Kimios Bay mangrove of Car Nicobar.



Plate 3.1.80: Degraded mangroves at Javal Nallah.



Plate 3.1.81: Mangrove areas deposited with coral sand in the devastated Kimios Bay, Car Nicobar island.



Plate 3.1.82: Dried mangroves at Magar Nallah.



Plate 3.1.83: Lone survivor – *Rhizophora* sp.



Plate 3.1.84: Blocked water ways of Jahul Nala, Car Nicobar island.



Plate 3.1.85: Permanently submerged mangrove habitat with dried mangrove plants, Campbell Bay.



Plate 3.1.86: Dried mangroves in Camorta island.



Plate 3.1.87: Dried mangroves in Trinket island.



Plate 3.1.88: Rejuvenating *Nypa* plants in Camorta.



Plate 3.1.89: Dried mangroves and coastal plants.



Plate 3.1.90: *Sonneratia apetala* tree at Surat.



Plate 3.1.91: *Sesuvium portulacastrum* at Bharuch.



Plate 3.1.92 *Avicennia marina* at Bharuch.



Plate 3.1.93 Site showing dead *Avicennia marina* at Kori creek region.



Plate 3.1.94: Mixed mangroves (*Acanthus ilicifolius* with *Ceriops tagal*) at location in Navsari district.



Plate 3.1.95: *Avicennia marina* growing close to human habitation in Saurashtra.

