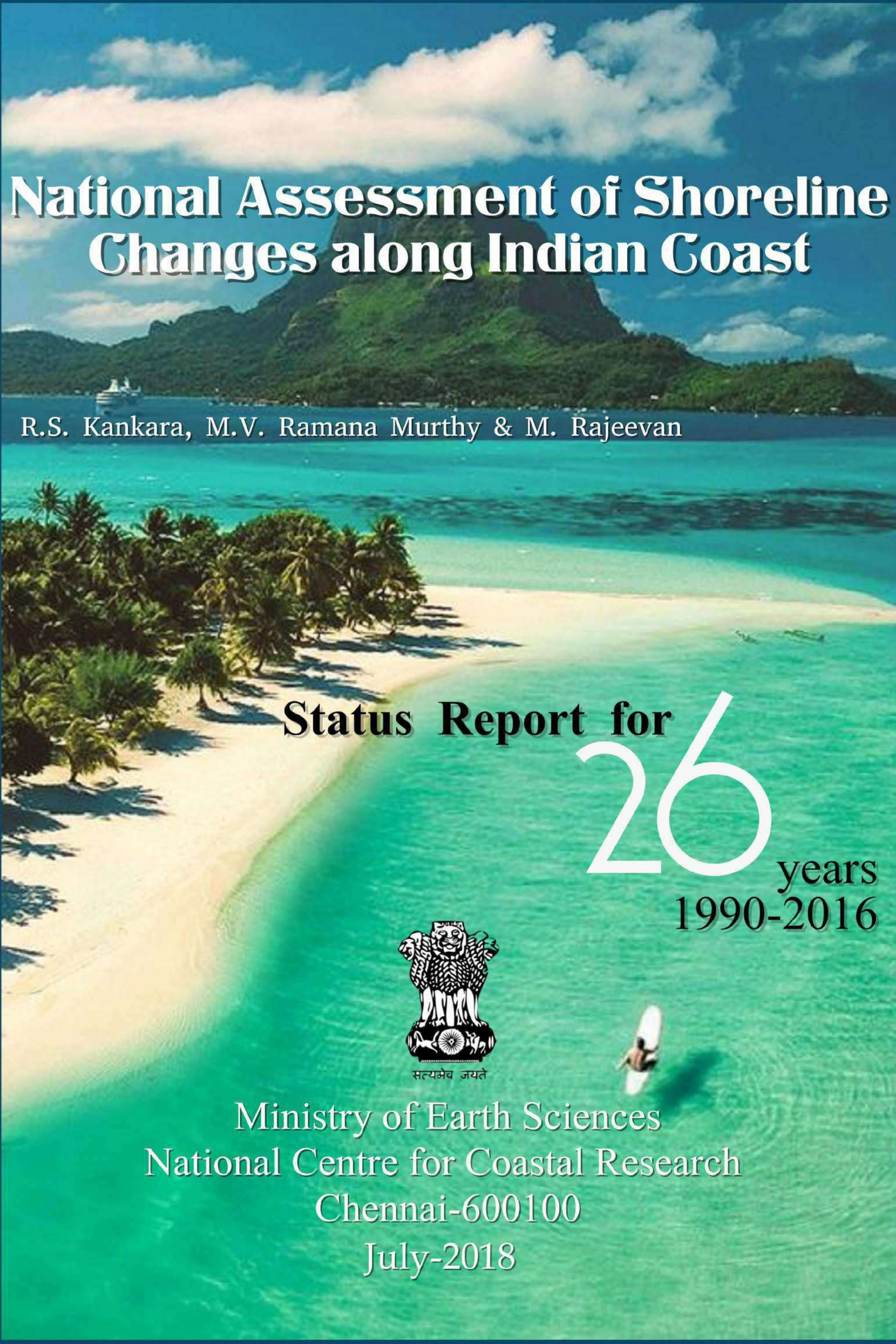


National Assessment of Shoreline Changes along Indian Coast

R.S. Kankara, M.V. Ramana Murthy & M. Rajeevan

Status Report for 26 years 1990-2016

सत्यमेव जयते

Ministry of Earth Sciences
National Centre for Coastal Research
Chennai-600100
July-2018

National Assessment of Shoreline Changes along Indian Coast

R.S. Kankara, M.V. Ramana Murthy & M. Rajeevan

Status Report for 26 years 1990-2016

सत्यमेव जयते

Ministry of Earth Sciences
National Centre for Coastal Research
Chennai-600100

July-2018

National Assessment of Shoreline changes along Indian Coast: Status report for 26 years (1990 - 2016)

NCCR PROJECT TEAM MEMBERS

1	Dr. M. V Ramana Murthy, Director & Scientist-G, NCCR
2	Dr. R. S Kankara, Group Head & Scientist F, CP & SM Group, NCCR
3	Dr. S. Chenthamil Selvan, Project Scientist-I
4	Mr. K. Prabhu, Project Scientist-I
5	Mr. B. Rajan, Senior Research Fellow
6	Mr. S. Arockiraj, Senior Research Fellow
7	Mrs. S. Dhanalakshmi, Senior Research Fellow
8	Miss. Padmini G, Senior Research Fellow
9	Dr. V. Noujas, Project Scientist-I
10	Miss. M. Umamaheswari, Senior Research Fellow
11	Mr. S. Sathish, Project Scientist-I

EXPERT COMMITTEE

1	Dr. Shailesh Nayak, Former Secretary, MoES New Delhi	Chairman
2	Dr. Ashok Kumar Saxena, Project Director, ICZMP, Gujarat	Member
3	Dr. Ajit Pattnaik, Project Director (Retd), ICZMP, Odisha	Member
4	Sh. Arvind Kumar Nautiyal, Director, MoEF & CC, New Delhi	Member
5	Sh. Sanjay Kumar Singh, Director, CWC, MoWR, RD&GR, New Delhi	Member

DISCLAIMER

This report is part of series of reports that includes text summarizing methods, results, in addition to maps illustrating zones of shoreline change. Zones of shoreline change are being published for the purpose of coastline characterization. The report / maps are not intended to be equated to either as revenue maps of the respective State/ UT/ Government agencies or as the topographic maps of the Survey of India. The maps conform to the National Map Policy dated May 19, 2005 of the Ministry of Science and Technology, Government of India.

CITATION:

R.S. Kankara, M.V. Ramana Murthy and M. Rajeevan (2018), National Assessment of Shoreline changes along Indian Coast - A status report for 26 years 1990-2016. NCCR Publication, 2018, available at NCCR Web site http://www.nccr.gov.in

Contact:

National Centre for Coastal Research (NCCR)

Velacherry-Tambaram Main Road, Pallikkaranai, Chennai - 600100, India

Tel: +91 44 66783599 Fax: +91 44 66783487

E-mail: kankara@nccr.gov.in

डॉ. एम. राजीवन
DR. M. RAJEEVAN

सचिव
भारत सरकार
पृथ्वी विज्ञान मंत्रालय
पृथ्वी भवन, लोदी रोड, नई दिल्ली-110003
SECRETARY
GOVERNMENT OF INDIA
MINISTRY OF EARTH SCIENCES
PRITHVI BHAVAN, LODHI ROAD, NEW DELHI-110003

PREFACE

The coastal zone of the world is in constant change due to natural and anthropogenic activities. Natural processes such as waves, tides, littoral currents, sea-level rise, severe storm events etc., have influence on shoreline changes at local and regional scales. While, human activities further aggravate these changes, as they interrupt the natural coastal processes and modify the sediment transport, which leads to rapid changes in the coastline.

The coastline of India is undergoing changes due to various anthropogenic and natural interventions. Population explosion along the coastal area has added to an increase demand for coastal resources. Precise information on shoreline changes is essential to address the various coastal problems such as coastal erosion, closure of river / lagoons /creeks mouths, etc. Thorough understanding of Long-term shoreline change, its behaviour, extent, etc are required before implementing any coastal protection scheme. It is also important to understand the causes of erosion to undertake proper safeguards in building structures, and infrastructure in eroding coastal areas. Coastal managers and policy makers need accurate information on long term shoreline changes before implementing any structure on coast.

The National Centre for Coastal research, Chennai an attached office of Ministry of Earth Sciences is engaged in mapping the shoreline changes along Indian coast to enhance the country's preparedness to face coastal hazards like storm-surges, tsunami etc and to guide the sustainable coastal development. Now NCCR has prepared a status report on shoreline changes for the period 26 years (1990 to 2016) using 9 shoreline data sets i.e. year 1990, 2000, 2006, 2008, 2012, 2013, 2014, 2015 and 2016. It provides details of shoreline changes, 3 types of map, shoreline vulnerability for erosion /accretion, land loss / land gain etc for entire mainland coast of India. These maps will be available online for each of the coastal state/ UT on the NCCR's website.

I congratulate Dr. M. V. Ramana Murthy, Director, NCCR, Dr. R. S. Kankara, Head, Coastal Processes and Shoreline Management Group, NCCR, Project Team and expert committee for bringing out the status report on Shoreline changes along Indian coast for the period of 1990 -2016. I also thank Dr. Shailesh Nayak, Former Secretary, MoES for conceptualising this important activity and reviewing the mapping work.

I hope this information will be very useful to coastal managers and other stakeholders in identifying critical area for coastal management to safeguard property and population living in coastal areas.

(M. Rajeevan)

Tel. : +91-11-24629771, 24629772 ❑ Fax : +91-11-24629777 ❑ E-mail : secretary@moes.gov.in

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

SHORELINE MAPS

East coast of India		
Sl. No	**State**	**Number of maps (1:25,000)**
1	Tamil Nadu & Puducherry	80
2	Andhra Pradesh	89
3	Odisha	46
4	West Bengal	29
West coast of India		
5	Kerala	55
6	Karnataka & Goa	32
7	Maharashtra	45
8	Gujarat and Daman Diu	150
	Total Numbers	**526***

* One sample map for each state is included in this report for reference.

ABBREVIATIONS

CPDAC	Coastal Protection and Development Advisory Committee
DSAS	Digital Shoreline Analysis System
EPR	End Point Rate
ESRI	Environmental Systems Research Institute
ETM+	Enhanced Thematic Mapper Plus
GCP	Ground Control Point
GIS	Geographical Information System
GPS	Global Positioning System
HTL	High Tide Line
HWL	High Water Line
LISS-III	Linear Imaging Self Scanning Sensor III
LISS-IV	Linear Imaging Self Scanning Sensor IV
LRR	Linear Regression Rate
MHW	Mean High Water
NNRMS	National Natural Resource Management System
NOAA	National Oceanic and Atmospheric Administration
NRSC	National Remote Sensing Centre
PAN	Panchromatic
PCA	Principal Component Analysis
TM	Thematic Mapper
USACE	U.S. Army Corps of Engineers
USGS	United States Geological Survey
WGS	World Geodetic System
WLR	Weighted Linear Regression Rate

MINISTRY OF EARTH SCIENCES
National Centre for Coastal Research, Chennai

National Assessment of Shoreline changes along Indian coast (1990 - 2016)

EXECUTIVE SUMMARY

Beach erosion is a chronic problem along many shores of the Indian coast. As coastal population continues to grow and community infrastructures are threatened by erosion, there is increased demand for accurate information regarding past and present trends and rates of shoreline movement. There is also a need for a comprehensive analysis of shoreline movement that is inconsistent from one coastal region to another. To meet these national needs, the National Centre for Coastal Research (NCCR) is carried out a study on shoreline changes along mainland of India. One purpose of this work is to develop standard, repeatable methods for mapping and analyzing shoreline movement so that systematic periodic updates on shoreline changes, coastal erosion hotspots, land gain/ loss etc. can be made for Indian coast.

In the case of the analysis of shoreline change along Indian coast, the shoreline proxy is interpreted as wet/dry line in sandy shore, vegetative line and sea shore facing direction of seawall. This report, summarizes the methods of analysis, interprets the results, provides information on shoreline changes for the period of 1990 to 2016, and rates of change. Shoreline change analyses are based on a comparison of different shoreline positions digitized from satellite images. The shorelines position covers a variety of time periods ranging from 1990 to 2016. Long-term rates of change are calculated using all 9 different shorelines positions i.e. for the year 1990, 2000, 2006, 2008,2012, 2013, 2014, 2015 and 2016. The rates of change presented in this report represent conditions up to the date of the most recent shoreline data and therefore are not intended for predicting future shoreline positions or rates of change. The Indian mainland was analyzed separately in a state-wise manner for the purpose of reporting regional trends in shoreline change rates.

About 6031 km long coastline was mapped in 1:25,000 scale to analyse the temporal shoreline changes during 1990 to 2016 using 9 data sets. The results are classified in three categories i.e. erosion, stable and accretion. Overall, about 34% of coastline is under varying degree of coastal erosion, 28% is of accreting nature condition and the remaining 38% falls stable state. The state wise analysis suggests that the more that 40% of erosion is noticed in four states/UT i.e. West Bengal (63%), Pondicherry (57%), Kerala (45%) and Tamil Nadu (41%) coast. While accretion is exceeding to 40% along Odisha (51%) and Andhra Pradesh (42%) coast. The west coast of India (except Kerala) is mainly stable condition, along with isolated pockets of eroding coast. Land loss and land gain analyses revealed that West Bengal coast has lost about 99 sq km land during last 26 years. The shoreline changes along with infrastructure details, ports, industries, anthropogenic activities, are also mapped. 526 maps are prepared for entire Indian coast for identifying the vulnerable coastal areas in 1:25000 scale along with 66 district maps, 10 state /UT maps. These maps shall be updated regularly as a part of coastal change system project. The project is aimed to generate the systematic information on coastal changes at various temporal scales, its nature, and extent, needed to evolve better management solutions.

MINISTRY OF EARTH SCIENCES
National Centre for Coastal Research, Chennai

National Assessment of Shoreline changes along Indian coast (1990 - 2016)

1. Introduction

The shoreline is constantly influenced by sea level variations, climate and ecosystems that occur over a wide range of time-scales. The combination of natural and manmade activities often exacerbates the shoreline change and increases the risk factors to coastal community. Shoreline change is one of the three identified environmental concerns considered for the developmental activities such as ports, harbour, fishing jetties and embankment facilities. The changing position of shoreline over time is of elemental importance to coastal scientists, engineers, and managers for coastal management and engineering design for coastal development. Precise shoreline information is required for the design of coastal protection, structures calibration/verification of numerical models, assessment of sea-level rise, preparation of hazard zones, formulation of policies, the regulation of coastal developmental activities, etc. A systematic long-term shoreline change study can provide information on shoreline re-orientation due to structures, changes in beach width, land loss, land gain and historical rate of changes.

Major causes for shoreline change

Shoreline is subject to change due to natural and manmade activities (P. Bruun and B. U. Nayak, 1980). Some of the changes are summarized below:

Natural Causes

1. Action of Waves: Waves are generated by offshore and nearshore winds, which blow over the sea surface and transfer their energy to the water surface. As waves move towards the shore, waves break, and the turbulent energy is released to the water column. This energy stirs up and moves the sediments deposited on the seabed.
2. Winds: Wind act not just as a generator of waves, but also aids in the landward movement of dunes (Aeolian erosion).
3. Tides: Tides are rise and fall in water elevation due to the attraction of water masses by the moon and the sun. During high tides, the energy of the breaking waves is released higher on the foreshore.
4. Nearshore currents: Sediments scoured from the seabed are transported away from their original location by currents. The transport of (coarse) sediments defines the boundary of coastal sediment cells, i.e. relatively self-contained system within which (coarse) sediments stay. Currents are generated by winds, tides (ebb and flood currents), wave breaking at an oblique angle with the shore (longshore currents), and the backwash of waves on the foreshore (rip currents). All these currents contribute for shoreline changes.
5. Storms: Storms generate storm surges and high energy waves. Combined with high tides, storms may result in catastrophic damages. Besides damages to coastal infrastructure, storms cause beaches and dunes to retreat tens of meters in a few hours.

6. Sea Level Rise: Sea level has risen about 40 cm in the past century and is projected to rise another 60 cm in the next century. Sea level has risen nearly 110 meters since the last ice age. Due to global warming, average rise of sea level is of the order of 1.5 to 10 mm per year. It has been observed that sea level rise of 1 mm per year could cause an inundation of the order of about 0.5 m per year (IPCC report).

Anthropogenic Causes

Human influence, particularly urbanization and economic activities, in the coastal zone has turned coastal erosion into a problem of growing intensity. Anthropological effects that trigger shoreline changes are: construction of coastal structures, mining of beach sand, offshore dredging and damming of rivers. Human intervention can alter the natural processes through the following actions:

- dredging of tidal entrances and navigational channels
- construction of harbours and coastal structures such as groins and jetties
- River water regulation works such as damming
- hardening of shorelines with seawalls
- beach nourishment
- Destruction of mangroves and other natural buffers
- Beach sand mining

1.1 Shoreline and its definitions

Coastal scientists and other coastal agencies have been quantifying the shoreline change rates for many decades. There are various definition of shoreline identified and some of them are summarized here.

The line of contact between land and water is defined as shoreline. In other term shoreline is defined as the intersection of a specified plane of water with the shore or beach (e.g., the high water shoreline would be the intersection of the plane of mean high water with the shore or beach).

However, the shoreline approximates the mean high-water line on coast and Geodetic Survey nautical charts and surveys. In Coast Survey usage, the term is considered synonymous with coastline (Shalowitz, 1962).The line delineating the shoreline on National Ocean Service nautical charts and surveys approximates the mean high water line (USACE, 1984).

Apparent shoreline is the line drawn on a map or chart in lieu of a mean high-water line or the mean water level line in areas where either may be obscured by marsh, mangrove, cypress, or other type of marine vegetation. This line represents the intersection of the appropriate datum on the outer limits of vegetation and appears to the navigator as the shoreline (Ellis, 1978).

High-Water Line Mark: A line or mark left upon tide flats, beach, or alongshore objects indicating the elevation of the intrusion of high water. The mark may be a line of oil or scum along shore objects, or a more or less continuous deposit of fine shell or debris on the foreshore or berm. This mark is physical evidence of the general height reached by wave run-up at recent high waters. It should not be confused with the mean high water line or mean higher high water line (Hicks, 1984).

High-water line - Visible in the field and can be identified by the change in grey or colour tone on aerial photographs or satellite imagery (Zhang et al., 2002). This definition makes it more practical when satellite imagery is concerned.

Different proxies for shoreline position are used to analyse the coastal changes. Some of the proxies of shoreline positions are High Water Line (HWL), wet-dry line, vegetation line, dune toe or crest, toe of the beach, cliff base or top and Mean High Water Line (MHWL) etc. Earlier days, High Water Line in Toposheets was also used as one of the shoreline positions.

1.2 Indian coast and its Geomorphology in general

Indian mainland coast includes 9 coastal states and 2 union territories having 66 coastal districts. Morphology of the coast consists of 43% sandy beach, 11% rocky coast, 36% of muddy flats 10% of marshy coast, 97 major estuaries and 34 lagoons (CPDAC Report). There are 13 major ports, 46fishing harbours and 187 minor ports.

Table 1: Coastal geomorphic features of India

Sl. No	State	Landforms and features
East coast of India		
1	Tamil Nadu	Deltas, long narrow beaches, spits, tidal flats, mangroves, coral reefs, sand dunes, Ridge swale complex etc.
2	Andhra Pradesh	Deltas, long narrow beaches, spits, mangroves, cliffs, long sand dunes, Ridge swale complex etc.
3	Odisha	Deltas, long beaches, spits, tidal flats, long sand dunes, ridges etc.
4	West Bengal	Large delta, very thick mangroves, tidal channels, islands, dunes, tidal flat, beaches etc
West Coast of India		
5	Kerala	Estuaries, lagoons, barriers, spits, dunes, tombolo, cliff, beaches etc
6	Karnataka & Goa	Estuaries, spits, sand dunes, tombolo, cliff, wave cut platforms, beaches etc
7	Maharashtra	Estuaries, cliffs, small sand dunes, tombolo, cliff, wave cut platforms, pocket beaches etc
8	Gujarat	Marshy land, tidal flats, estuaries, cliffs, mud flats, mangroves wave cut platforms, beaches etc.

Coastal geomorphology deals with the shaping of coastal features (landforms), the processes at work on them and the changes taking place. The shore is the zone between the water's edge at low tide and the upper limit of effective wave action, usually extending to the cliff base. It includes the foreshore exposed at low tide and submerged at high tide and the backshore extending landward from the normal high tide limit, but inundated by exceptionally high tides or by large waves during storms.

Coastal geomorphology is susceptible to coastal changes and plays an important role in determining the impact of sea-level rise. Every landform offers certain degree of resistance to erosion. For example, rocky coast and wave-cut benches offers maximum resistance. On the other hand, sandy beaches, sand dunes, mudflats, mangroves, etc, show least resistance to sea-level rise.

East coast is mostly dominated by coastal plains and is wider with many large deltas, lagoons, mangroves, long and wide stretches of sand dunes, ridges and beaches are the common features observed along the coast. Along the west coast, most common geomorphic features are rocky coast, headlands, cliffs, estuaries and bays, etc. The general distribution of geomorphic features along the Indian coast is given in Table 1.

1.3 Past studies on Shoreline mapping in India

Several proxies are being used worldwide for shoreline change studies. In India, NCSCM has prepared shoreline change mapsfor few coastal states. The shoreline changes maps were prepared by considering the latest shoreline for year 2010 as a onetime exercise in 1:50,000 scale.

Further, SAC has prepared shoreline change maps with Central Water Commission in the form of Atlas (1; 25000 scale). The major objective of this activity is to prepare a digital shoreline change atlas in GIS environment on 1:25,000 scale using satellite data (1989-91 and 2004-06). This report gives an overview of erosion/accretion by plotting 2 high water line polygons obtained from land use /land cover mapping work carried out at SAC earlier for these two different periods of datasets i.e. 1989-91 and 2004-06.However, these maps don't depict the temporal behaviour and non-linear changes of shoreline, which is very essential for coastal management.

1.4 Shoreline proxies adopted Shoreline mapping at ESSO-NCCR

In 2013 ICMAM has conducted a R&D study on shoreline changes using different proxies and varying datasets and prepared a report on methodology for shoreline change mapping. In this report, ICMAM proposedhigh Water line (HWL) mark as shoreline position considering the varying coastal features, other variability and limitations of RS data along Indian coast.In August 2014, a committee of experts from ICMAM, INCOIS and NCESS evaluated the results and recommended that,

- In sandy shore,**"wet/dry line"** which is clearly identifiable from all images was considered as shoreline proxy. This wet/dry lineis equivalent to **high water line (HWL)** mark from all satellite images. The identification of the feature **"wet/dry line"** from the images is as follows: on a rising tide, it is equal to maximum run up line, and on falling tide, it is equal to part of beach which is still wet, but it may be beyond the instantaneous run up limit.
- **Vegetative line** is considered as shoreline proxy, where there is no sandy beach. The waves directly interact with the vegetations along the coast. Seashore facing direction of vegetative limits is demarcated as shoreline proxy and it can be clearly interpreted with the satellite images.
- In case of **artificial structures** (seawalls), the sea shore facing direction of seawall is considered as shoreline position.In rocky coast, cliff base or sea shore edge is considered as shoreline position.

1.5 Scope of long-term shoreline change mapping

The knowledge on shoreline changes, its behaviour, erosion in historical perspective and related morphological characteristics are primary requirements for coastal development and shore protection projects. Though some attempts are made, systematic information of Indian coast based on widely accepted, standardized method of shoreline change is not available. Therefore, in XII plan(October 2012), MoES (ICMAM) was entrusted the task of studying shoreline changes along the Indian coast using remote sensing, field investigation, Numerical modelling and GIS. The main objectives of this work are:

- To assess the consistency and generate reliable information of complex systems of the Indian coast using a standard method
- To prepare shoreline change maps using standard protocol (1:25000 scale) for the entire coast.
- To carry out shoreline change analysis at state and district levels.
- To estimate annual land loss / land gain due to shoreline changes.
- To initiate a web based coastal service on annual shoreline changes along the Indian coast.

2. Data used

Satellite data sets are used as the primary data source. The multi-temporal satellite data such as Landsat TM, ETM+, IRS-P5 (Cartosat-1), IRS-P6 (LISS-III) and (LISS-IV) were used to calculate the shoreline change for different years (Table 2).

Table 2: Details of satellite data used

List of Image	Pixel Size(m)	Date	Source
Landsat 5 TM	30.0	1989-1992	USGS
Landsat 7 ETM+	30.0	1999-2001	USGS
IRS P5 (Cartosat-1) PAN	2.5	2005-2006	INDIAN
IRS P6 (Resourcesat-1) - (LISS-III)	23.5	2008	INDIAN
Resourcesat 2 - (LISS-IV)	5.8	2012	INDIAN
Resourcesat 2 - (LISS-IV)	5.8	2013	INDIAN
Resourcesat 2 - (LISS-IV)	5.8	2014	INDIAN
Resourcesat 2 - (LISS-IV)	5.8	2015	INDIAN
Resourcesat 2 - (LISS-IV)	5.8	2016	INDIAN

3. Methodology

Shoreline evolution is one of the most significant factors in analyzing the change rate. There are several approaches to calculate the rates of shoreline change, such as numerical models and remote sensing technique. Remote sensing technique and GIS technology are considered as dominant tools for quantifying the shoreline change on temporal scale (Nayak. S., 2002). By integrating the modern techniques of remote sensing and GIS, rates of shoreline change would be easily and quickly determined for any given area. The methodology adopted for shoreline change calculation is shown in the flow chart (Figure 1).

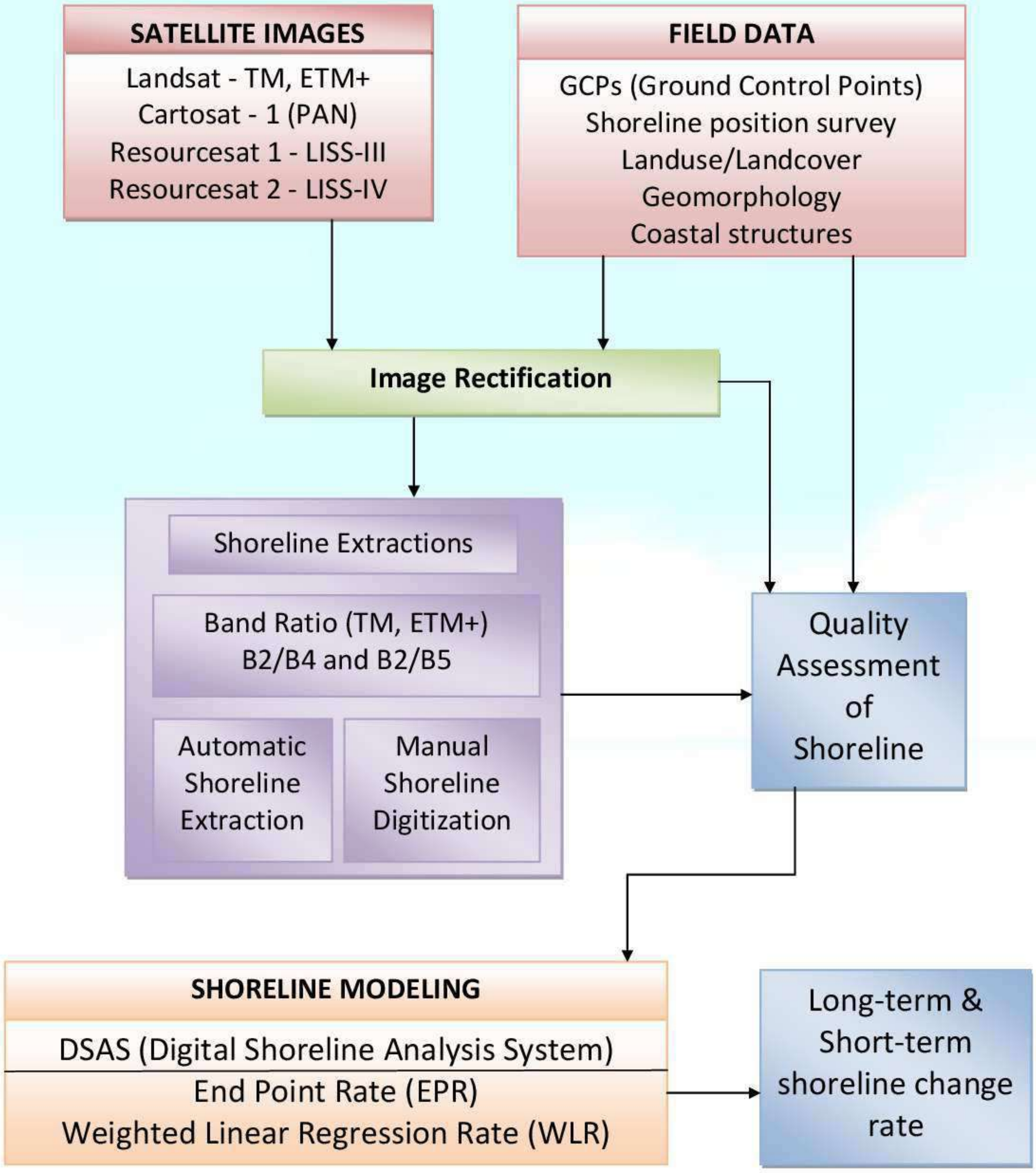


Figure 1: Flow chart of methodology

3.1 Determination of shoreline from Remote Sensing and fielddata

Determination of shoreline position from satellite data is very subjective due to limiting factors such as, different ranges of tide induced variability, variations in meteorological conditions, inequalities in data resolution, seasonal setup and scaling of RS data during different periods of data acquisition. In the past, the researchers had used various proxies such as high tide line (HTL) (Fisher and Overton, 1994; Stockdon*et al.*, 2002), high water line (HWL) (Fenster and Dolan, 1999), wet-dry line (Overton *et al.,* 1999), vegetation line (Hoeke*et al.,* 2001), dune toe or crest (Stafford and Langfelder, 1971), toe or Berm of the beach (Norcross *et al.,* 2002), cliff base or top (Moore *et al.,* 1998) and mean high water (MHW) line (Galgano and Leatherman, 1991). However, it becomes subjective to extract these proxies in practical sense due to varying geomorphology of coastal environment. Some of the shoreline proxies which are commonly used in shoreline extraction are shown in Figure 2.

Figure 2: Shoreline proxies used for shoreline extraction. **A**-Sand dunes with vegetative cover. **B**-Vegetative line. **C**-Riprap structures in case there is no sandy shore. **D**-High water line (HWL). **E**- Debris brought by the waves.

3.2 Shoreline extraction from satellite data

Before analyzing the shoreline change rate, it is necessary to define the shoreline proxy for any particular scenes used in the analysis. Advantages and limitations of the coast have to be understood before defining the shoreline position within the available data source. Same proxy cannot be used for the entire coast due to different geomorphological conditions.

In the present study, semi-automated method (automatic and manual digitization) was carried out to extract the shoreline. It can reduce the pixel misinterpretation error which is more common in automatic method. The shoreline proxy used in the analysis also varies from place to place. Therefore, semi-automated method is the best suited for shoreline extraction.

3.3 GIS database for shoreline mapping

The 'GEODATABASE" term describes any information system that integrates, stores, edits, analyzes, shares and displays geographic information for informed decision making. GDB supports all the different elements of GIS data used by ArcGIS. The shoreline GDB includes the attribute fields such as ObjectID (a unique number assigned to each transect, shape, shape length, ID, date (original survey year) and uncertainty values for calculating the rate. The other information stored in GDB format are shoreline rate file, field photographs, co-ordinates, base map information and sediments locations.

3.4 Shoreline change calculation

There are many statistical methods used by DSAS to calculate the shoreline change rate. These methods are End Point Rate (EPR), Linear Regression Rate (LRR) and Weighted Linear Regression (WLR). Of these methods, EPR and WLR are used for the analysis. DSAS is purely a statistical approach which gives output based on input parameters such as date and year.

3.4.1 Periodic changes

End point rate (EPR)

The minimum requirement is 2 data sets of shoreline over a time to compute shoreline movement. This is a simple and popular approach adopted to calculate the shoreline change rates by dividing the distance of shoreline movement by time elapsed as given in Figure 3.

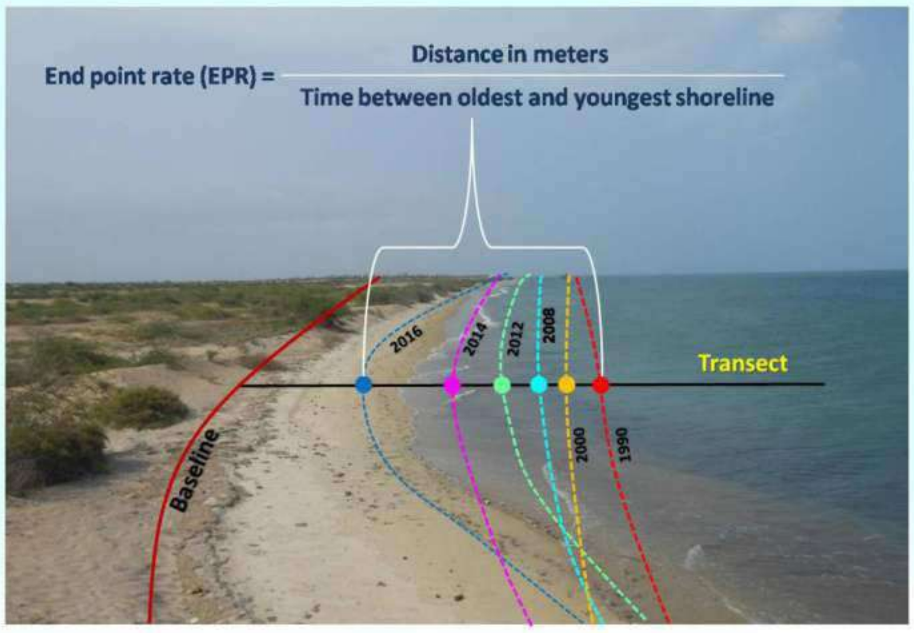


Figure 3: Shoreline change: End point rate method(distance between the 1990 and 2016 shorelines divided by the span of time elapsed between the two shoreline positions; all other shoreline data are ignored in this computation).

3.4.2 Cumulative changes

Weighted linear regression rate (WLR)

The cumulative shoreline changes are computed considering the nine series of data sets. These rates are calculated by determining a linear regression rate-of-change (fitting a least-square regression lines) for point/transect along the coast. Further, a weightage was attached to shoreline data considering the measurement and positional uncertainties involved in obtaining the data. Fine resolution/quality data sets are given greater emphasis or weightage towards determining a best-fit line in comparison with unreliable or poor data sets, i.e. the regression line can be placed in such a way that the sum of the squared residuals is minimized.

The weight (w) is defined as a function of the variance in the uncertainty of the measurement (e): **$w = 1/ (e^2)$,** where, e = shoreline uncertainty value. The uncertainty and shoreline position at these transects are used to calculate the rate-of-change statistics. Figure 4 shows the shoreline positions of a particular transect plotted with respect to time. The error bar in shoreline measurement point is obtained after adding the weighted values to each shoreline position.

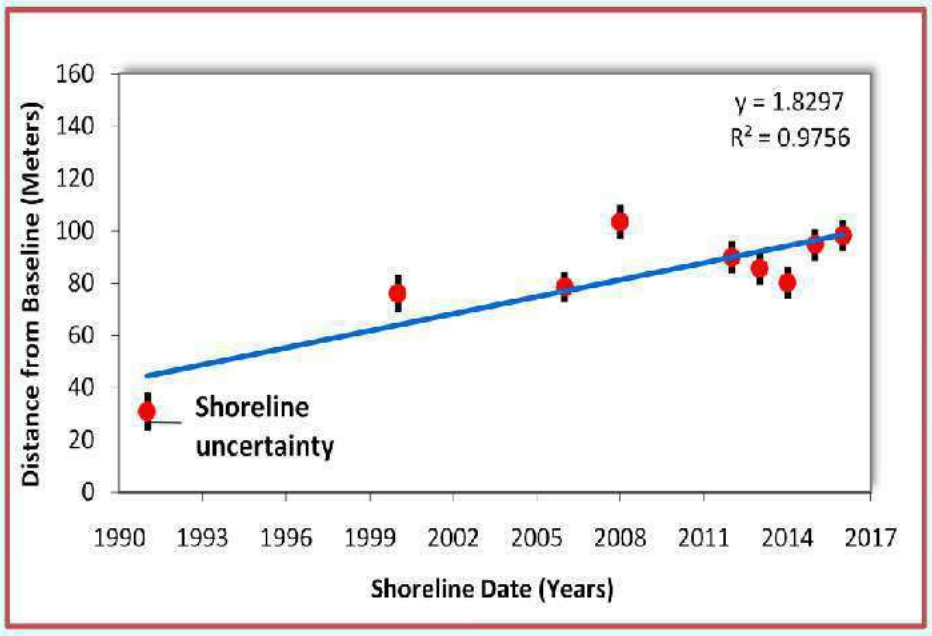


Figure 4: Shoreline change by the weighted linear regression rate method (determined by plotting the shoreline positions with respect to time and calculating the linear regression equation of y. The slope of the regression line is the rate).

3.5 Uncertainty in shoreline measurement

Further the accuracy of shoreline positions extracted from remote sensing data is influenced by several factors such as positional uncertainties (Seasonal error, & Tidal fluctuation) and measurement uncertainties (Digitizing, Pixel, & Rectification).

There are issues in shoreline mapping in wider intertidal zones. The extraction of "HWL" or "wet/dry line" from various images has potential uncertainties and errors with reference to tide and resolution. Therefore, the same may be accounted while considering these positional and measurement uncertainties, which may be within in the limitations of the data itself.

Positional Uncertainties: related to the features and phenomena that reduce the precision and accuracy of defining a shoreline position from a given data set such as Seasonal error (E_s), and Tidal fluctuation (E_{td}).

Measurement Uncertainties: related to the skill and approach such as Digitizing error ($E_{d,}$) Rectification error (E_r) and Pixel error (E_p)

Finally, overall total uncertainty value has been estimated for each shoreline by accounting for both positional and measurement uncertainties as:

$$Et = \pm\sqrt{E_s^2 + E_{td}^2 + E_d^2 + E_P^2 + E_r^2} \quad \longrightarrow Eqn\ 1$$

This approach considers varying rate of changes between each dataset by fitting a least-square regression line for all datasets. In this approach, high resolution data sets are given greater emphasis or weightage towards determining a best-fit line in comparison with unreliable or poor data sets.

The total uncertainties considered in the analysis are given in Table 3.

Table 3: List of uncertainties used in the analysis

Errors	Consideration	Uncertainty Value
Tidal error	Tidal values are taken from the tide table and tidal stations along the coast. The tidal value differs from place to place based on the station.	Tide range from the nearest station.
Seasonal error	Seasonal error is the horizontal distance along the coast. This error mainly depends on the coastal slope. The coasts are either steep or gentle. Taking this factor in to account the seasonal error to be considered.	based on the slope. (availability of slope data is a question; or 5 - 10 m based on the regions).
Digitizing error	Digitizing the shoreline is a difficult task. Digitizing the shoreline position by the same analyst may change when he does it again. After considering all the factors, the error is fixed.	Half of the pixel size is considered.
Rectification error	Rectification error is the error obtained from the ortho-rectification process. The RMSE error thus obtained during rectification is considered as error value.	RMSE value (the rectification accuracy should be maintained with in a pixel).

3.6 Field Database

Field work was undertaken for entire coastal region of India, mainly focusing to collection of GCPs, shoreline tracking during satellite pass time, sediment data collection, validation/verification of landuse/landcover and geomorphology.

3.6.1 Shoreline Mapping

Shorelines were tracked for select locations using handheld GPS instrument. Shoreline tracking was carried out mainly during the satellite pass time. The shoreline extracted from satellite imagery is then cross validated with the shoreline tracked from the field. Plate 1 shows the shoreline tracking along Battigavuru coast, Andhra Pradesh.

Plate 1. Shoreline tracking along Battigavuru, Andhra Pradesh

Plate 2. GCP collection at NH-5, Srikakulam, Andhra Pradesh

3.6.2 Collection of Ground Control Points (GCP's)

GCP's were collected to rectify the satellite imagery which is used for shoreline extraction. 15km width from the coast is considered as the boundary for GCP collection. All the GCP's were evenly collected all along the image for minimising the error while extracting the shoreline positions. All the satellite images should be brought into a common projection system (WGS 84) so that the error or shift in the images can be reduced. GCP collection at NH-5, Srikakulam , Andhra Pradesh is shown in Plate 2.

3.6.3 Sediment Sample Collection

About 1050 Sediment samples were collected at various locations along Indian coast (Figure 5). Three samples (foreshore, bermline and backshore) at each location were collected. Position of sampling locations was observed by hand-held GPS. In the laboratory, dead shells were separated from sediments and the mixed saline content was removed from the grains by washing with water. The grain size distribution was carried out using a sieve shaker and it consisted of 8 sieves containing mesh sizes of 75µm, 125µm, 180µm, 250µm, 355µm, 500µm, 1000µm and 2000µm. The statistical parameters such as mean, standard deviation, skewness and kurtosis were computed by (Folk and Ward, 1957) using the GRADISTAT grain size distribution and statistical package (Blott and Pye, 2001).The sediment sample collection in the foreshore at Lakshmipuram, AP is shown in Plate 3.

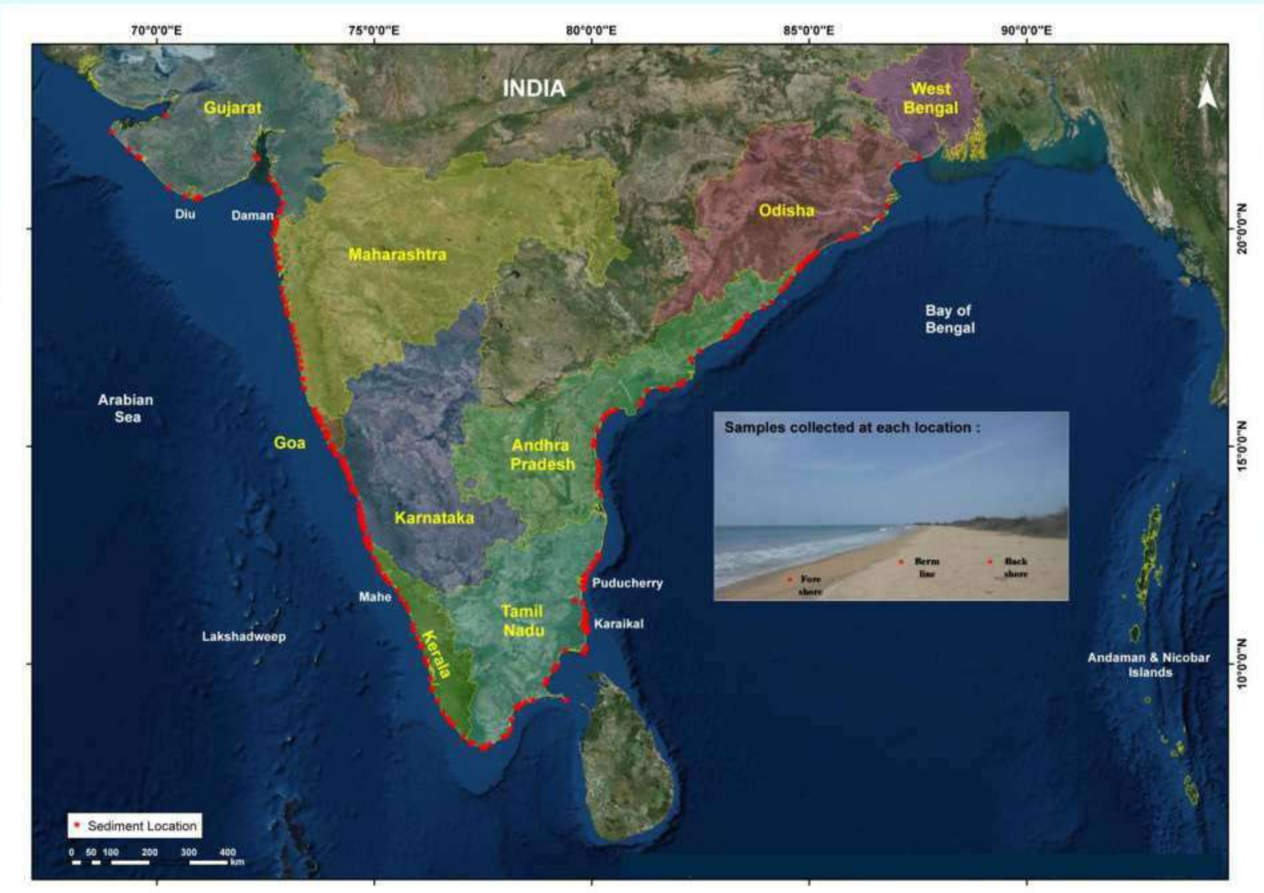


Figure 5: Locations of sediment samples collected along coastline

Plate 3. Sediment collection at Lakshmipuram, Andhra Pradesh

3.6.4 Landuse/Landcover feature identification/validation

Management of coastal areas depends on understanding the different uses of coastal land and the physical processes impacting on the coast. Hence delineation of landuse and landcover is important for understanding the impact of shoreline changes. The land features thus digitized from imagery is then classified based on the NRSC classification schemes. Resourcesat-2 (LISS-IV) data were used to classify the land features and results were validated with field observation at select locations.

3.7 Other Observations

3.7.1 Beach Width

The width of the beach changes continually because beaches are naturally dynamic, and their width can be altered by human activities or natural processes.

Plate 4. Beach during non-monsoon season at Midalam, Tamil Nadu

Plate 5. Beach during monsoon season at Midalam, Tamil Nadu

Measuring the beach width gives indirect evidence about the erosion process at any given coastal sites. In most of the places beaches erode during monsoon season, and again regain in post-monsoon season (Plates 4 & 5). Therefore, understanding of these features is very important to precisely measure the shoreline from satellite images.

3.7.2 Artificial Structures

The major artificial structures adopted for coastal protection are seawalls and groins. The jetties, fishing harbours and ports are constructed at many coastal sites for development purpose. Construction of any structure on the coast naturally causes erosion in the downdrift side and accretion in the updrift side. Extensive field work was carried out for mapping these artificial structures to calculate the shoreline positions precisely (Plates 6 to 8).

Plate 6. Damaged seawall at Thengaipattinam, Tamil Nadu

Plate 7. Pier at Valiathura, Kerala

Plate 8. Seawall at Chellanam, Kerala

3.8 Quality Check

There are several geospatial standards, viz. Natural Resources Information System (NRIS), National Natural Resources Management System (NNRMS), National Spatial Data Infrastructure (NSDI) and National Urban Information System (NUIS), are being used in India. These standards were used for quality check at NCCR in integrated manner to suite our requirement. The broad points are given below:

- NCCR has prepared a Standard Operating Protocol (SOP) to generate shoreline change map at 1:25000 scale.
- Image rectification, shoreline digitization, and map accuracy were followed as per NNRMS standard. The rectification accuracy is maintained within a pixel using 2nd order polynomial method.
- The planimetric shoreline map accuracy was maintained within 1mm in scale at 90% confidence interval and classification accuracy of 90% at 90% confidence interval.
- Considering the uncertainties, shoreline change rate was analyzed using weighted linear regression rate method along with 85% confidence interval (DSAS manual).

3.9 Mapping of Shoreline Change

The results obtained from the analysis of shoreline changes are in the form of numbers i.e., ±m/yr, where + is for accretion, and - is for erosion. These quantitative results are plotted in GIS environment using standard mapping format in 1:25000 scale. However, mapping requires classifications of accretion/erosion rates in sub-classes considering the magnitude of changes. The classification of shoreline changes is further a subjective aspect. We have classified the shoreline change rates into seven classes (Table 4) (Kankara et al., 2014). The marginal change of ±0.5m/yr is considered as no change or stable coast, in view of uncertainties in the data.

Table 4: Shoreline classification schemes used in the analysis

Classification	Rate (m/year)	Colour Schemes
High Erosion	< -5.0	
Moderate Erosion	-5.0 to -3	
Low Erosion	-3.0 to -0.5	
Stable Coast	-0.5 to 0.5	
Low Accretion	0.5 to 3.0	
Moderate Accretion	3.0 to 5.0	
High Accretion	> 5.0	

4. Status of shoreline changes along the Indian coast

4.1 Status of coastal erosion along the Indian mainland

About 6632km long shoreline (in 1:25000 scale) distributed among nine coastal states and two union territories was analyzed for the period 1990-2016 to estimate the shoreline change i.e., erosion, accretion and stable. Coastal erosion has become one of the most alarming threats in varying pockets along the Indian coast. Shoreline length used in the analysis is the shoreface length (excluding the interior parts of river / creeks) obtained from Resourcesat-2, LISS-IV satellite data (by zooming in 1: 15000 scales). The shoreline analysis suggests that 34% of coast is eroding, 28% is accreting and 38% is in stable state (Table 5).

Table 5:Summary of shoreline changes along the Indian coast

Sl No	States		Shoreline used for mapping (in km)*	Status of the coast					
				Erosion		Stable		Accretion	
				km	%	km	%	km	%
1	West Coast	Gujarat, Daman & Diu	1701.78	524.84	31	741.98	43	434.96	26
2		Maharashtra	739.57	178.26	24	472.67	64	88.64	12
3		Goa	139.64	16.82	12	95.58	68	27.24	20
4		Karnataka	313.02	70.02	22	151.16	48	91.84	30
5		Kerala	592.96	263.04	45	201.52	34	128.40	21
6	East Coast	Tamil Nadu	991.47	407.05	41	353.56	36	230.86	23
7		Pondicherry	41.66	23.80	57	14.63	35	3.23	8
8		Andhra Pradesh	1027.58	272.34	27	320.98	31	434.26	42
9		Odisha	549.50	153.80	28	113.52	21	282.18	51
10		West Bengal	534.35	336.52	63	68.78	13	129.05	24
Total			6631.53	2246.49		2534.38		1850.66	
%				34		38		28	

* Length of shoreline estimated from imageries(1:25000 scale) excluding river /creak mouths etc.

The state-wise analysis suggests that in the West Bengal (63%) and Pondicherry (57%) coasts, erosion exceeds more than 50%, followed by Kerala (45%) and Tamil Nadu (41%). Odisha (51%) is the only coastal state which is having more than 50% of accretion, followed by Andhra Pradesh with 42%. Apart from Kerala coast, coasts in other states on the west coast of India fall in stable condition. More than 50% of West Bengal and Pondicherry coasts are under erosion, followed by Kerala (45%) and Tamil Nadu (41%). Odisha is the only coastal state which has more than 50% accretion followed by Andhra Pradesh with 42%. The state-wise details of shoreline change status are given in Tables 6 & 7.

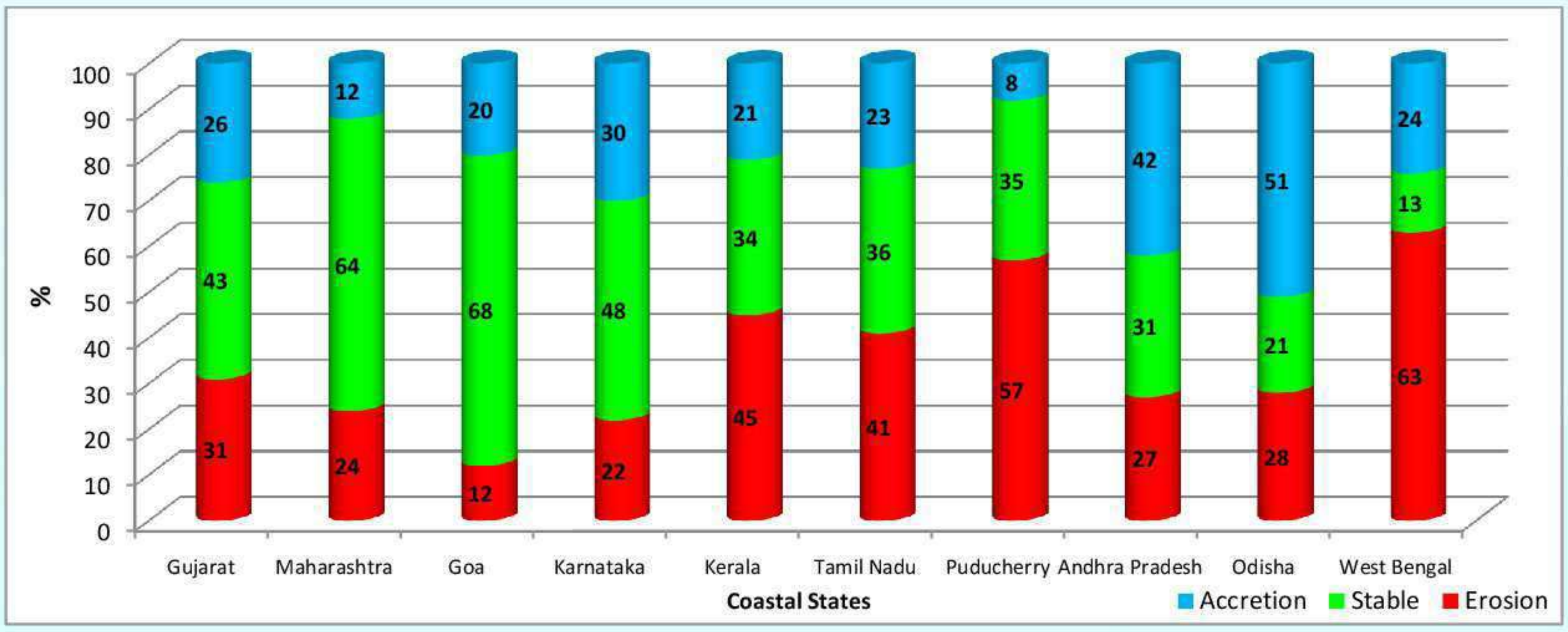


Figure 6: Shoreline change status of Indian coastal states in percentage

Table 6: Erosion-stable-accretion status along the west coast of India

SL No	State	Coast Length (in km)	Coast length (in km)						
			High Erosion	Moderate Erosion	Low Erosion	Stable	Low Accretion	Moderate Accretion	High Accretion
1	Gujarat, Daman and Diu	1701.78	30.96	46.04	447.84	741.98	357.64	50.06	27.26
2	Maharashtra	739.57	2.54	9.38	166.34	472.67	78.22	5.38	5.04
3	Goa	139.64	0.08	1.46	15.28	95.58	23.00	3.52	0.72
4	Karnataka	313.02	2.20	4.46	63.36	151.16	81.64	8.12	2.08
5	Kerala	592.96	5.30	8.98	248.76	201.52	96.50	14.68	17.22
Total		**3486.97**	37.62	74.48	850.82	1662.392	727.44	78.04	56.18
%			1	2	24	48	21	2	2

Table 7: Erosion-stable-accretion status along the east coast of India

SL No	State	Coast Length (in km)	Coast length (in km)						
			High Erosion	Moderate Erosion	Low Erosion	Stable	Low Accretion	Moderate Accretion	High Accretion
1	Tamil Nadu	991.47	14.66	36.65	355.74	353.56	194.27	23.96	12.63
2	Puducherry	41.66	0.00	0.32	23.48	14.63	1.45	1.78	0.00
3	Andhra Pradesh	1027.58	101.50	32.78	138.06	320.98	273.58	67.18	93.50
4	Odisha	549.50	68.26	30.50	55.04	113.52	138.94	45.60	97.64
5	West Bengal	534.35	173.64	51.96	110.92	68.78	56.26	19.80	52.99
Total		**3144.56**	**358.06**	**152.20**	**683.24**	**871.47**	**664.51**	**158.31**	**256.76**
%			11	5	22	28	21	5	8

4.2 Status of land loss and land gain due to shoreline changes

Land loss and gain due to shoreline changes were quantified in square kilometres (sq. km) by geoprocessing shorelines of 1990 and 2016 in GIS environment (Figure 7). The results elucidate significant amount of land either gained or lost during the above time frame. It can be seen that the coastal states of Gujarat, Andhra Pradesh, Odisha and West Bengal have undergone drastic change in the past 26 years. Land gain of greater than 60 sq.km is observed along the states of Gujarat and Odisha. In Andhra Pradesh, Kerala and Tamil Nadu both land gain as well as loss is seen to have occurred simultaneously in significant amounts. Land gain is slightly higher than land loss in Andhra Pradesh and Kerala; however in case of Tamil Nadu it's reverse (land loss is more than gain). States in the Konkan sector along the west coast of India viz., Maharashtra, Goa and Karnataka are seen to exhibit very less changes. Land gain and loss in these states are of the order of 0.55 and 5.84 sq. km respectively. Of all the states maximum land loss is in West Bengal, 99.05 sq. km is seen to have lost by erosion. Over all during 1990 to 2016, about 231.50 sq. km of land is gained by accretion and 234.25 sq. km land is lost by erosion along the Indian mainland.

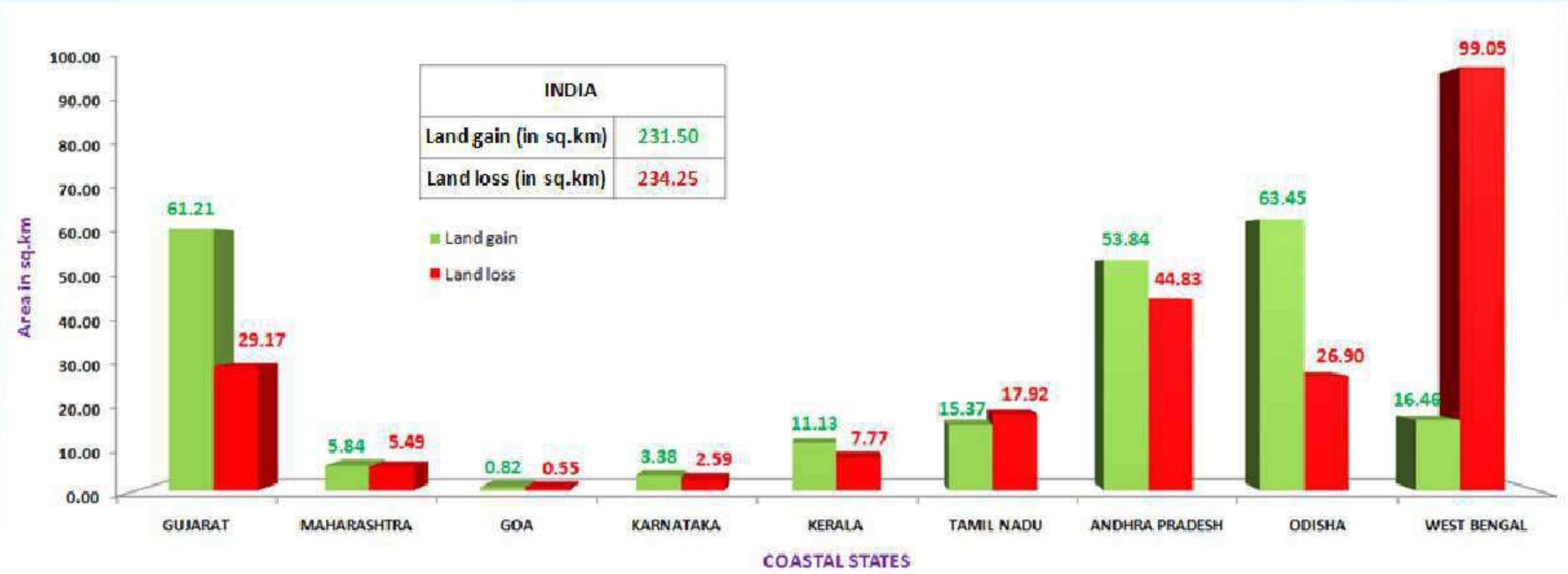


Figure 7: Land loss/land gain distribution along Indian coast.

4.3 List of Shoreline change maps in 1:25000 scale

The shoreline change maps for both long and short term were prepared in 1:25,000 scale and shall be hosted on NCCR website. These maps are being updated every subsequent year. The details state-wise maps are listed in Table 8 and Gird wise information is listed in **Annexture-1**.

Table 8: Total number of 1:25,000 scale maps along the Indian coast

East coast of India		
Sl. No	**State**	**Number of maps(1:25,000)**
1	Tamil Nadu & Puducherry	80
2	Andhra Pradesh	89
3	Odisha	46
4	West Bengal	29
West coast of India		
5	Kerala	55
6	Karnataka & Goa	32
7	Maharashtra	45
8	Gujarat and Daman &Diu	150
Total Numbers		526

Considering the maximum and minimum values of the shoreline change rate, the shoreline is divided into seven categories as low erosion, moderate erosion, high erosion, stable, low accretion, moderate accretion and high accretion (Figure 8). The status of the shoreline change along with infrastructure details, assessment of erosion, locations likely factor of erosion ports, industries, anthropogenic activities, will also be provided the shoreline change maps. The map will be updated every year. The overall distribution of shoreline change rate along the Indian coast for 1990-2016 is shown in Figure 6.

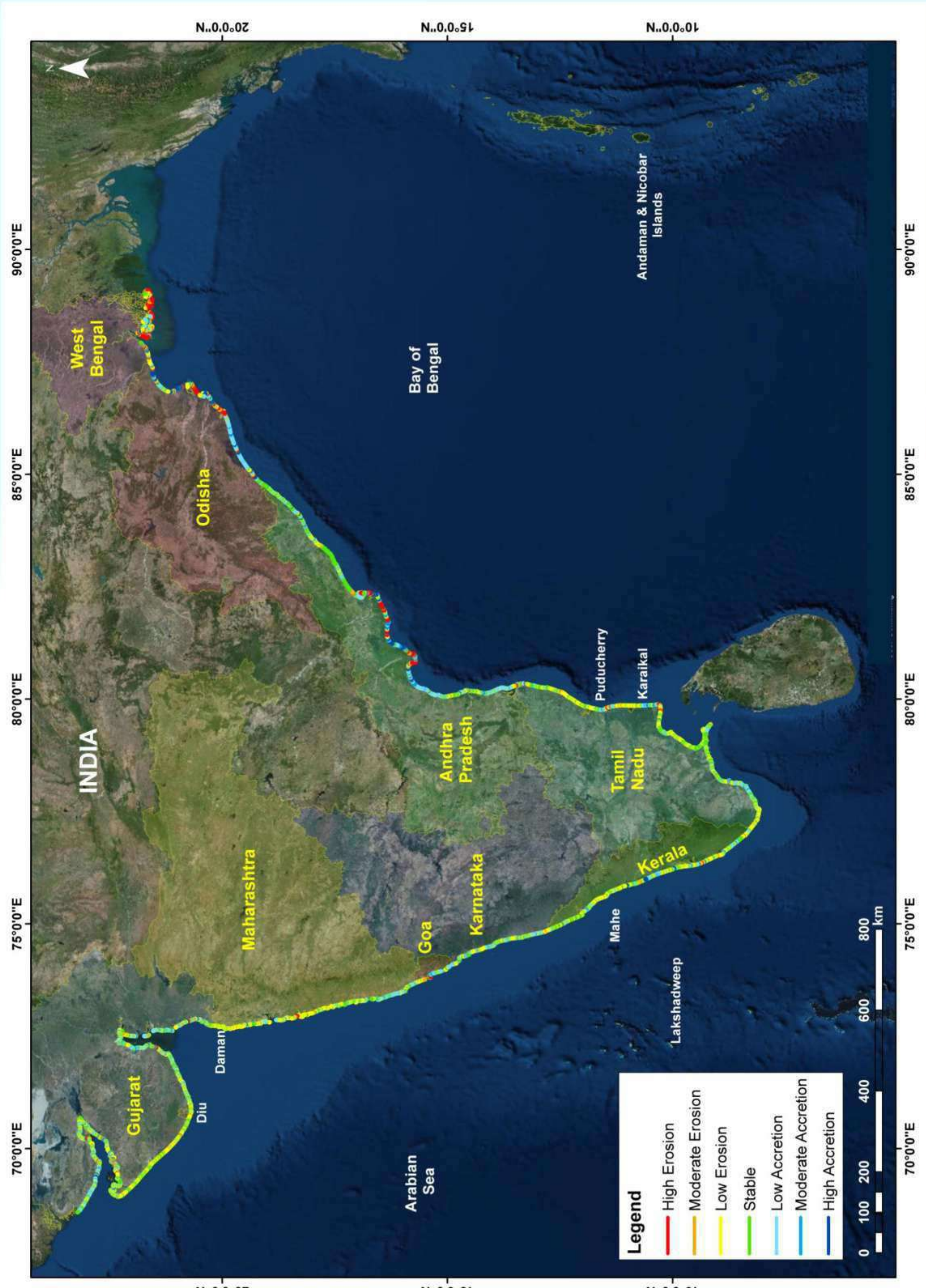


Figure 8: Shoreline change map along Indian coast (1990-2016)

4.3.1 Gujarat, Daman & Diu

The Coastal state of Gujarat is on the western end of Indian peninsula. It is endowed with long coastline of varying geomorphic features, and based on the varied physiographic features, geomorphology, coastal processes and river discharge the coast can be broadly classified into five regions (1) The Rann of Kachchh (2) Gulf of Kachchh (3) The Saurashtra coast (4) Gulf of Khambhat and (5) The south Gujarat coast. The coastlines of the Gulf of Khambhat and Kachchh are tide dominated with tidal mudflats, salt flats, mangroves and salt marshes prevalent all along the stretch. Major rivers like Narmada, Tapti, Mahi and Sabarmati drain into the Gulf of Khambhat to form an estuary. Tidal variation of 8-11m is observed in the coast with strong tidal currents influencing the landforms. Wave dominance can be seen along Saurashtra coast. Sandy beaches, rocky terrace, cliffs, coastal plains and estuary are few of the geomorphic features of the Saurashtra sector. Coral reefs and coral islands in the Gulf of Kachchh are another remarkable aspect of the coast, around 37 species of corals are found here. Human intervention in the form of developments of structure plays a major role in influencing the shoreline change system. Gujarat, because of its strategic location near the Middle East, Africa and Europe is dotted with 49 ports which include 1 major port at Kandla and 48 minor ports. Apart from this, other industrial and developmental activities such as salt industry, cement industry and aquaculture also the landuse and catalyse shoreline changes.

Coastal length of the state constituting 14 coastal districts and 2 union territories is measured to be approximately 1701 km from 2016 satellite imagery. The 1990 to 2016 shoreline change assessment result shows that 43% of the coast is stable, 31% is eroding and remaining 26% is accreting. It is observed that south Gujarat districts of Valsad, Navsari, Bharuch and district of Kachchh exhibit all three (stable, accretion and erosion) conditions.Bhavnagar and Surat coasts are dominated by stable and accretion conditions. Districts of Anand and Ahmedabad in the Gulf of Khambhat are dominated by stable conditions with 57% and 69% of their respective coastal lengths remaining stable. In the Saurashtra sector, viz. Amreli, Girsomnath, Porbandar, DevbhumiDwaraka and Jamnagar, erosion and stable conditions are prevalent. About 66% of Junagadh coast faces erosion. In the case of Union Territory of Daman and Diu are erosion and stable trends are recorded respectively.Erosion hot spots are identified along Bhat, Onjal and Borsri of Navsari district, Bhagwa of Surat and along Degam, Isanpur, Devla and Dhej of Bharuch district. In the Saurashtra sector, erosion is observed along Jaspara,Mithi, Viradi, Thalsar and Gogha of Bhavnagar and in Adri , Navapara of Girsomnath. Regions around Mundra and Kandla, where leading ports operate, are also observed to be eroding. Notable accretion is seen along Nada of Bharuch district and Bhavnagar.

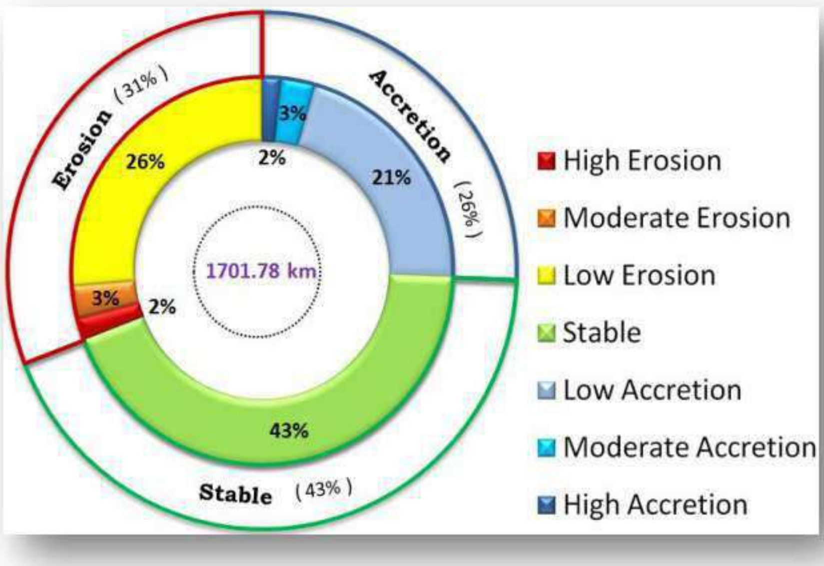


Figure 9: Percentage of shoreline change rate along Gujarat coast.

Table 9: Erosion-stable-accretion status of Gujarat coastal districts

SL No	District	Coast Length (in km)	Coast length (in km)						
			High Erosion	Moderate Erosion	Low Erosion	Stable	Low Accretion	Moderate Accretion	High Accretion
1	Valsad	75.46	2.36	3.90	24.78	25.76	14.34	2.44	1.88
2	Navsari	43.32	1.18	3.86	7.20	18.40	9.38	0.66	2.64
3	Surat	42.48	0.00	0.42	4.82	17.62	13.62	5.40	0.60
4	Bharuch	77.32	1.84	4.54	16.64	29.70	20.96	2.56	1.08
5	Anand	59.88	0.28	1.08	13.12	34.18	9.02	1.52	0.68
6	Ahmedabad	77.52	0.64	0.62	3.00	53.32	17.56	1.34	1.04
7	Bhavnagar	173.66	6.04	3.30	27.92	67.40	56.94	9.30	2.76
8	Amreli	57.00	0.16	0.88	22.40	18.68	14.50	0.34	0.04
9	Gir Somnath	114.40	1.42	2.56	46.70	44.72	17.64	0.92	0.44
10	Junagadh	42.98	0.08	4.64	23.48	11.20	3.48	0.10	0.00
11	Porbandar	112.60	0.02	0.38	52.70	54.70	4.48	0.08	0.24
12	Devbhumi Dwarka	228.60	5.26	6.36	80.40	95.54	35.22	3.14	2.68
13	Jamnagar	177.38	5.22	4.68	34.70	87.60	31.48	8.44	5.26
14	Kachchh	386.64	6.42	7.92	78.38	169.66	103.58	12.76	7.92
15	Diu	18.18	0.00	0.82	9.54	5.96	1.82	0.04	0.00
16	Daman	14.36	0.04	0.08	2.06	7.54	3.62	1.02	0.00
TOTAL		**1701.78**	**30.96**	**46.04**	**447.84**	**741.98**	**357.64**	**50.06**	**27.26**

Figure 10: Shoreline change map of Gujarat coast (1990-2016).

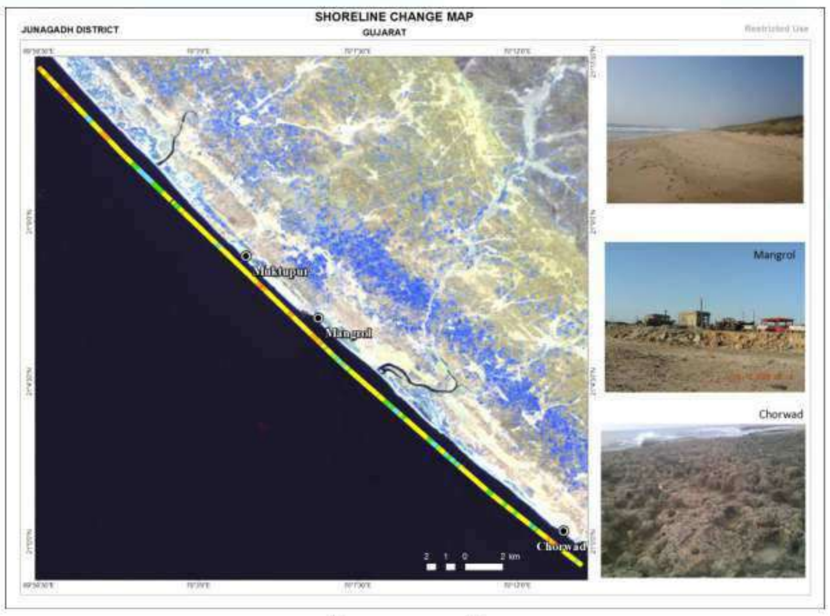
Figure 11: Coastal districts of Gujarat

Kachchh

Jamnagar

Dev Bhumi Dwarka

Porbandar



Junagadh

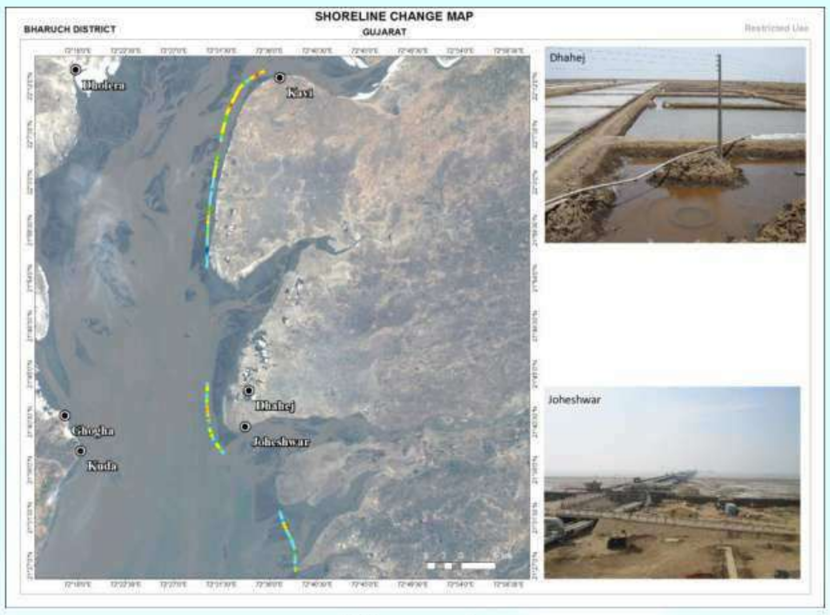
Gir Somnath

Amreli

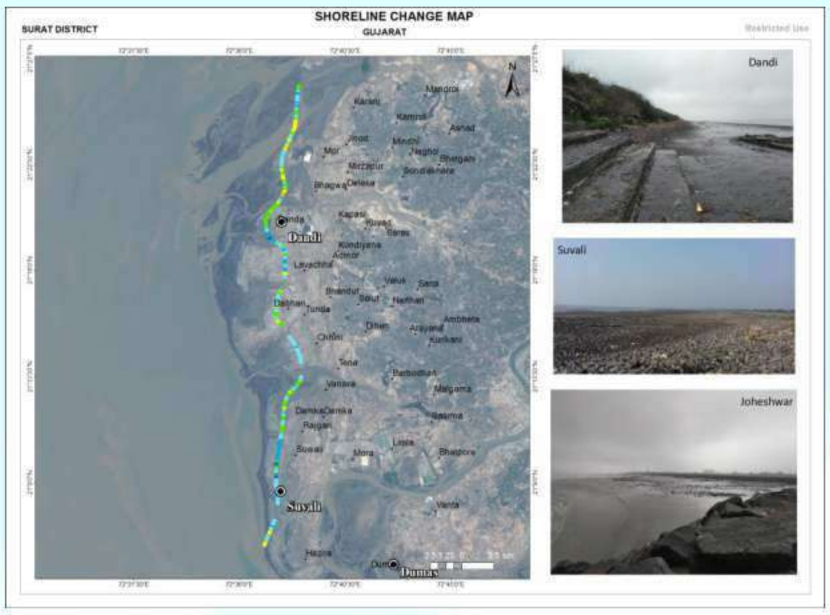
Bhavnagar

Ahmedabad

Anand



Bharuch



Surat

Navsari

Valsad

Diu

Daman

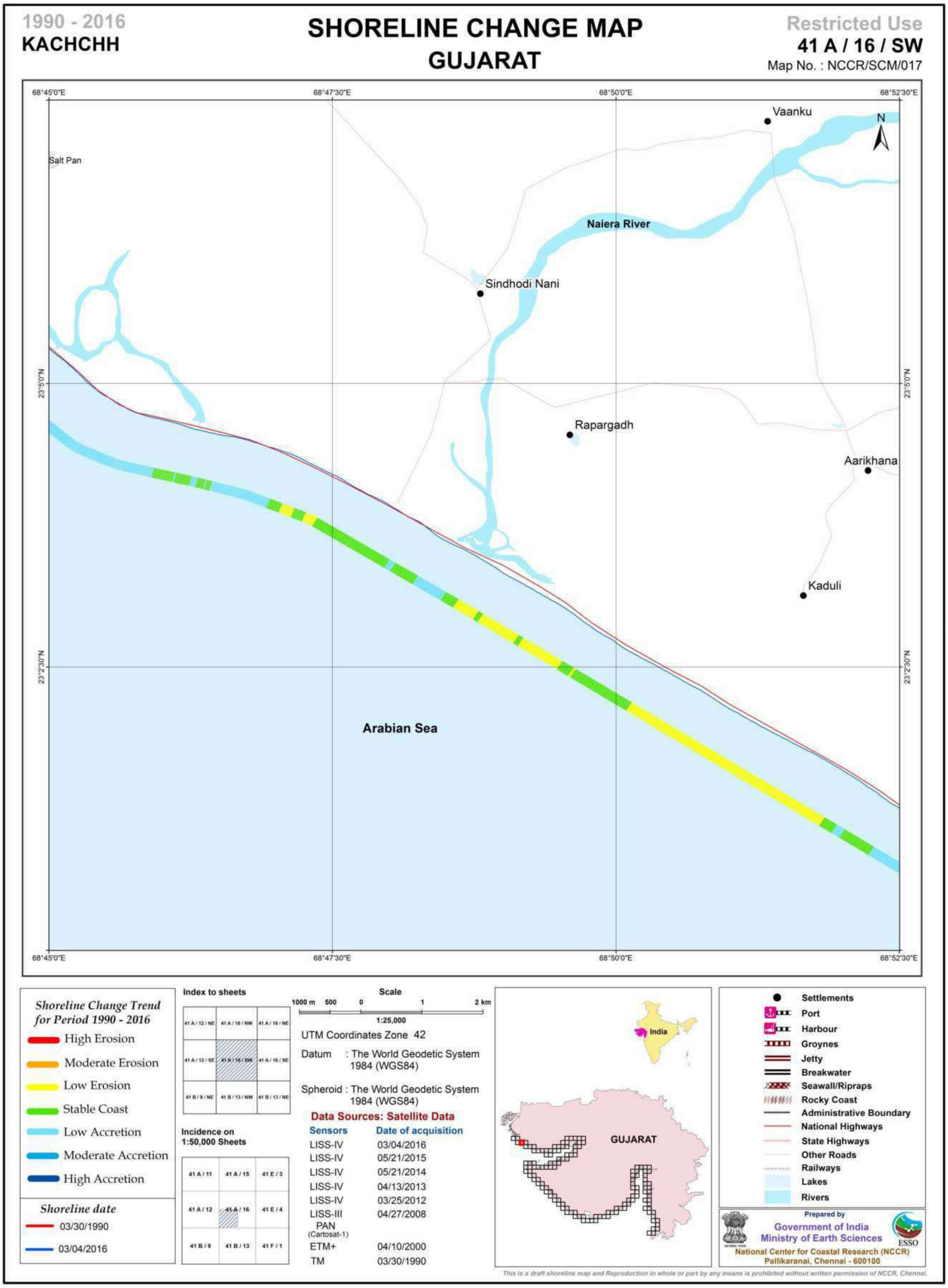


Figure 12: 1:25,000 scale map of Kachchh district, Gujarat.

4.3.2 Maharashtra

The coastline of Maharashtra is more or less N-S oriented and is bound by Arabian Sea in the west and Western Ghats in the east, with narrow coastal tract. Rivers like Terekhol, Karli, Savitri, Vashi, Shastri, Patalganga, Kundalika, Ulhas and Vaitarna and 5 major creeks are reported along the coast. The drainage pattern is parallel to sub parallel structurally controlled by joints and faults. Rocky coast, sandy shores, muddy and mangrove shore are the coastal types prevalent here with the occasional presence of patches of corals in places like Malvan. Rivers, creeks and outcrops from foot hills of Sahyadri highly dissect the coast and contribute to the diversified coastal configuration and beaches along this stretch. The coastal stretch constitutes 7 districts, viz., Sindhudurg, Ratnagiri, Raigad, Mumbai city, Mumbai suburban, Thane and Palghar.

Coastal length of the state is estimated to be approximately 740 km from 2016 satellite imagery. Shoreline change analysis carried out along the 740 km of coast from 1990-2016 elucidates that around 24% of the coast is eroding, 12% is accreting and 64% remains in stable condition. It is seen that Sindhudurg, Ratnagiri and Raigad districts of the state is dominated by stable coast with a few pockets of low erosion and accretion. Upon moving north of Thane creek, from Mumbai to northern end of the state in Thane district, erosion is evident. Coastal protection measures taken in the form of ripraps, seawall etc., can be observed along the districts of Palghar, Thane and Mumbai.

Accretion is observed along Malvan, Tarkarli, Gad River, Girye, Devgad, Undi, Ambolagad, Velas, Revadanda, Alibag, Akshi and Aksa regions. Above mentioned places are seen to accrete naturally. Artificial land reclamation of 20.23 ha is observed north of Mahim bay in Mumbai. Rocky coast of the state constitutes to about 331.08 km, which remains in stable condition. Coast of Shiroda and Anjarle are also found to exhibit stable condition. Beach in Arvai, Vengurla, Mirya, Velshwar, Dabhol, Murud, Shrivarshan, Diveaga, Kihim, Erangal, Manori, Gorai, Bordi, Kelva&Shrigaon are observed with erosion.

Table 10: Erosion-stable-accretion status of Maharashtra coastal districts

SL No	District	Coast Length (in km)	Coast length (in km)						
			High Erosion	Moderate Erosion	Low Erosion	Stable	Low Accretion	Moderate Accretion	High Accretion
1	Sindhudurg	137.02	0.04	0.20	6.50	82.00	46.88	1.02	0.38
2	Ratnagiri	258.93	0.78	1.08	36.32	203.39	15.80	0.82	0.74
3	Raigad	134.83	0.58	2.90	42.98	81.73	5.16	0.70	0.78
4	Mumbai city	41.02	0.00	0.00	1.34	38.36	1.32	0.00	0.00
5	Mumbai suburban	41.15	0.02	0.22	17.54	18.77	2.78	0.58	1.24
6	Palghar &Thane	126.64	1.12	4.98	61.66	48.44	6.28	2.26	1.90
TOTAL		**739.57**	**2.54**	**9.38**	**166.34**	**472.67**	**78.22**	**5.38**	**5.04**

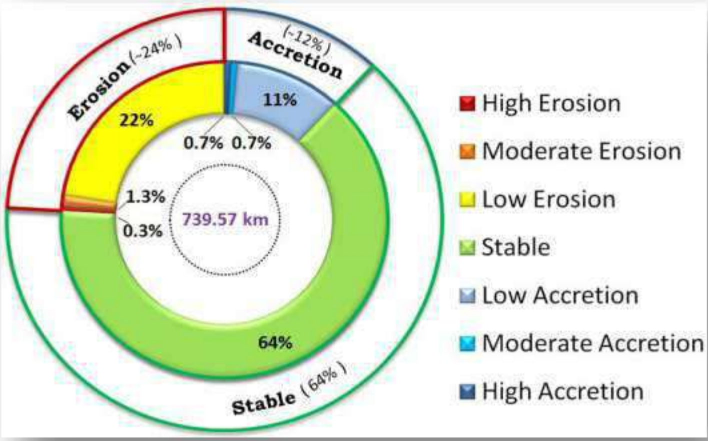


Figure 13: Percentage of shoreline change rate along Maharashtra coast.

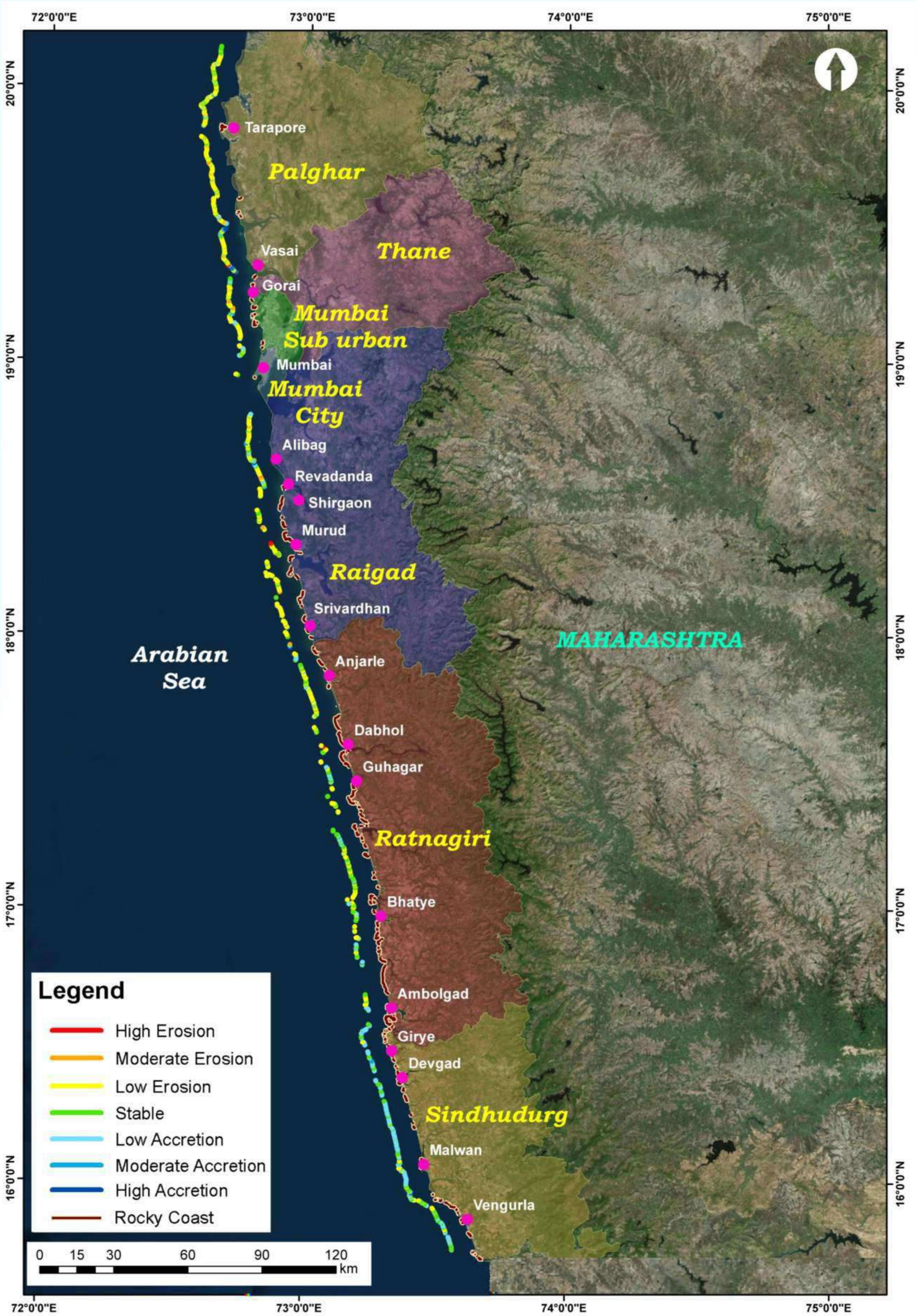


Figure 14: Shoreline change map of Maharashtra coast (1990-2016).

Figure 15: Coastal district of Maharashtra

Palghar and Thane

Mumbai city

Mumbai suburban

Raigad

Ratnagiri

Sindhudurg

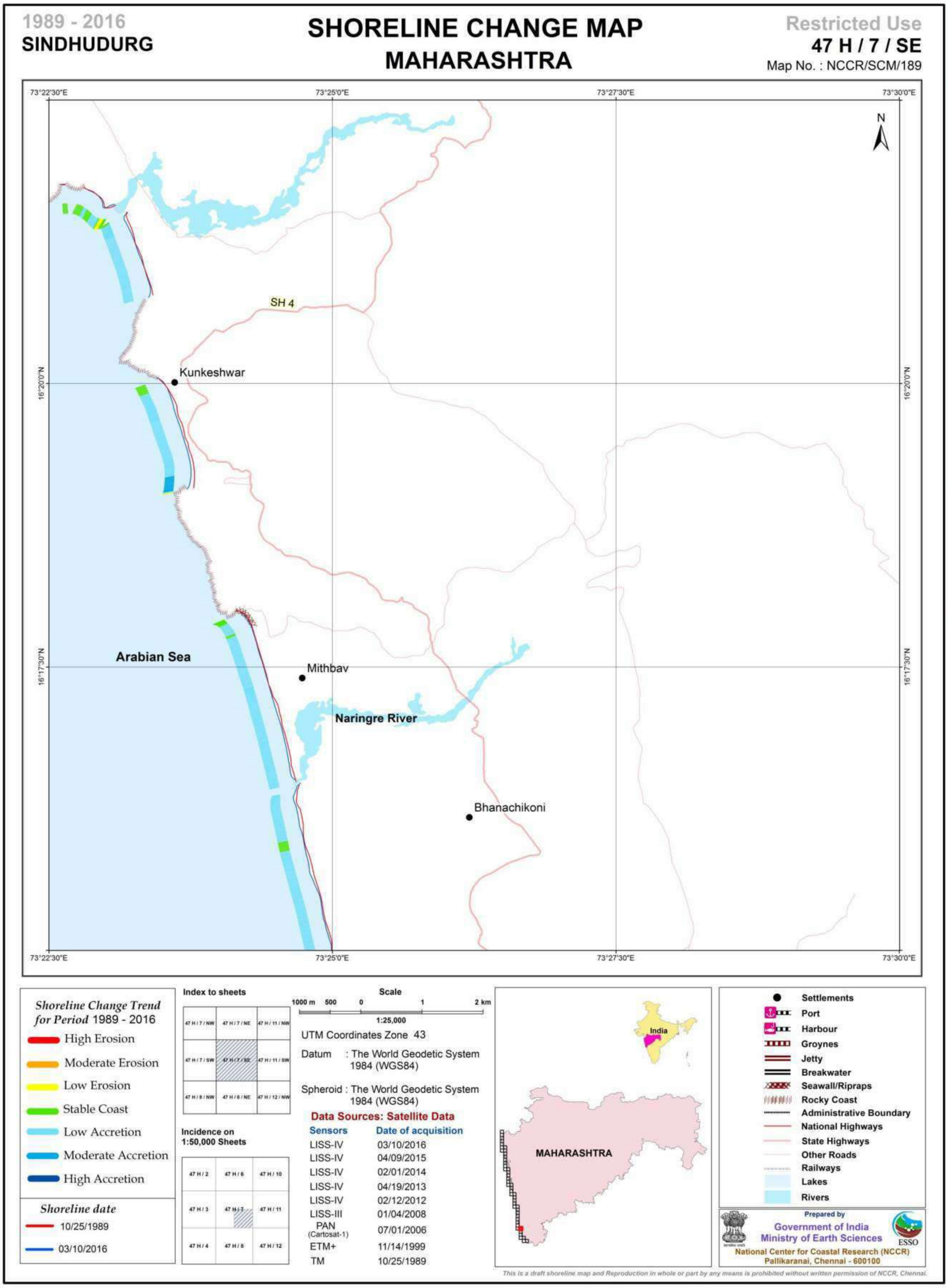


Figure 16: 1:25,000 scale map of Sindhudurgdistrict, Maharashtra.

4.3.3 Goa

Geomorphologically the coast of Goa can be divided into three sections - long, linear and wide beaches of north, central bay area around Aguada & Mormagao and rocky cliff with pocket beaches of south. Zuari, Mandovi, Chapora, Talpona and Galgibag are a few of the important rivers flowing through the state. These rivers drain into Arabian Sea forming estuary at their mouth region. About 12 species of mangroves are found along the estuaries in the state. Morjim beach found north of Chaporariver is nesting site of endangered olive ridley sea turtles. Picturesque beaches along the coast attract international tourists and promote economy of the coastal belt through tourism. Port in Mormagao bay of the state is one of the biggest natural ports of south Asia.

Coast length of Goa is about 140 km as measured from 2016 satellite imagery. Shoreline analysis of the state from 1990 - 2016 shows that around 68% of the coast is in stable condition, 20% is accreting and 12% is eroding. The coast of North Goa district is stable with a few pockets of erosion and accretion regions. It's observed that 29% of North Goa district is eroding. South Goa is also dominated by stable coast with about 20% of the coast showing accretion. Major portion of the Goa coast which comes under stable category constitutes rocky cliff, headlands and promontories of basaltic origin which are resistant to wave action. Headlands and promontories occurring in the stretch play an important role in controlling the morphology of the beach adjacent to them. Sediments along the pocket beaches get circulated within the headland, bounding their ends depending on season.

InFigure 18, we find that accretion is observed in Majorda, Velsao, Arossim, Utorda, Colva, Morbor, Betul regions of South Goa and northern part of Calangute beach, northern bank of Chapora river and along coastal stretch from Harmal to Mandrem of North Goa. Erosion is seen in the coast of Keri, Vagotor, southern part of Calangute, Mandrem to Morjim, Candolim in North Goa and Palolem, Talpona, north of Galgibaga and region from Varca to Cavelossim in South Goa.

Table 11: Erosion-stable-accretion status of Goa coastal districts

SL No	District	Coast Length (in km)	Coast length (in km)						
			High Erosion	Moderate Erosion	Low Erosion	Stable	Low Accretion	Moderate Accretion	High Accretion
1	North Goa	36.40	0.06	1.36	9.18	19.46	6.08	0.22	0.04
2	South Goa	103.24	0.02	0.10	6.10	76.12	16.92	3.30	0.68
TOTAL		**139.64**	**0.08**	**1.46**	**15.28**	**95.58**	**23.00**	**3.52**	**0.72**

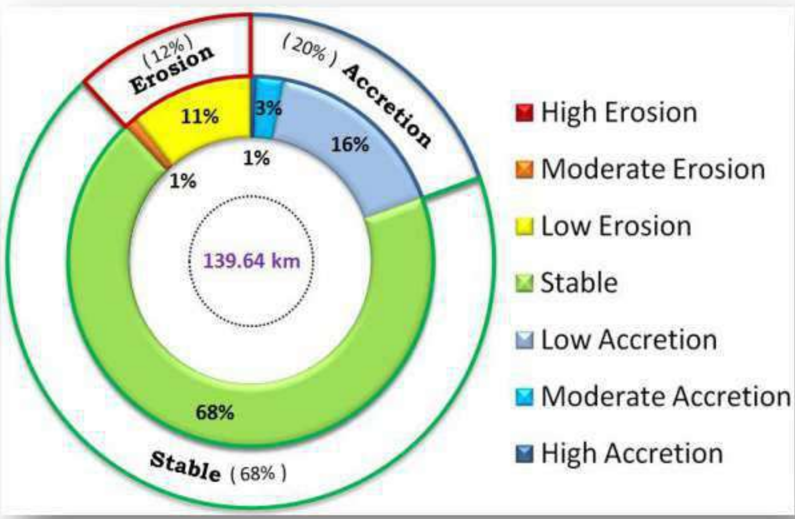


Figure 17: Percentage of shoreline change rate along Goa coast.

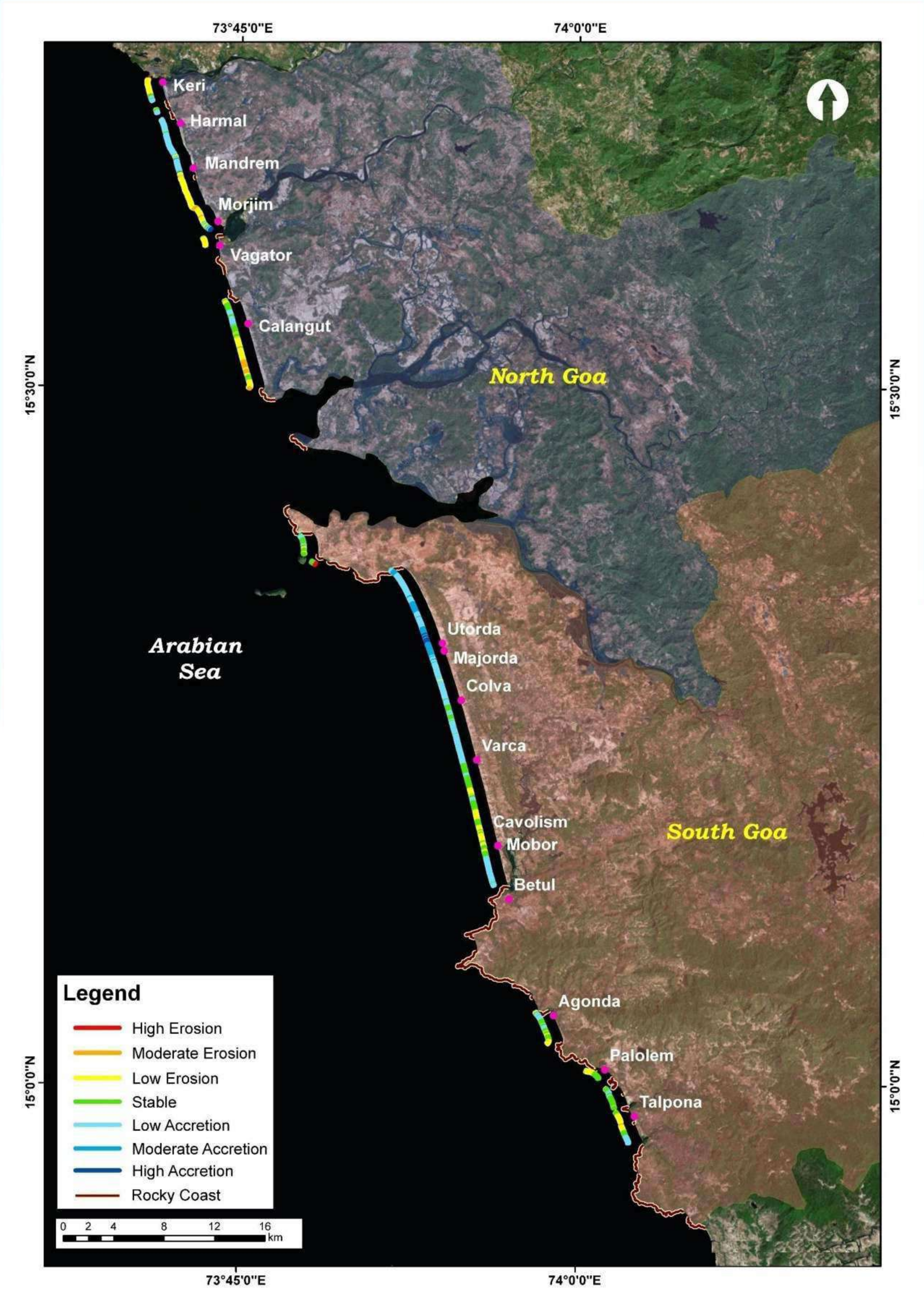
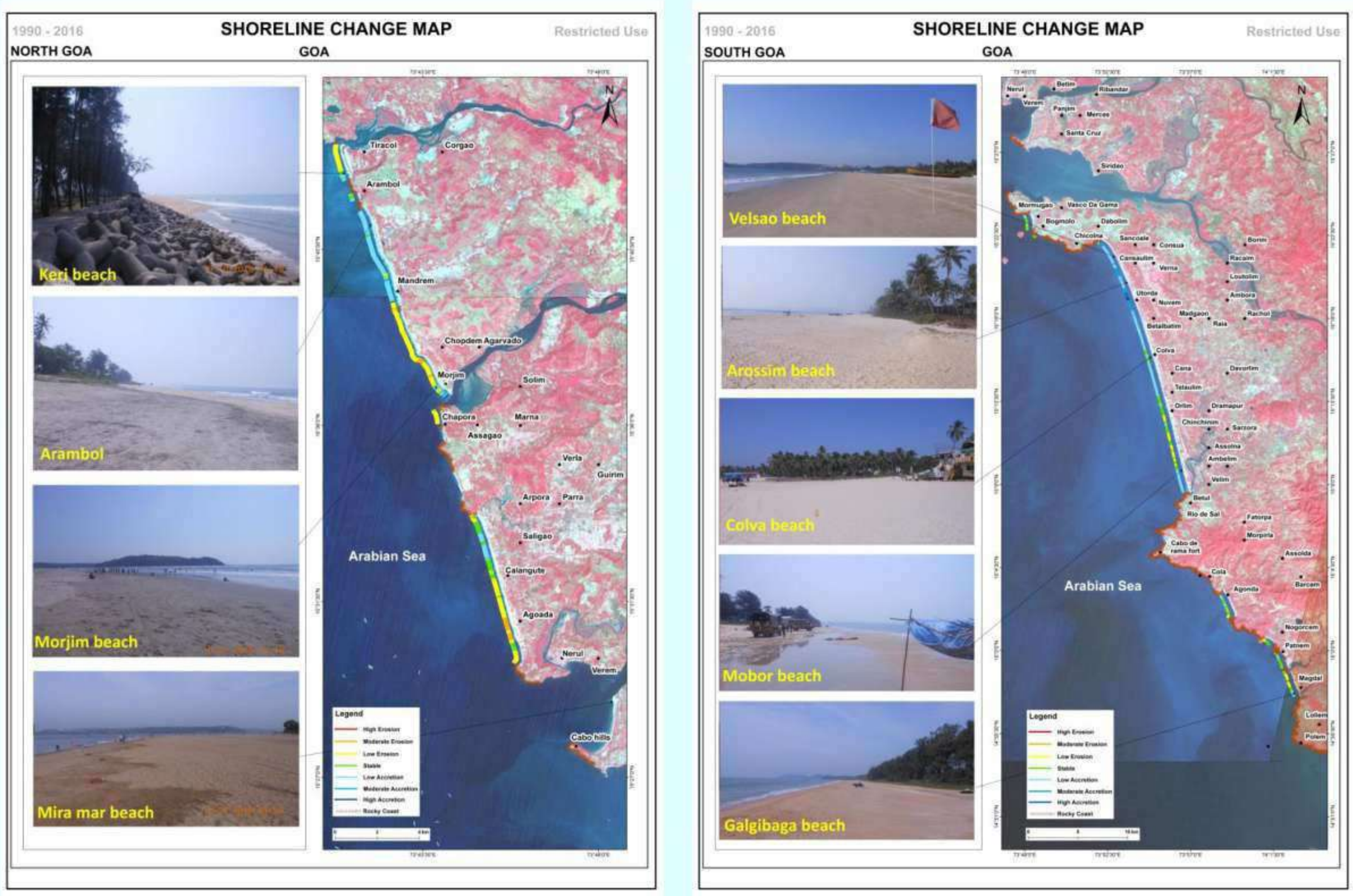
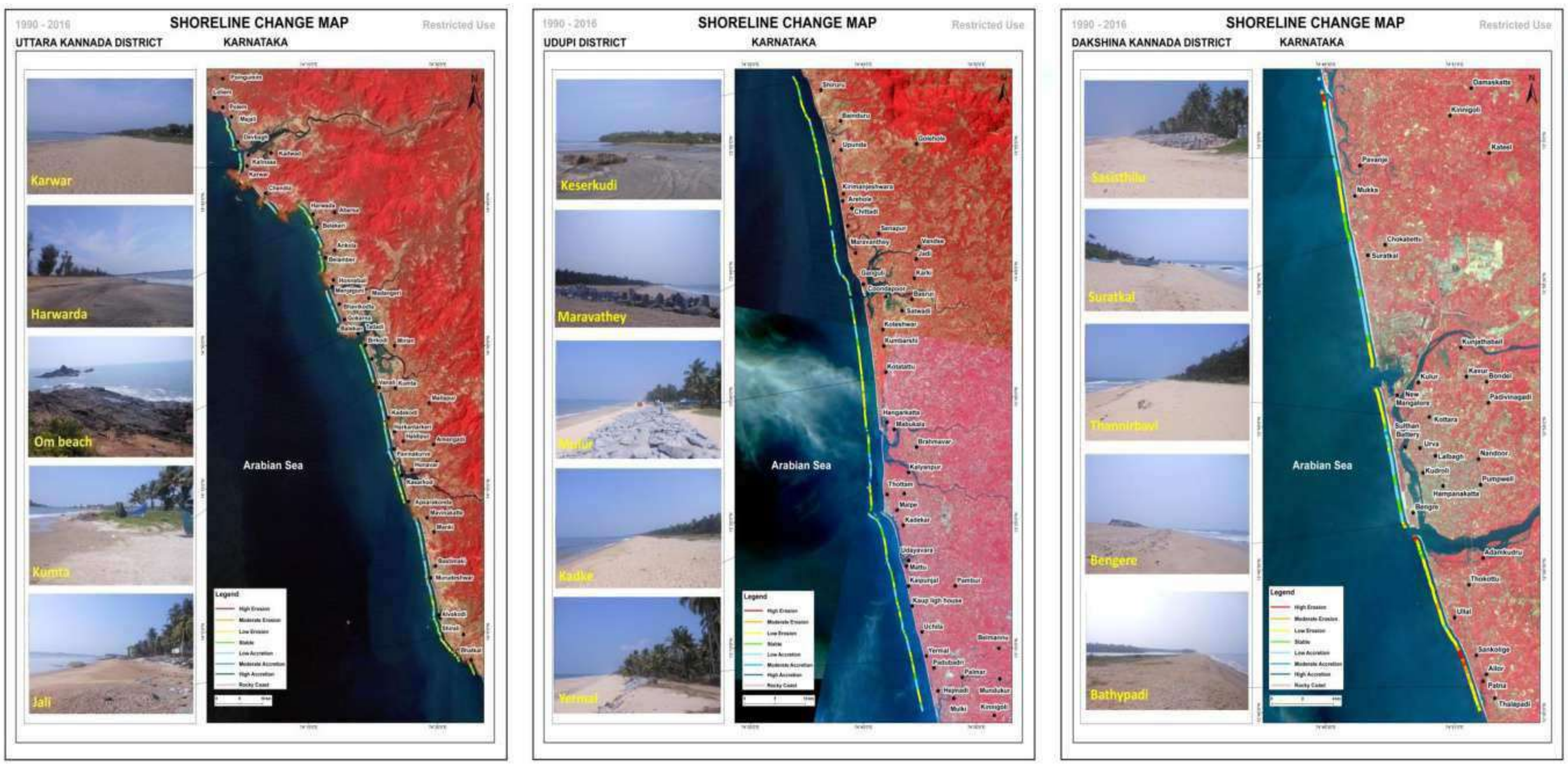


Figure 18: Shoreline change map of Goa coast (1990-2016).



North Goa **South Goa**

Figure 19: Coastal district of Goa



Uttara Kannada **Udupi** **DakshinaKannada**

Figure 20: Coastal district of Karnataka

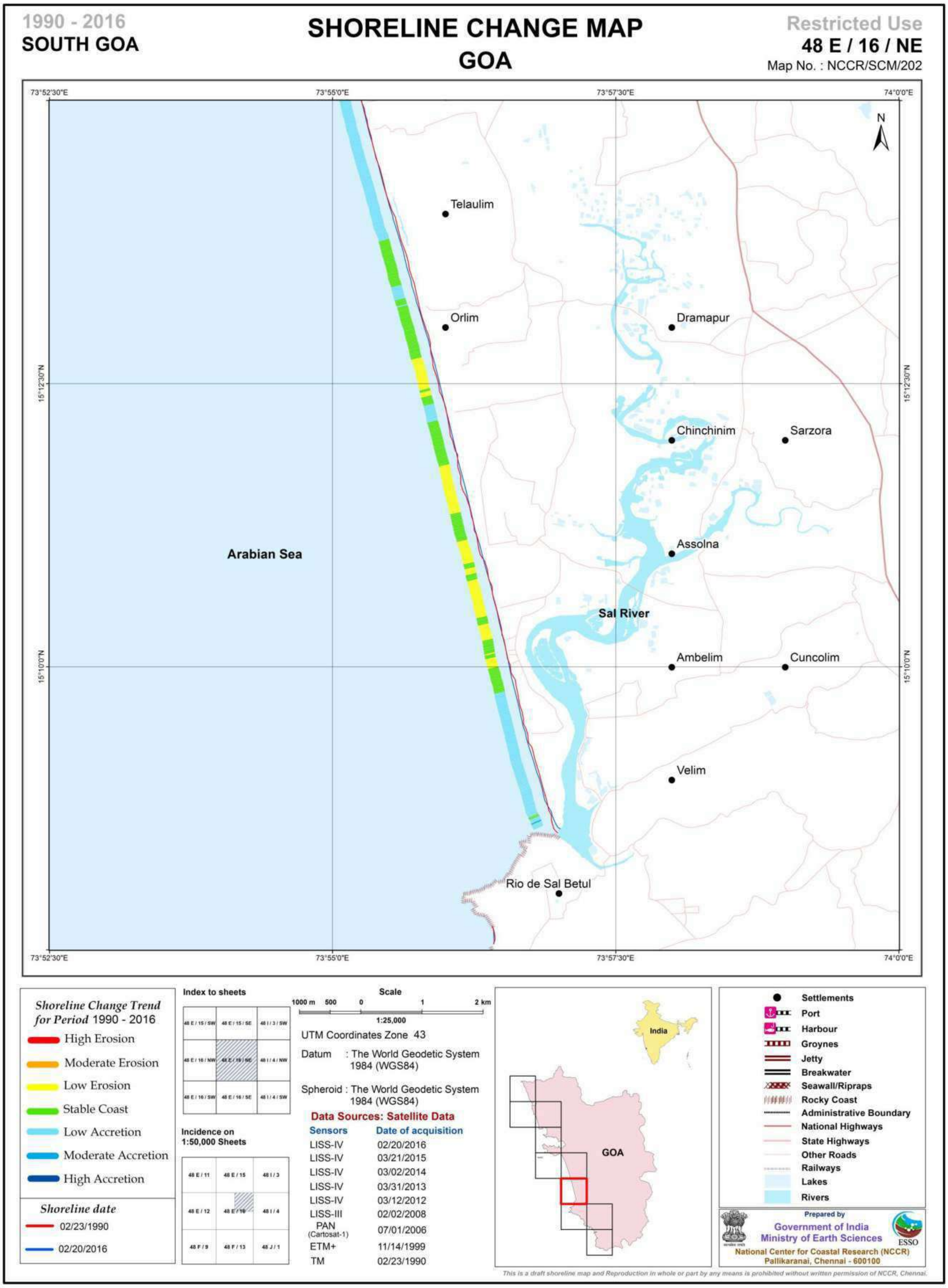


Figure 21: 1:25,000 scale map of South Goa district, Goa.

4.3.4 Karnataka

The coastal plain of the state is narrow, except at estuaries. Netravati and Sharavathi are the major west flowing rivers in the region. Rocky headlands, promontories and sea cliff are present along the northern part of the state with the prevalence of pocket beaches. Long, narrow and straight beaches are observed in the central and southern parts of the state (eg. Suratkal, Panamburu and near Coondapur). Estuaries, spit, shallow lagoons and mudflats are some of the geomorphic features found on the coast. Patches of Mangroves are present along the estuaries of Mulki, Sita, Kali, Swarna, Chakra, Haldi, Kolluru and Agnashani. Major port at New Mangalore and 10 other minor ports in Belkeri, Tadadi, Honnavar, Bhatkal, Malpe, Kundapura, Hangarakatta and Padubidricontribute to the economy of the coastal districts. Sand mining, petrochemical, fertilizer and allied industries are seen along the coast.

The coastal length of the state is about 313 km as estimated from 2016 satellite imagery. Shoreline analysis of the coast from 1990-2016 shows that 30% of the coast is accreting and 22% is eroding and 48% in stable state. It is observed that 45% of Dakshina Kannada district is relatively affected by erosion and Uttara Kannada is dominated by stable condition with a few pockets of erosion and accretion. Stable and erosion conditions are prevalent along the Udupi coast with a few sectors of accretion.

Eroding coastal stretches are Mukka, Ullal, Thalapadi, north of Thannirbavi and Bathypadi in Dakshina Kannada District and Malpe, Mulur, Yermal, Kirimanjeshwara, Hejmadi, Pithrody, Kinara, Maravathey, Koravadi and Kaipunjal regions of Udupi. Though Uttara Kannada District of the state is dominated by low accretion and stable coast, erosion is observed in Apsarakonda, Harwarda, Kasarkod and about 11 km from Keserkudi to Jali. Accretion is observed along Bengere, south of Thannirbavi and Chitrapura in the southern end of the state and along Kadke, Udyavara and Beejadi in Udupi district. Regions of Murudeshwar, Pavinakurve, Gokarna, Majali, Devbag and Karwar beaches are observed to exhibit accretion.

Table 12: Erosion-stable-accretion status of Karnataka coastal districts

SL No	District	Coast Length (in Km)	Coast length (in Km)						
			High Erosion	Moderate Erosion	Low Erosion	Stable	Low Accretion	Moderate Accretion	High Accretion
1	Dakshinna Kannada	36.66	1.08	2.36	13.18	7.72	12.08	0.22	0.02
2	Udupi	100.71	0.32	0.98	34.92	35.69	25.44	2.36	1.00
3	Uttara Kannada	175.65	0.80	1.12	15.26	107.75	44.12	5.54	1.06
TOTAL		**313.02**	**2.20**	**4.46**	**63.36**	**151.16**	**81.64**	**8.12**	**2.08**

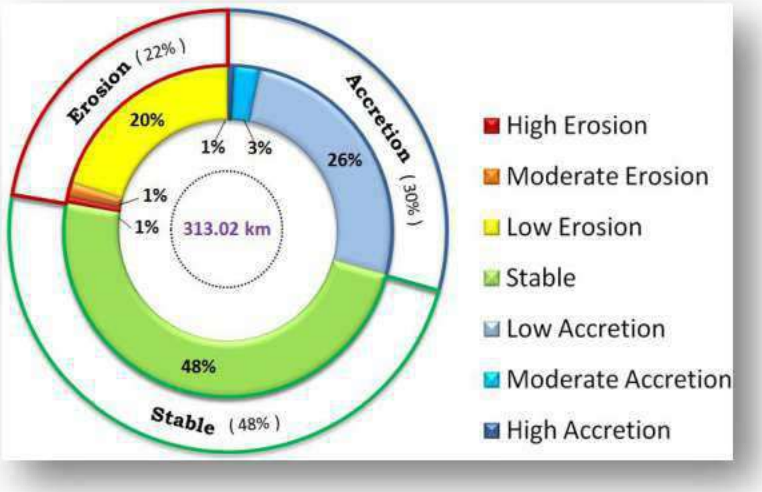


Figure 22: Percentage of shoreline change rate along Karnataka coast.

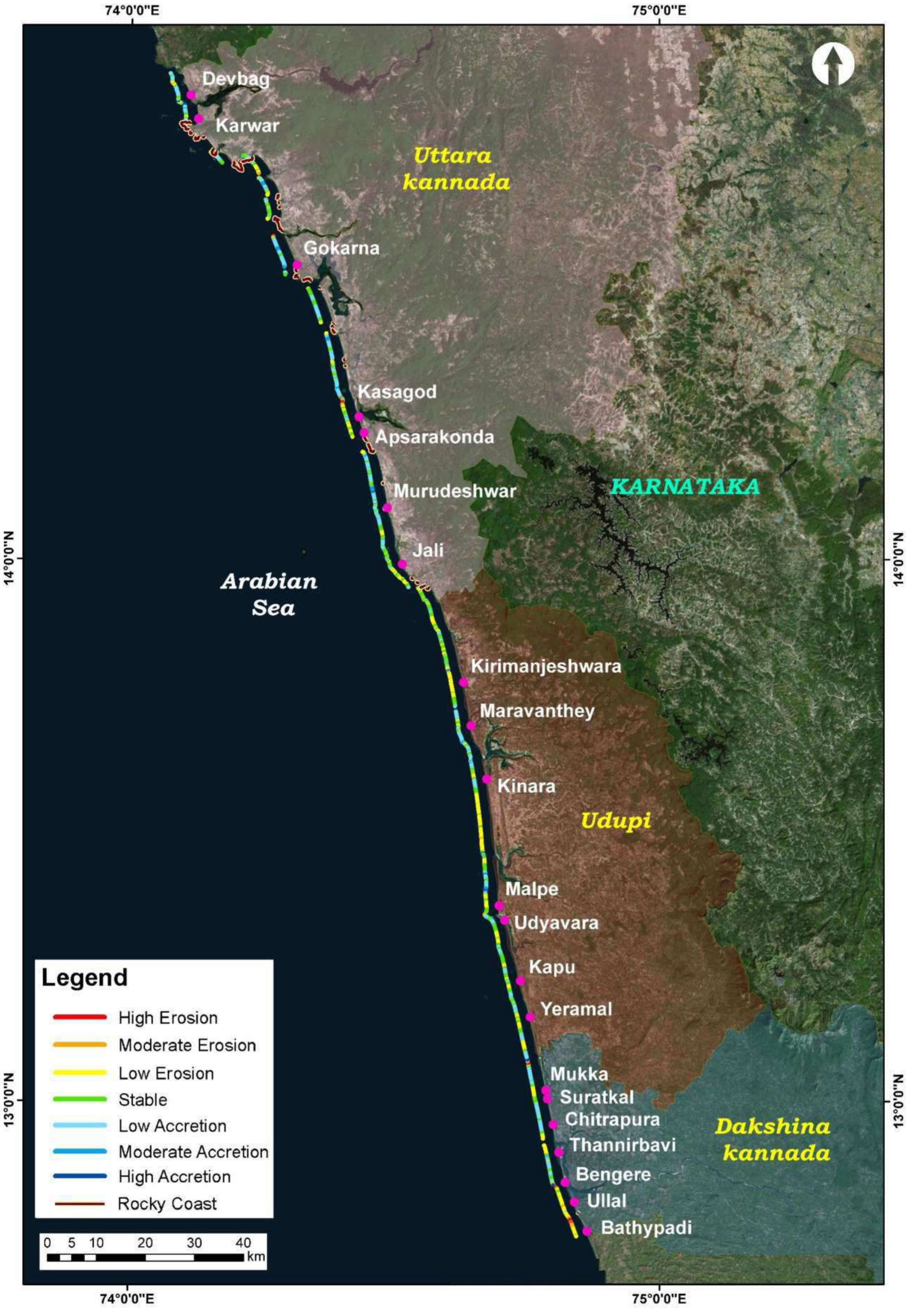


Figure 23: Shoreline change map of Karnataka coast (1990-2016).

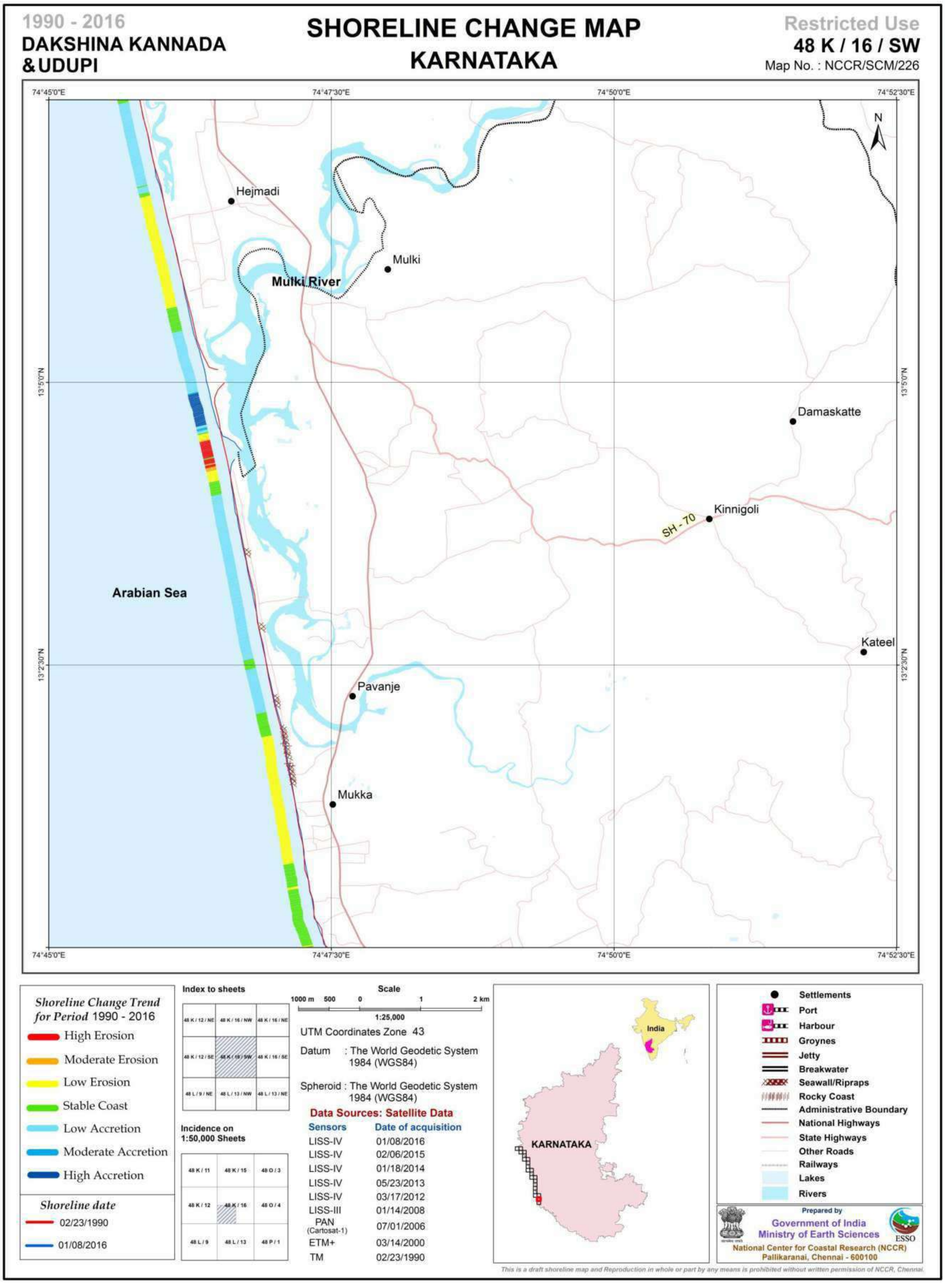


Figure 24: 1:25,000 scale map of Dakshina Kannada and Udupidistrict, Karnataka.

4.3.5 Kerala

The coastal state of Kerala is in the southern end of Indian peninsula, with its low lying coastal plain fringing into the Lakshadweep Sea. The coastline is generally straight trending NNW-SSE with minor variations. Physiographically the state can be divided in to three sections viz., 1) Coastal plains 2) Laterite plateaus of midland and 3) Highland - Western Ghats. The width of the coastal plain varies from 5-29 km, with the maximum width observed at Cherthala. In many places like Bekal, Ezhimala, Azhikode and Kadalur of north Kerala and Vizhinjam, Varkala and Tangasseri of south Kerala coastal plain is void with rocky laterite midlands extending up-to the shoreline. These promontories, along with 41 east flowing rivers of the state make the shoreline discontinuous. Periyar, Bharathapuzha and Pamba are a few of the prominent west flowing rivers while Kabini, Bhavani and Pambar are the only east flowing rivers of the region. The west flowing rivers originating from western ghats drain into either backwater system or Arabian Sea. The state has one of the largest backwater networks in the country with Vambanad being the largest backwater lake in that network. Water way transport being operated in these backwaters attract many tourists and thereby add economic dimension to the coast. Landforms such as beach, lagoons, barrier islands, beach ridges, paleo strandlines, alluvial plains, marshy plains, spits, mangroves and islands locally called as *'thuruths'* are observed along the coast. Dharmadam Island seen north of Kerala has mangrove vegetation. Another striking feature of the coast is high population density of the narrow coastal belt. This has aggravated human interference in shoreline change system. Construction of structures such as fishing harbours, ports, groins, seawall and beach sand mining for monazite ores has highly altered the nature of coastline and induced changes.

9 coastal districts from Kasaragod in the north to Thiruvananthapuram in the south attribute the coast belt of the state. The coastal length is measured to be approximately 592 km from 2016 satellite imagery. Shoreline change analysis carried out for a span of 26 years (1990-2016) indicates that 45% of the coast is eroding, 34% is stable and 21% is accreting. Further,it may be seen fromTable 13, that the coasts of Kasaragod, Kannur, Malappuram, Ernakulam and Kollam are dominated by both erosion and stable condition with a few pockets of accretion. The only district showing accretion trend is Thrissur, about 50% of its length shows accretion. As far as Thiruvananthapuram is concerned erosion, accretion and stable conditions are observed in equal amounts.

Table 13: Erosion-stable-accretion status of Kerala coast.

SL No	District	Coast Length (in km)	Coast length (in km)						
			High Erosion	Moderate Erosion	Low Erosion	Stable	Low Accretion	Moderate Accretion	High Accretion
1	Kasaragod	83.60	0.02	0.18	28.48	40.20	12.64	0.44	1.64
2	Kannur	69.05	0.04	0.14	28.04	27.85	9.92	2.60	0.46
3	Kozhikkode	78.03	0.46	0.84	47.56	24.93	3.74	0.24	0.26
4	Malappuram	50.85	0.22	1.06	23.70	18.45	7.10	0.18	0.14
5	Thrissur	61.50	0.00	0.34	17.58	12.76	18.72	6.08	6.02
6	Ernakulam	45.04	0.00	0.30	20.80	16.76	3.32	0.72	3.14
7	Alappuzha	83.56	2.12	5.08	40.66	15.84	13.08	2.68	4.10
8	Kollam	45.72	1.64	0.20	16.88	19.42	6.52	0.30	0.76
9	Thiruvananthapuram	75.61	0.80	0.84	25.06	25.31	21.46	1.44	0.70
TOTAL		**592.96**	**5.30**	**8.98**	**248.76**	**201.52**	**96.50**	**14.68**	**17.22**

Noticeable erosion is seen at Kappil, Mahe, southPonnani, Veliancode (Puthuponnani), Thannithura, Ramanthali, Choottad, Chombala, Kolavipalam, Pakkayil, Moodai, Chettikulam, Kappad, Calicut, Thekkepuram, Kozhikode, Beypore, Cherai (Vypin), Kuzhupilly, Anyail, Narakkal, Malippuram, Kannamaly, Thalakadavu, Chellanam fishing harbor, kodamthuruth and Kochi port to Chellanam (Figure 10). Whereas coastal belts of Kanhangad, Valiyaparamba, Trikannad, Bekal, Mattool, Azheekkal, Meenkunnuchal, Kadikkad, Chavakkad, Nakshatra, Samithi, Mararikulam to Chethy, Kackary to Ayiramthai, Chavara, Anjuthengu, Perumathura, Pallithura and Veli are noticed with accretion.

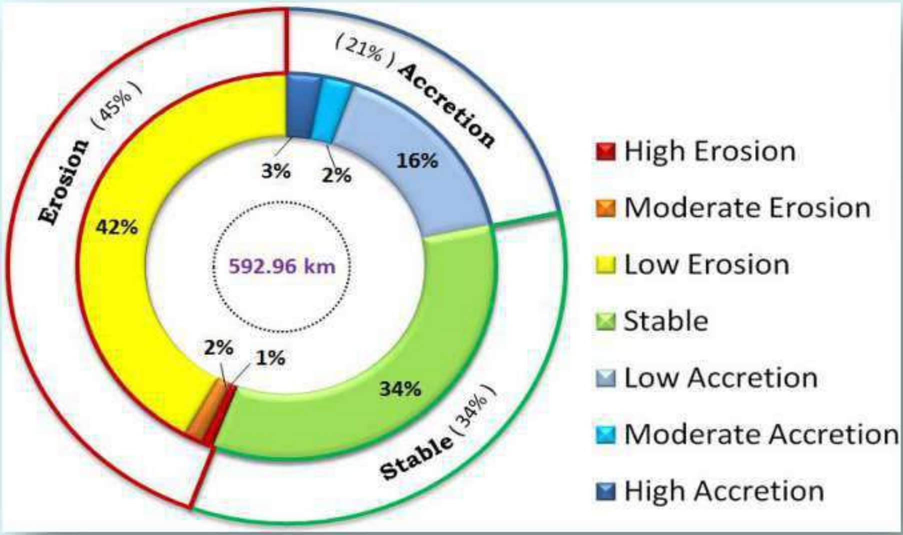


Figure 25: Percentage of shoreline change rate along Kerala coast.

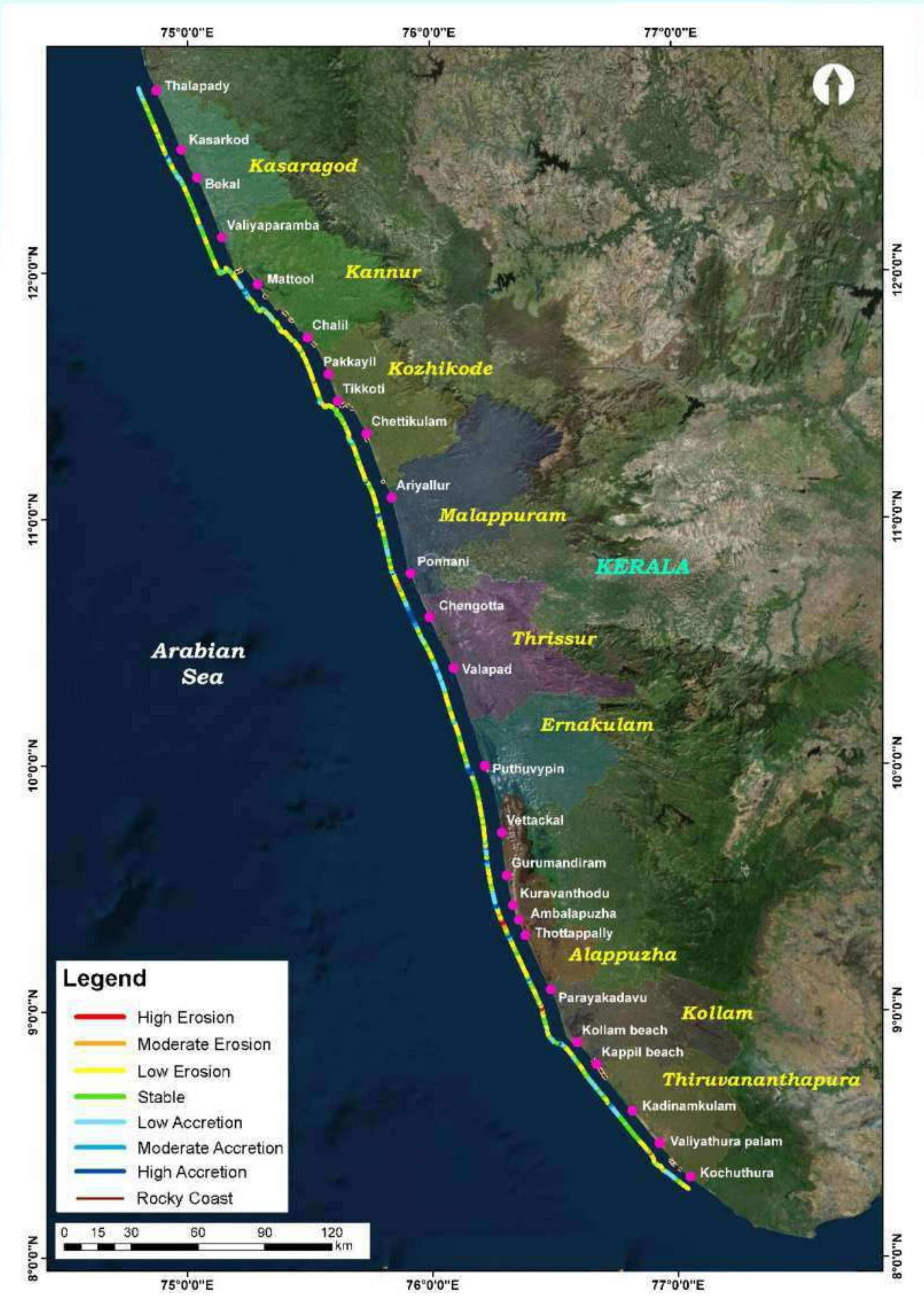


Figure 26: Shoreline change map of Kerala coast (1990-2016).

Figure 27: Coastal districts of Kerala

Kasaragod

Kannur

Kozhikode

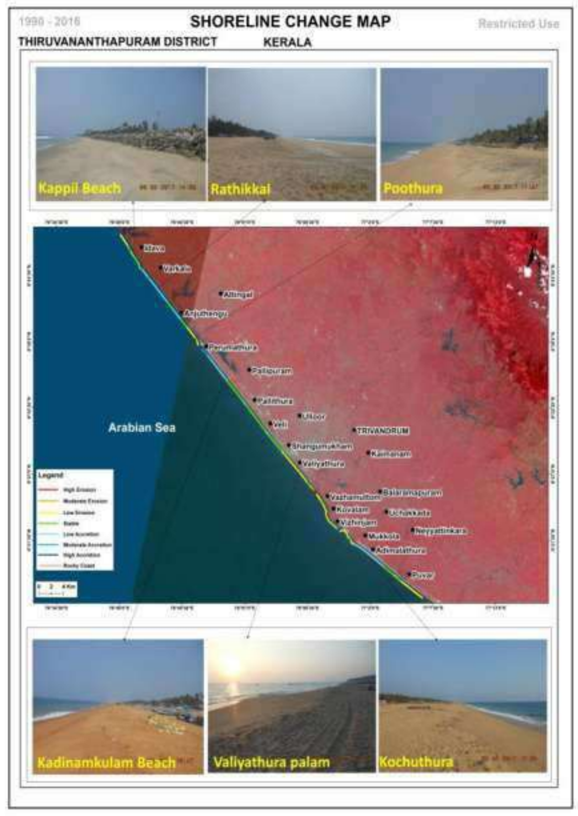
Malappuram

Thirissur

Ernakulam

Alappuzha

Kollam



Thiruvananthapuram

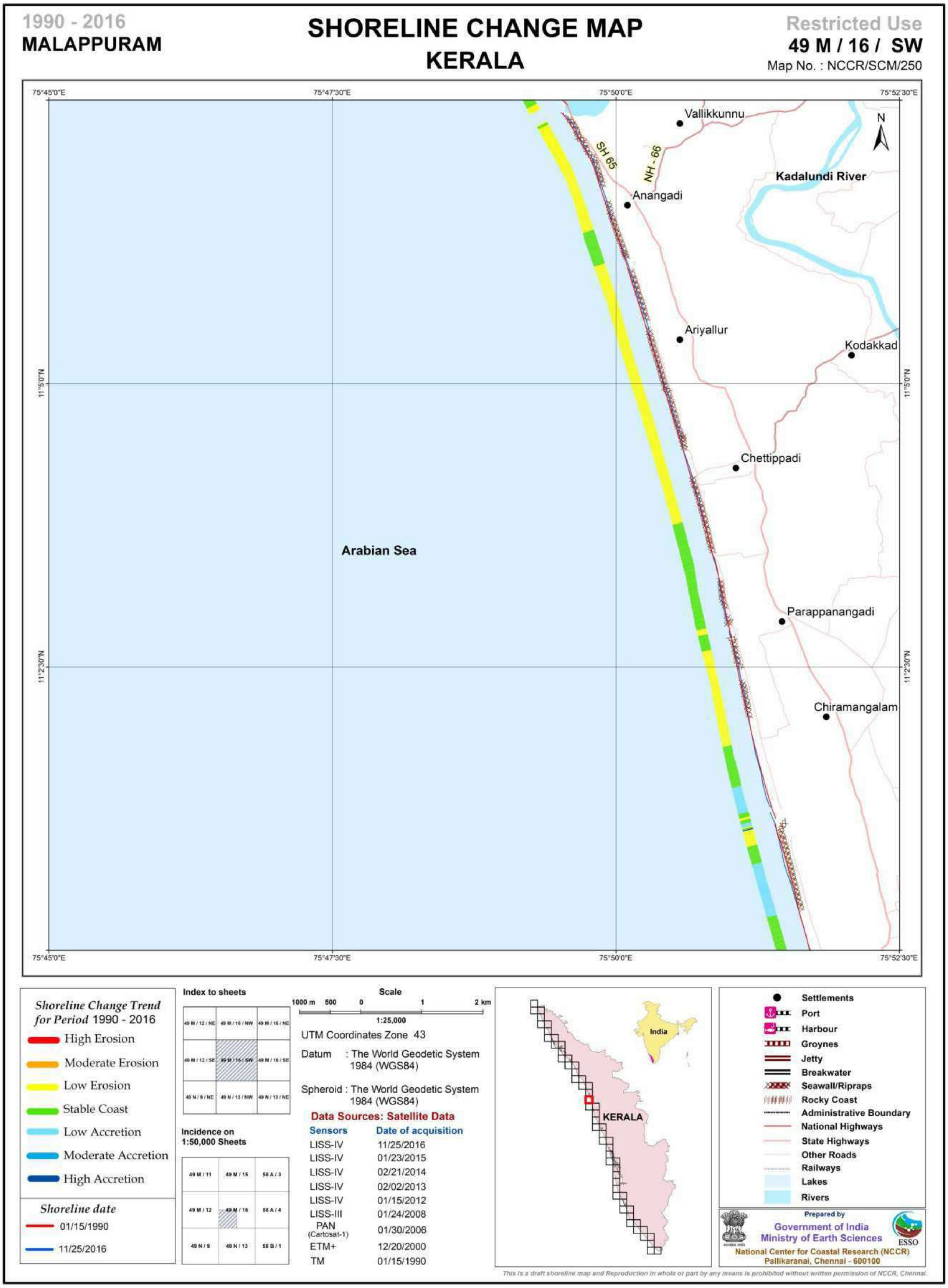


Figure 28: 1:25,000 scale map of Malappuramdistrict, Kerala.

4.3.6 Tamil Nadu

The coastal state of Tamil Nadu is in the southern part of India, bound by Bay of Bengal in the east. The coastal length is dissected by a number of rivers, streams and by varying geomorphic features. Cauvery, Palar, Vaigai, Noyyal, Cheyyar, Bhavani and Thamirabarani are a few of the prominent rivers flowing through the state. Mudflats, beaches, spits, coastal sand dunes, lagoons, estuaries, beach ridges, strand features and rocky coasts are some of the geomorphic features identified along the coast. Pulicat found north of the state is the second largest lagoon of India. Coastal dunes stabilized by casuarinas and coconut plantations are observed along Ennore, Mahabalipuram, Manakkanam to Puducherry, Cuddalore to Pichavaram, Karaikal to Velangani, Vedaranniyam to Manamelkudi and Pudupattanam to Tondi. Two major ports are located along the coast. Madras Port and Tuticorin Port. Ports, fishing harbours and industries add economic aspect to the coast. The Gulf of Mannar Biosphere Reserve, Point Calimere Wildlife Sanctuary, mangrove forests at Pichavaram, Muthupet and coral reefs at Thothukudi show the significance of the sector.

Coastal length of the state consisting of thirteen coastal districts starting from Thiruvallur at north and Kanyakumari district at the south is estimated to be approximately 991 km from 2016 satellite imagery. Cumulative shoreline change analyzed for the past 26 years (1990-2016) shows that, about 41% of the coast is falling in erosion category, 23% is in accretion category and remaining 36% in stable category. District-wise interpretation of the results as shown in Table 14 elucidates that the coastal length of Kancheepuram, Villupuram, Thiruvarur and Kanyakumari are dominated by erosion. On the other hand, accretion of greater than 50% is observed in the districts of Thirunelveli and Thoothukudi. Along the Tamil Nadu coast, both natural coastal processes and human intervention in the form of artificial structures play a major role in shaping the coastline.

Erosion hot spots are identified along the coast of Thiruvottiyur, KasikovilKuppam, Chinnakuppam, Periyakuppam, Nadukuppam, Oyalikuppam, Bommiyarpalayam, ChinnamudalaiyarChavadi, PeriyamudalaiyarChavadi, Pettodai, Periyakuppam, Kodiakarai, Pombuhar, Kaveripattinum, Tharangapadi, Kilathotam, Tiruchendur, Thengapattanam, Midalam, Vaniakudi, Pillayarkovil, Puthenthurai, Murungavilai, Manakad, Melmidalam, Poonthurai, Colachel, Manavalakuruchi and Kovalam.

Accretion are noticed at the following places: Marina beach, between Ennore port and Korattalaiyar River, Thanthiriyankuppam, Vellingarayapettai, Pudukuppam, Samiyarpettai, Annappanpettai, Ayyampettai, Kodiakarai, Vedharanyam, Manamelkudi, Pillaiyartidal, Vallinokkam, Manapadu, Muthaipuram, Periyatalai, Pulianmarudar, Kunchiyapuram, Kuttam, Koodavallai, Kudutalai, Kuttappandi and Muttam.

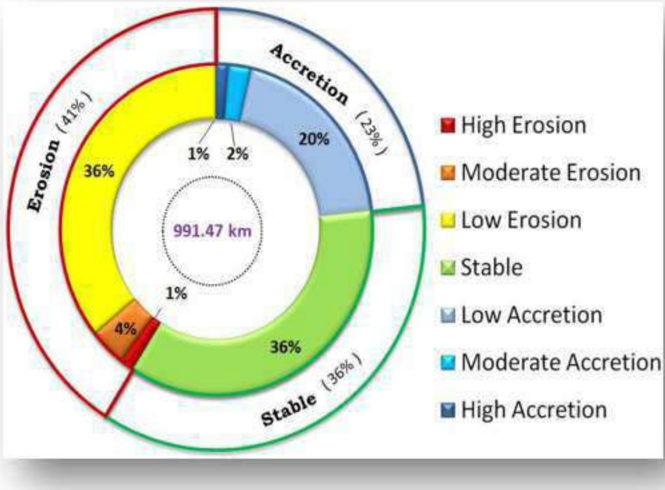


Figure 29: Percentage of shoreline change rate along Tamil Nadu coast.

Table 14: Erosion-stable-accretion status of Tamil Nadu coastal districts.

SL No	District	Coast Length (in km)	Coast length (in km)						
			High Erosion	Moderate Erosion	Low Erosion	Stable	Low Accretion	Moderate Accretion	High Accretion
1	Thiruvallur	40.97	1.66	3.12	9.22	17.22	6.54	0.61	2.60
2	Chennai	24.87	0.00	0.00	3.08	14.31	7.13	0.35	0.00
3	Kancheepuram	84.41	1.30	3.54	44.56	27.74	7.27	0.00	0.00
4	Villupuram	34.52	0.00	0.31	24.83	8.39	1.00	0.00	0.00
5	Cuddalore	43.35	2.47	2.21	13.06	9.93	12.08	3.60	0.00
6	Nagapattinam	125.65	3.48	14.46	43.84	17.70	33.92	8.65	3.60
7	Thiruvarur	24.39	3.08	0.99	11.01	6.84	2.38	0.06	0.02
8	Thanjavur	52.36	0.20	0.77	16.84	20.05	13.36	1.01	0.13
9	Pudukkottai	46.74	0.04	0.28	22.67	18.98	4.66	0.11	0.00
10	Ramanathapuram	272.01	1.27	3.48	99.55	125.95	37.81	1.97	1.99
11	Thothukudi	121.43	1.05	3.27	17.48	46.99	44.05	6.33	2.26
12	Thirunelveli	51.70	0.00	0.00	9.40	21.60	19.26	0.41	1.03
13	Kanyakumari	69.06	0.12	4.24	40.20	17.86	4.79	0.85	1.00
TOTAL		**991.47**	**14.66**	**36.65**	**355.74**	**353.56**	**194.27**	**23.96**	**12.63**

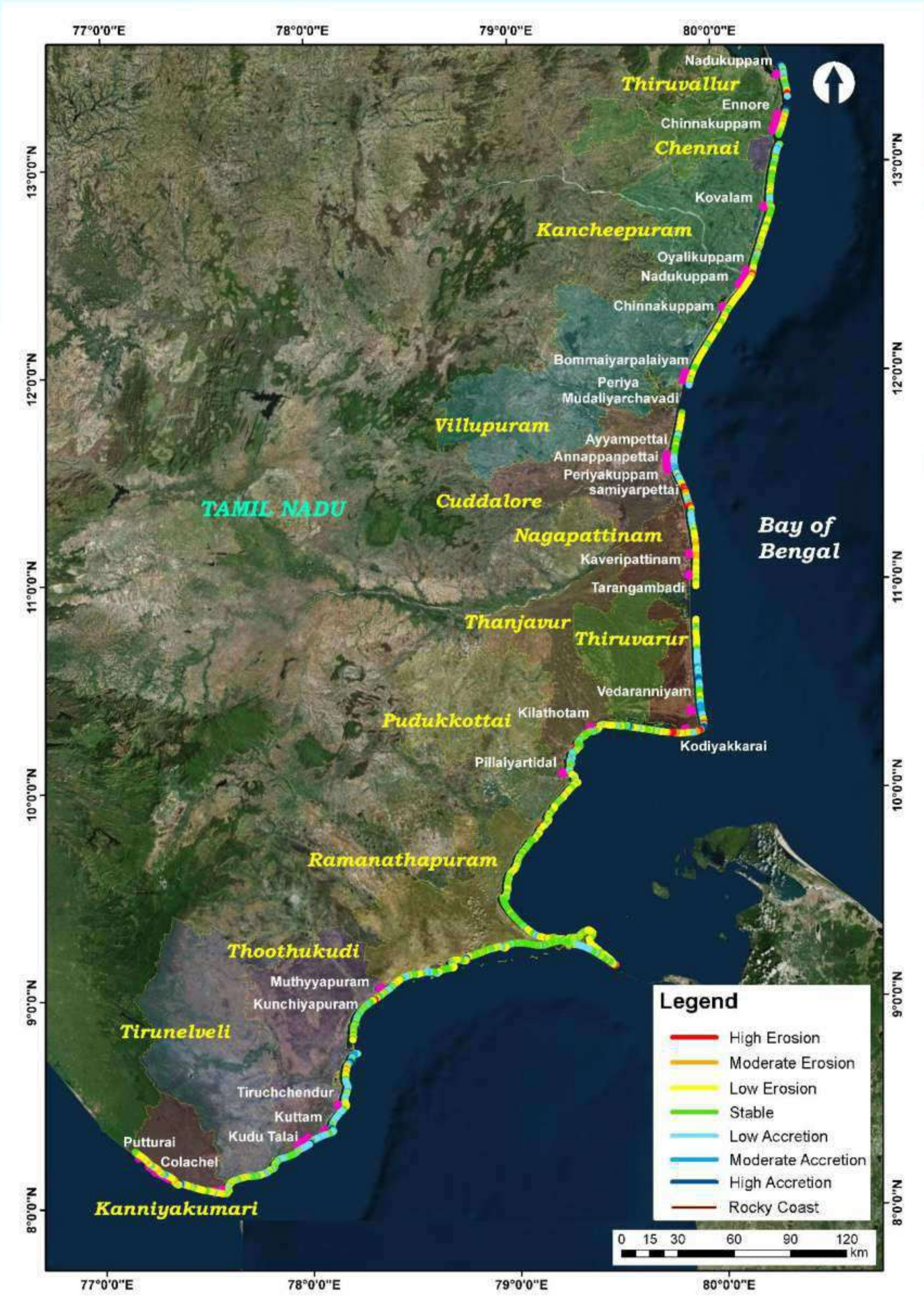


Figure 30: Shoreline change map of Tamil Nadu coast (1990-2016).

Figure 31: Coastal Districts of Tamil Nadu

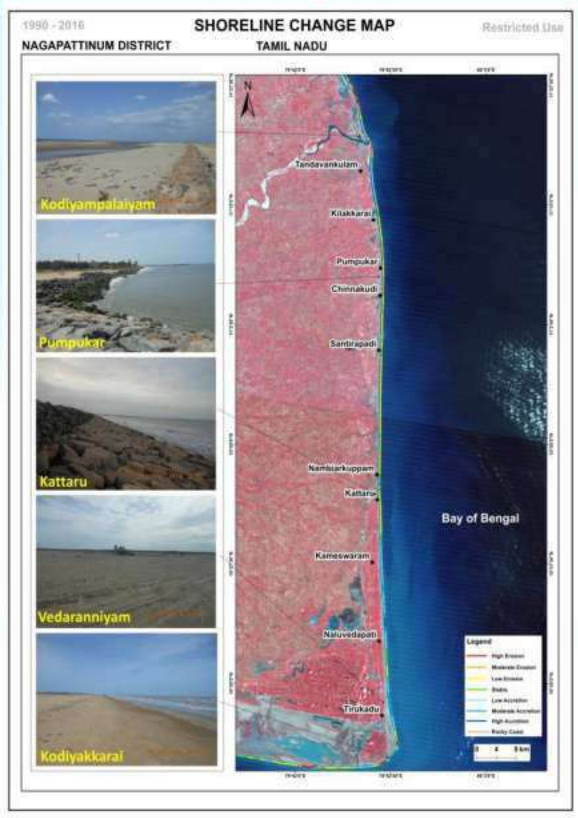
Thiruvallur

Chennai

Kancheepuram

Villupuram

Cuddalore



Nagapattinam

Thiruvarur

Thanjavur

Pudukottai

Ramanathapuram

Thothukudi

Thirunelveli

Kanyakumari

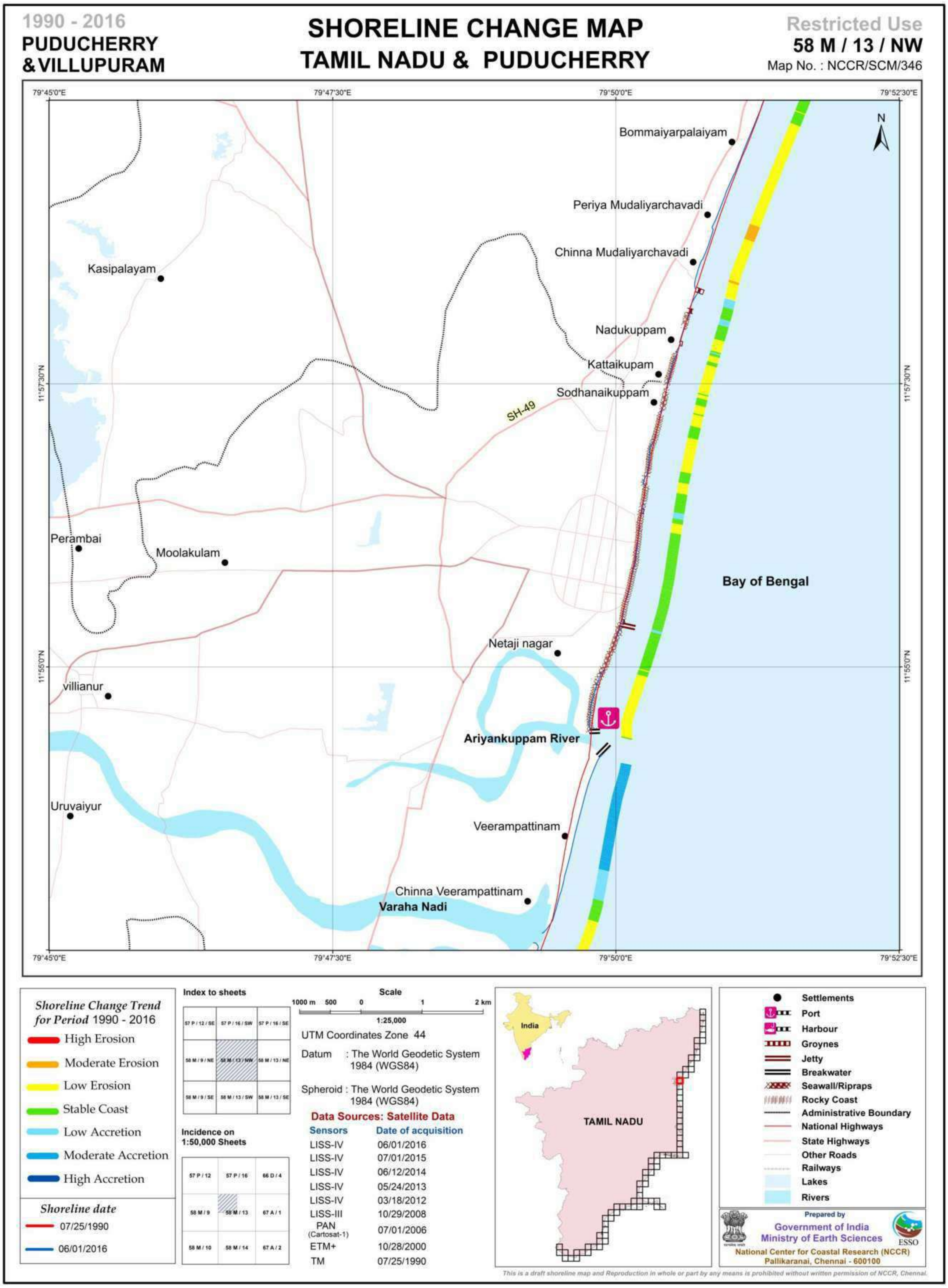


Figure 32: 1:25,000 scale map of Puducherry and Villupuram district, Tamil Nadu.

4.3.7 Puducherry and Karaikal

Puducherry is one of the Union Territories (UT) of India, located in the southern part of the Indian Peninsula. Puducherry, Karaikal, Yanam and Mahe districts together constitute Puducherry UT. Puducherry district and Karaikal district are bound by the state of Tamil Nadu in the deltaic region of Cauvery, While Yanam district and Mahe district are enclosed by the states of Andhra Pradesh and Kerala, respectively. Gingee and Ponnaiyar are the two major rivers flowing along the coast of Puducherry. In Karaikal, Arasalar, Tirumalarajanar and Vettar are the rivers draining into Bay of Bengal. About 5.2 km is protected with big boulder all along the north of Puducherry coast. Seawall extending for about 2 km can be observed 27 feet above the mean sea level in the Puducherry city. This wall is constructed by the French in the year 1735 to protect the city from direct wave action.

The coastal length of Puducherry and Karaikal is 23.48 km and 18.16 km, respectively, together it is about 42 km. Long term cumulative shoreline analysis of the coast from 1990 to 2016, indicates that 57% of the coast is in eroding condition, 35% in stable condition and only 8% under accreting condition. Erosion is one of the major concerns along these coasts. Artificial structures play a major role for erosion along these coasts.

North of the Puducherry port i.e., Thengaithithu, coastal villages of Pudukuppam, Pannithittu, Nallavadu, Kalapettai and ChinnaKalapettai are noticed to undergo erosion. Accretion is noticed at Virampattinum and ChinnaVirampattinum. Majority of the Karaikal coast is experiencing erosion. Along karaikal coast, erosion is observed in the coastal villages of Akkampettai, Kasakkudimedu, Kilinimedu and Pattanacheri.

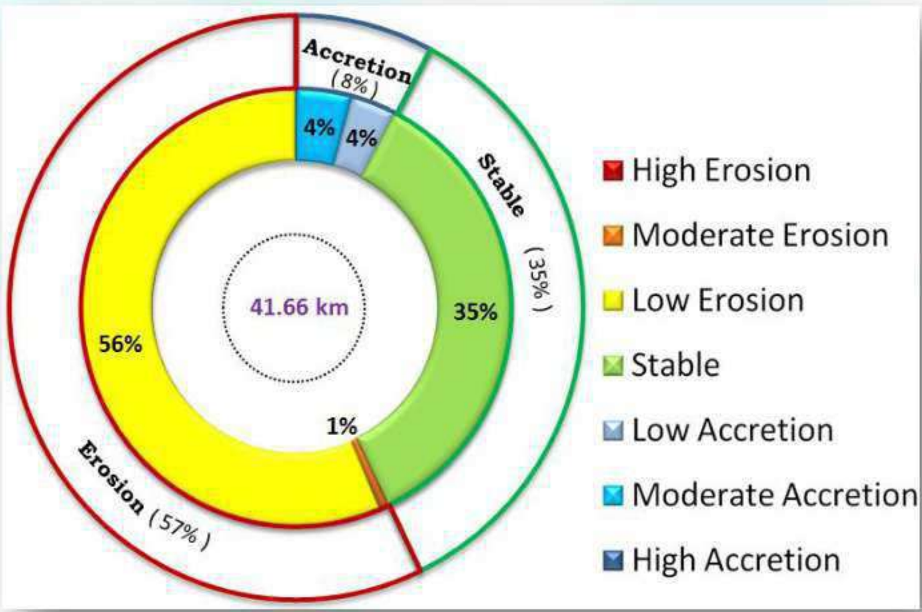


Figure 33: Percentage of shoreline change rate along Puducherry coast.

Table 15: Erosion-stable-accretion status of Puducherry coastal districts

SL No	Union Territory	Coast Length (in km)	Coast length (in km)						
			High Erosion	Moderate Erosion	Low Erosion	Stable	Low Accretion	Moderate Accretion	High Accretion
1	Puducherry	23.50	0.00	0.00	9.61	11.55	0.61	1.72	0.00
2	Karaikal	18.16	0.00	0.32	13.87	3.07	0.84	0.06	0.00
TOTAL		**41.66**	**0.00**	**0.32**	**23.48**	**14.63**	**1.45**	**1.78**	**0.00**

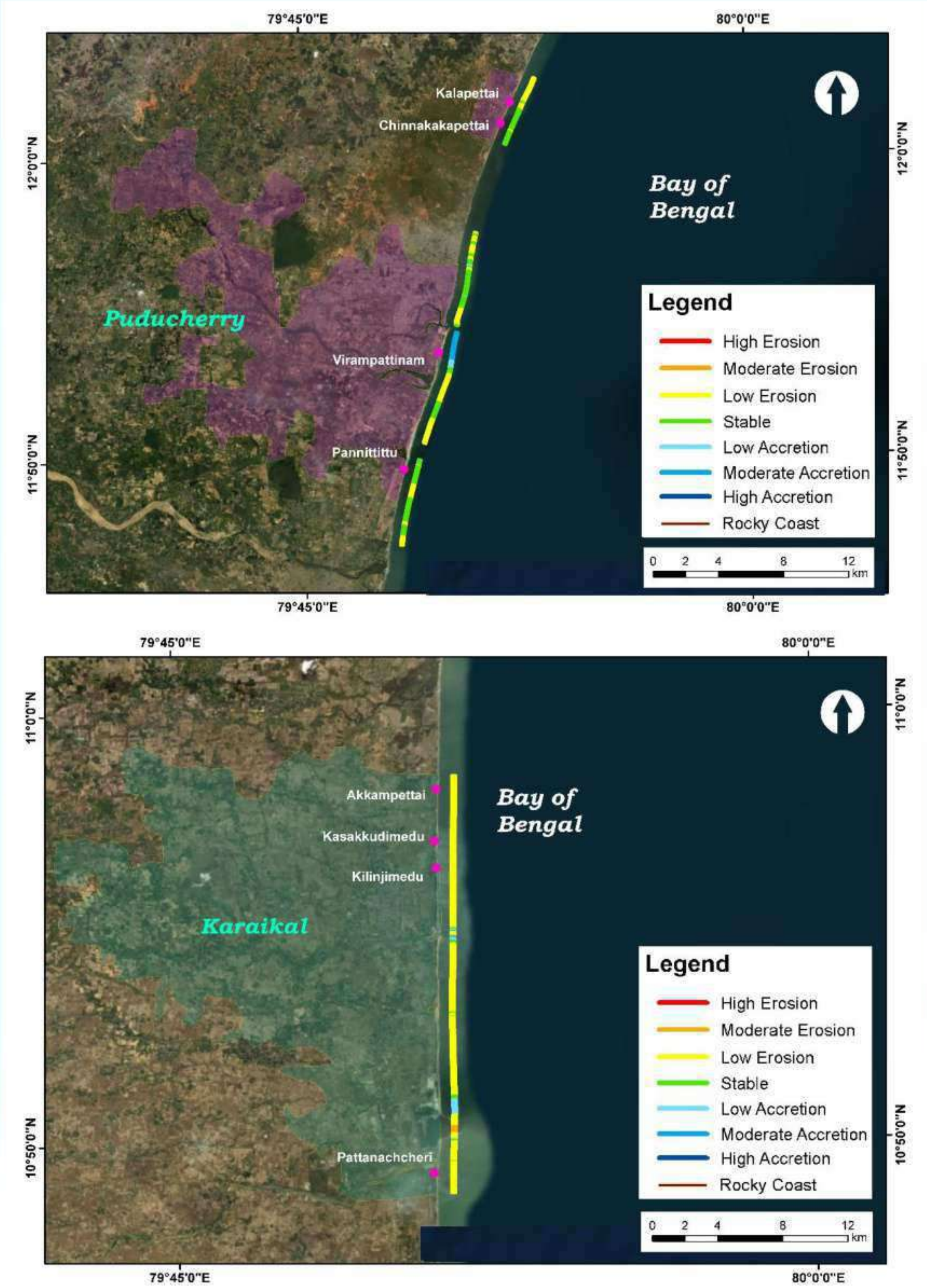


Figure 34: Shoreline change map of Puducherry coast (1990-2016).

Puducherry

Karaikal

Figure 35: Coastal Districts of Puducherry

4.3.8 Andhra Pradesh

The Coastal stretch of Andhra Pradesh on the western side of Bay of Bengal is the second longest coast after Gujarat. It extends from Ichchapuram of Srikakulam district in the north to Tada of Nellore district in the south. Coastal geomorphic features like deltas, dune system, red sediments, beach rock, etc are prominent along this sector. Godavari and Krishna rivers, form the two important deltas of the region, influence the landforms occurring in the stretch. Stabilized and well developed sand dunes are observed north of Visakhapatnam. Mangroves are seen in the districts of Prakasam, Guntur, West Godavari and East Godavari. Region of the coast above Guntur is dotted with industries like cement, oil terminals, etc. About 10 ports including the major port in Visakhapatnam boost the economy of the coastal belt. During northeast monsoon the coast is often ravaged by tropical cyclones originated in the Bay of Bengal basin. Natural calamity and developmental activities together exert pressure on the coastal system and induce coastal changes.

From 2016 satellite imagery, coastal length of the state spread across 9 districts, is measured to be about 1027 km. Cumulative shoreline change analysis from 1990 to 2016 indicates that 27% of the coast is eroding, 31% is stable and 42% is accreting. Nellore district shows accretion trend with a few pockets of erosion and stable condition. In the districts of Prakasam, Guntur and West Godavari, accretion is observed to be dominating the coast. Delta regions of Krishna and East Godavari show alternating band of accretion and erosion. Visakhapatnam, Vizhianagaram and Srikakulam districts are observed to exhibit stable condition.

Regions like Korakupalaiyam, Pallikuppam, Toppalappalaiyam, Virrasettitannippandal, Vatturupallipalem (above the Upputeru River), Ramulapatisangam, Binginipalle, Rayaduruvu, Peddaboyanapalem, Ullapalem and Uppada are identified as erosion prone areas. Visakhapatnam is found to be the most stable in the Andhra coast as it is protected with Kailasa and Yarada ranges. Accretion is seen along Pattapupalem, Pallepalem, Kesavapalem and Gundamala. In the northern part of the coast, from Ichchapuram to Beemunipatanam, no significant change is observed. These areas are covered with sand dunes and sandy beach.

Table 16: Erosion-stable-accretion status of Andhra Pradesh coastal districts

SL No	District	Coast Length (in km)	Coast length (in km)						
			High Erosion	Moderate Erosion	Low Erosion	Stable	Low Accretion	Moderate Accretion	High Accretion
1	Nellore	172.10	5.36	3.16	41.72	50.36	62.22	7.14	2.14
2	Prakasam	107.18	3.20	4.72	15.38	19.70	53.64	7.18	3.36
3	Guntur	64.24	0.84	0.00	1.72	9.54	26.06	13.78	12.30
4	Krishna	133.36	40.30	6.18	8.64	17.86	21.02	10.18	29.18
5	West Godavari	17.98	5.52	0.72	0.98	1.04	2.74	1.98	5.00
6	East Godavari	189.84	45.92	13.84	19.54	25.60	33.10	18.22	33.62
7	Vishakhapatnam	136.98	0.34	2.24	12.36	102.74	17.78	1.34	0.18
8	Vizhianagaram	32.78	0.00	0.00	11.96	12.54	7.66	0.00	0.62
9	Srikakulam	173.12	0.02	1.92	25.76	81.60	49.36	7.36	7.10
TOTAL		**1027.58**	**101.50**	**32.78**	**138.06**	**320.98**	**273.58**	**67.18**	**93.50**

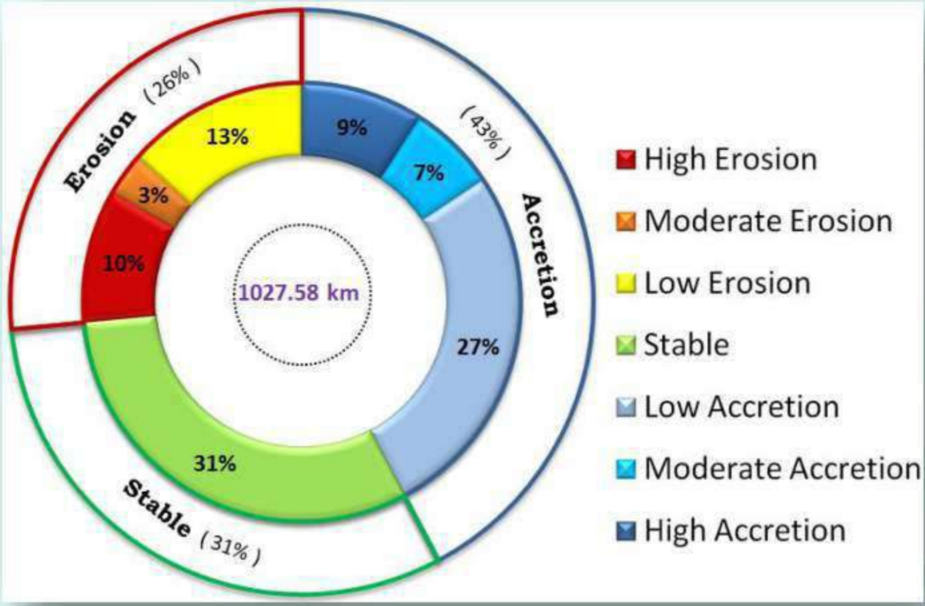


Figure 36: Percentage of shoreline change rate along Andhra Pradesh coast.

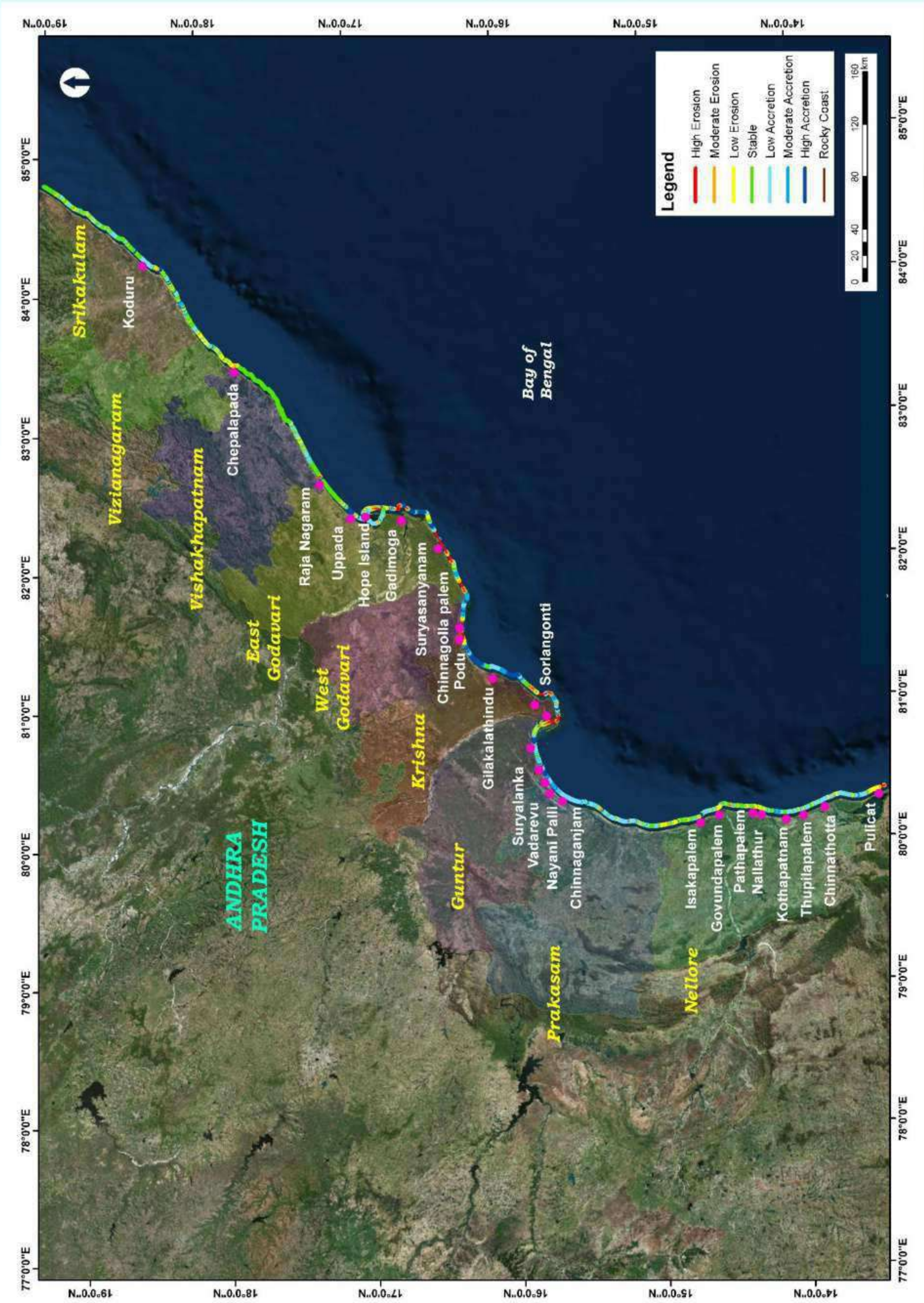
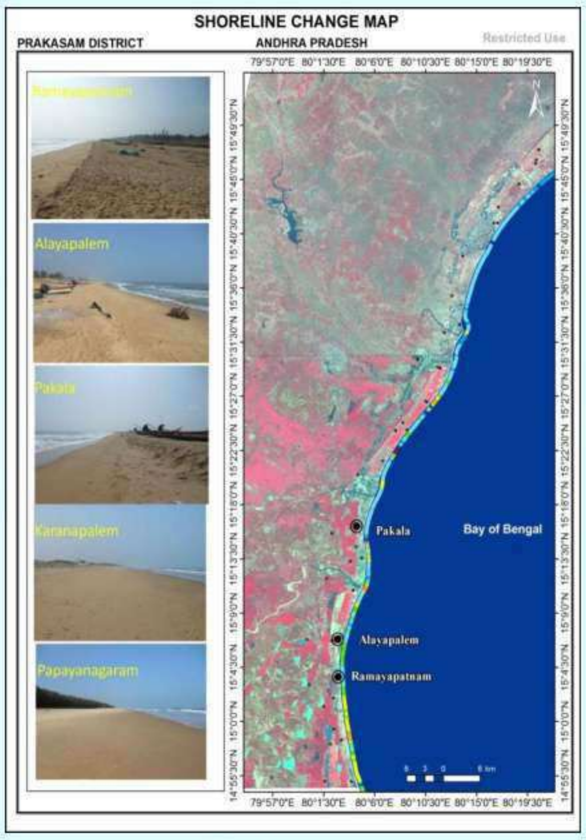
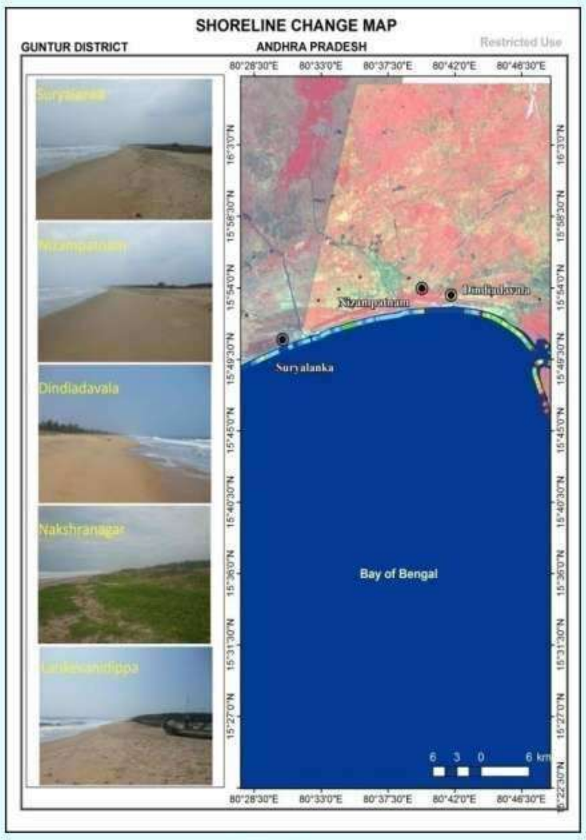


Figure 37: Shoreline change map of Andhra Pradesh coast (1990-2016).

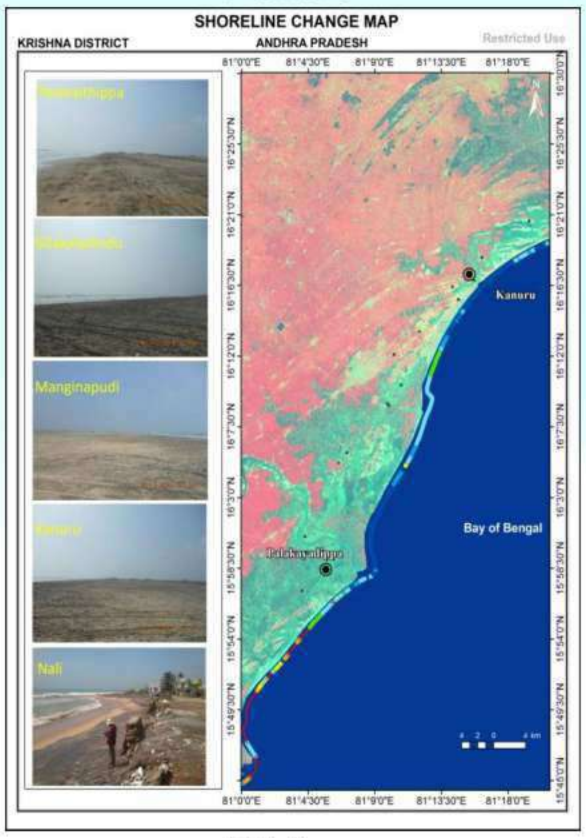
Nellore



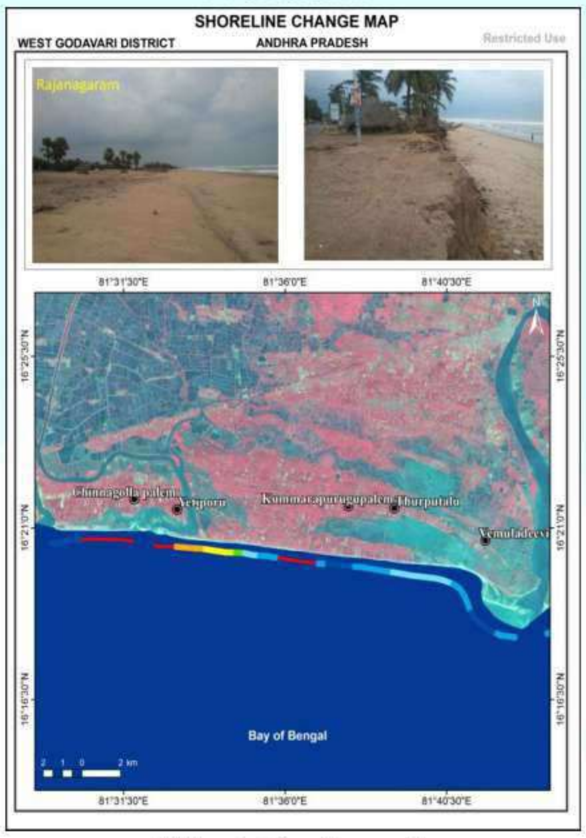
Prakasam



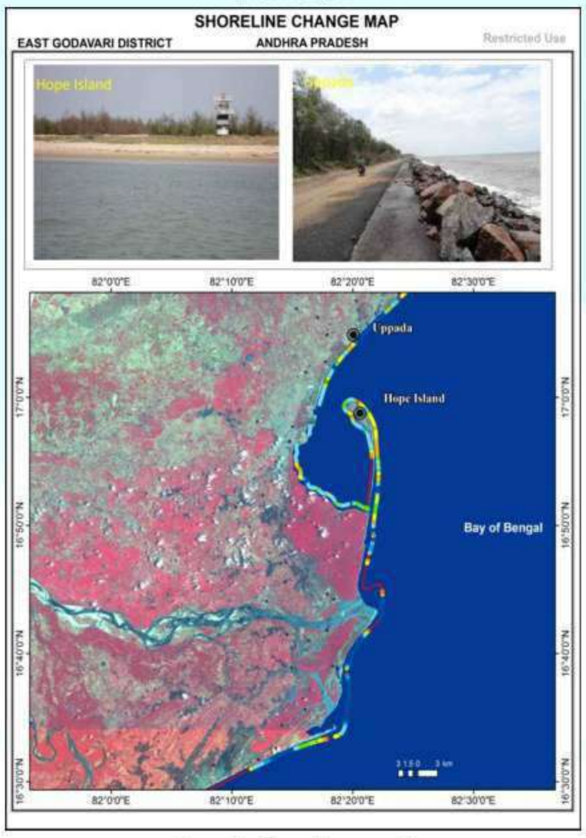
Guntur



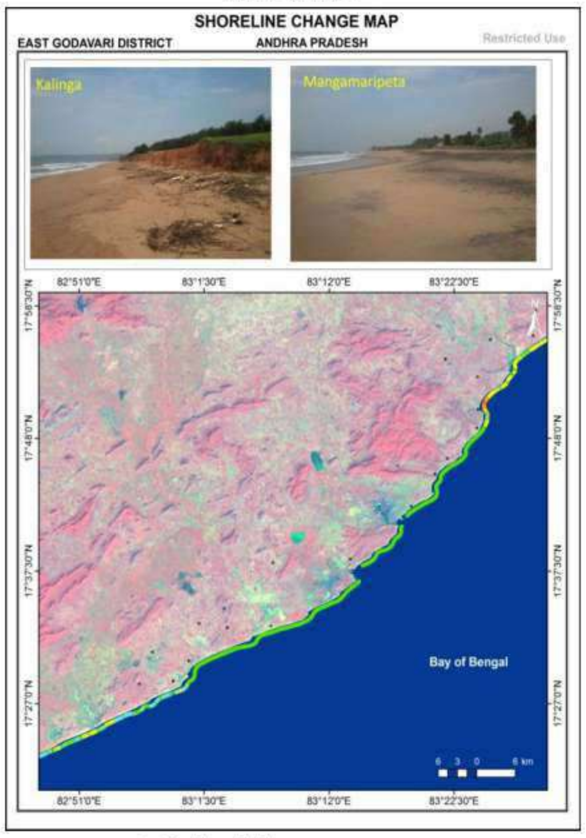
Krishna



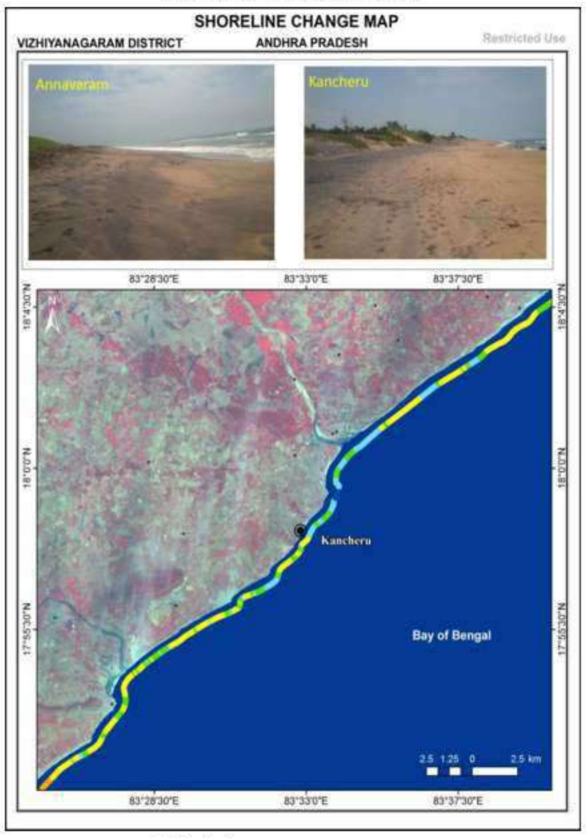
West Godavari



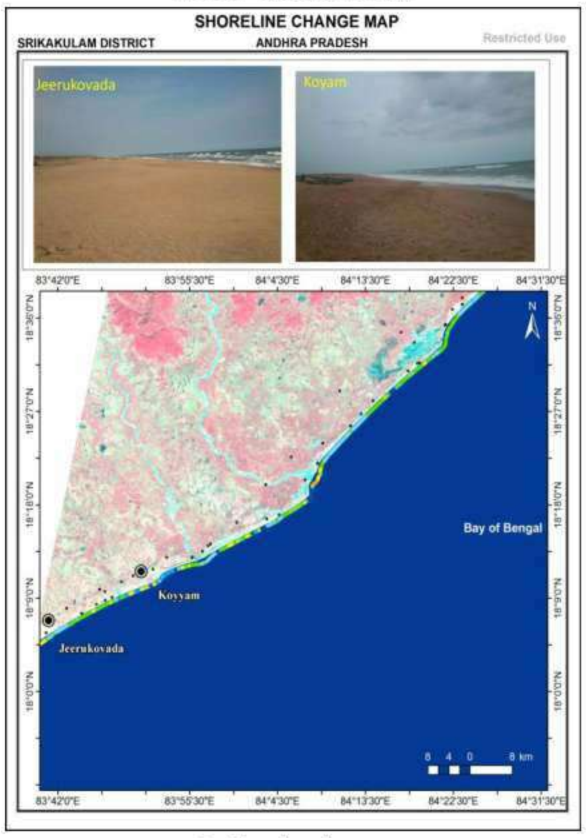
East Godavari



Vishakhapatnam



Vizhiyanagaram



Srikakulam

Figure 38: Coastal district of Andhra Pradesh

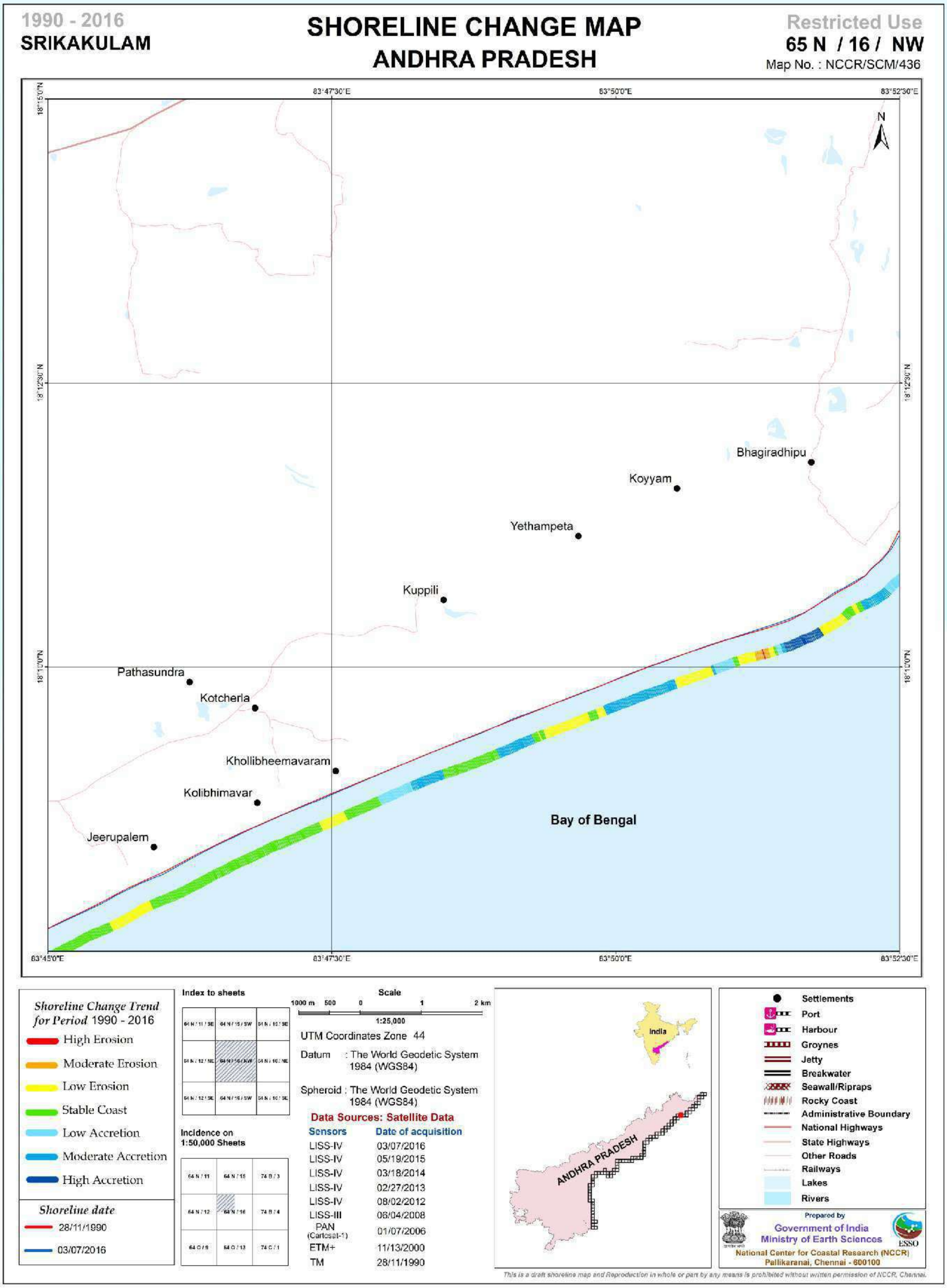


Figure 39: 1:25,000 scale map of Srikakulam district, Andhra Pradesh.

4.3.9 Odisha

Odisha located in the north-eastern coast of India, is a maritime state with immense potential in natural resources. The coastal plain of the state is a combination of several deltas of varied sizes and shapes formed by the major riversthe Subarnarekha, the Budhabalanga, the Baitarani, the Brahmani, the Mahanadi and the Rushikulya. The coast is characterized by several depositional geomorphic features like beach ridges, deltas, tidal flats, sand spits, and barrier spits, etc. Sandy beaches enriched with many rare earth minerals are observed in the southern part of the state from Rushikulya River mouth to Devi River mouth, while in the northern part subtidal mudflats are prevalent. The coast is of great ecolological significance too. Asia's largest brackish water lagoon Chilika is located along the coast. World's largest known nesting site of olive ridley turtles is observed along the coast of Gahrim and Rushikulya. Mangrove vegetation is seen along the creek network of Mahanadi, Brahmani and Baitarani. The mangrove of Bhitarkanika is the second largest mangrove formation in the Indian subcontinent. Apart from this, the coast is vulnerable to natural disaster tropical cyclone. Further, increase in population and developmental activity along the coastal belt in the recent years has induced coastline changes.

The coastal length of state with 6 districts constitute to about 550 km. Long-term shoreline analysis from 1990 to 2016 indicates that 28% of the coast is eroding, 21% is stable and 51% is accreting. Districts of Puri, Badhrak and Baleshwar to show accretion trend; more that 50% of their respective coastal length is accreting. Jagatsighpur district found to exhibit erosion; about 58% of its coast is eroding. In the districts of Ganjam and Kendrapara, erosion, accretion and stable conditions are observed.

From figure 18 it is noted that north of the Gopalpur port and Rushikulya river mouth exhibit erosion. The seasonal movement of sand bars plays an important role in shoreline configuration. In Jagatsinghpur district, major erosion zone starts from Devi River mouth and continues further 25 km north. Southern part of Paradip port is noticed with accretion. Spit observed north of Paradip port in 1973 has totally eroded and a new spit Hukitola is observed to grow north of Mahanadi River. It is noted that Hukitola spit is accreting at a higher rate in the tip, along Kendarapara district. Erosion is seen in the coastal villages of Pentha, Kanhupur, Satbhaya, Gairmatha and Habalikhuti. Wide mud flats with inter tidal zone of more than 0.5 km are observed in the Baleshwar district.

Table 17: Erosion-stable-accretion status of Odisha coastal districts

SL No	District	Coast Length (in km)	Coast length (in km)						
			High Erosion	Moderate Erosion	Low Erosion	Stable	Low Accretion	Moderate Accretion	High Accretion
1	Ganjam	62.90	3.84	1.92	8.30	18.46	22.10	1.84	6.44
2	Puri	140.04	6.68	4.34	10.38	9.18	73.72	23.66	12.08
3	Jagatsinghpur	58.72	14.58	7.76	11.88	9.24	5.18	0.88	9.20
4	Kendrapara	135.82	31.02	8.72	9.22	54.26	11.26	5.02	16.32
5	Bhadrak	59.88	6.64	3.44	3.48	4.14	4.58	6.66	30.94
6	Baleshwar	92.14	5.50	4.32	11.78	18.24	22.10	7.54	22.66
TOTAL		**549.50**	**68.26**	**30.50**	**55.04**	**113.52**	**138.94**	**45.60**	**97.64**

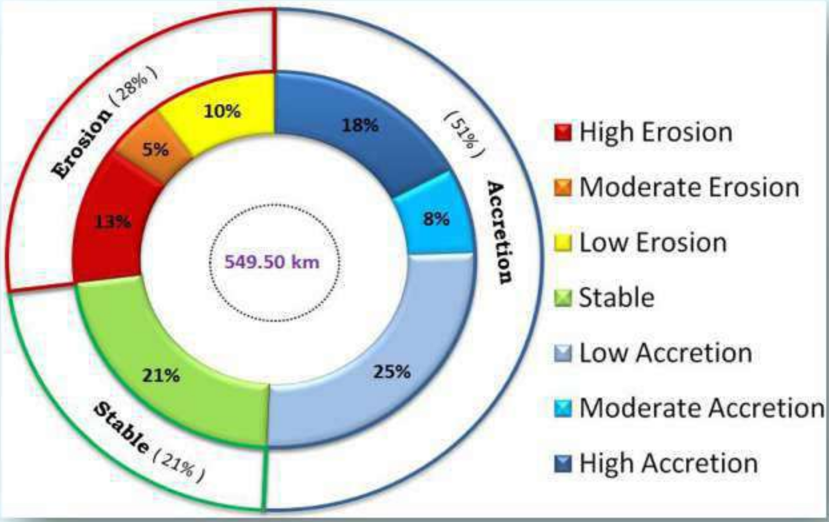


Figure 40: Percentage of shoreline change rate along Odisha coast.

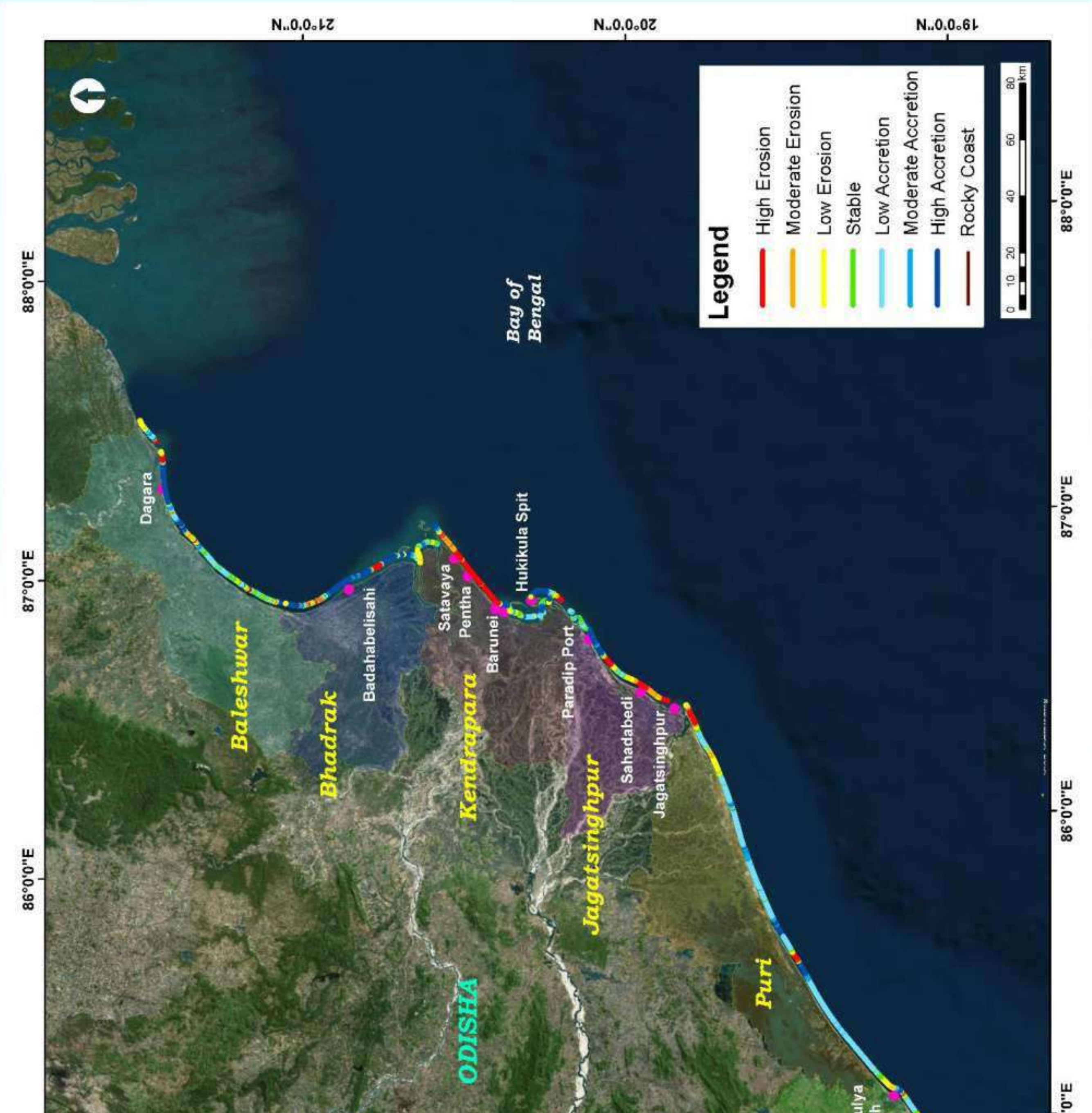


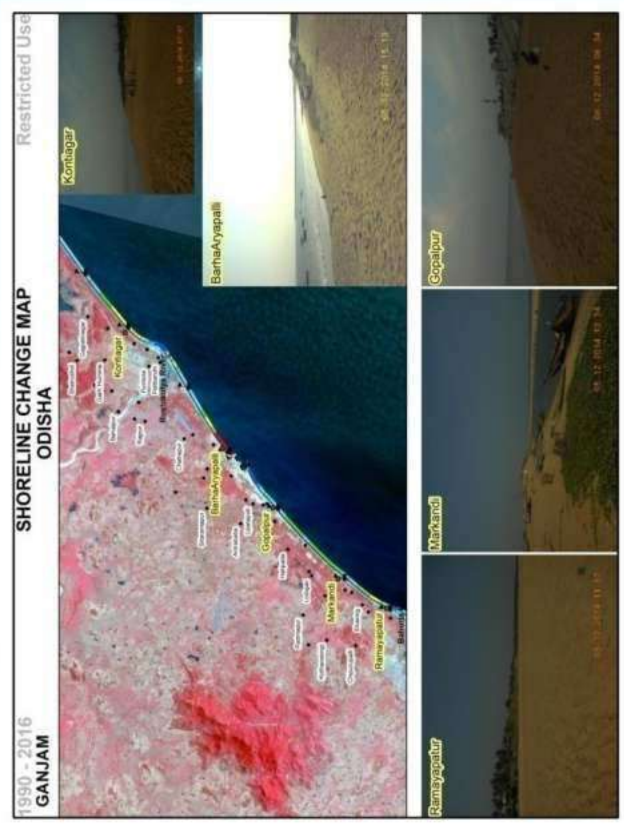
Figure 41: Shoreline change map of Odisha coast (1990-2016).

Figure 42: Coastal districts of Odisha

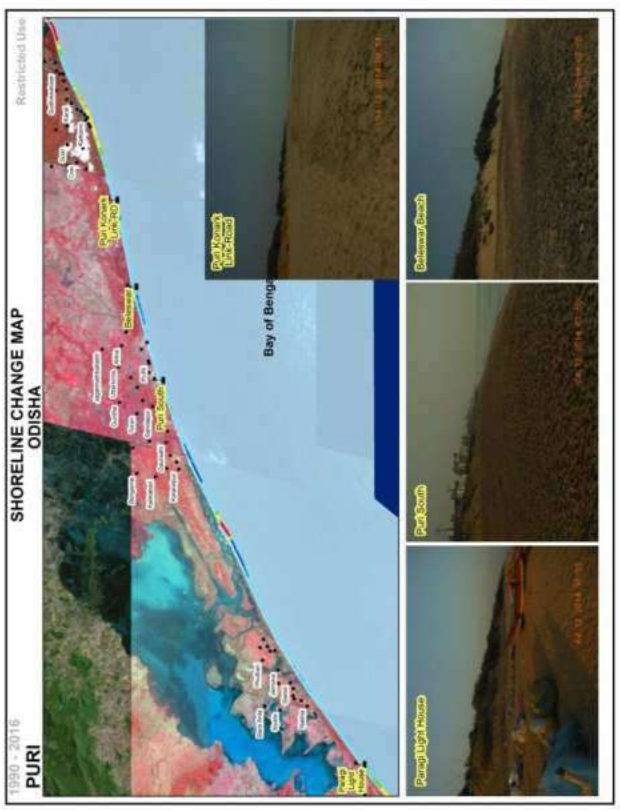
Baleshwar

Jagathsingpur

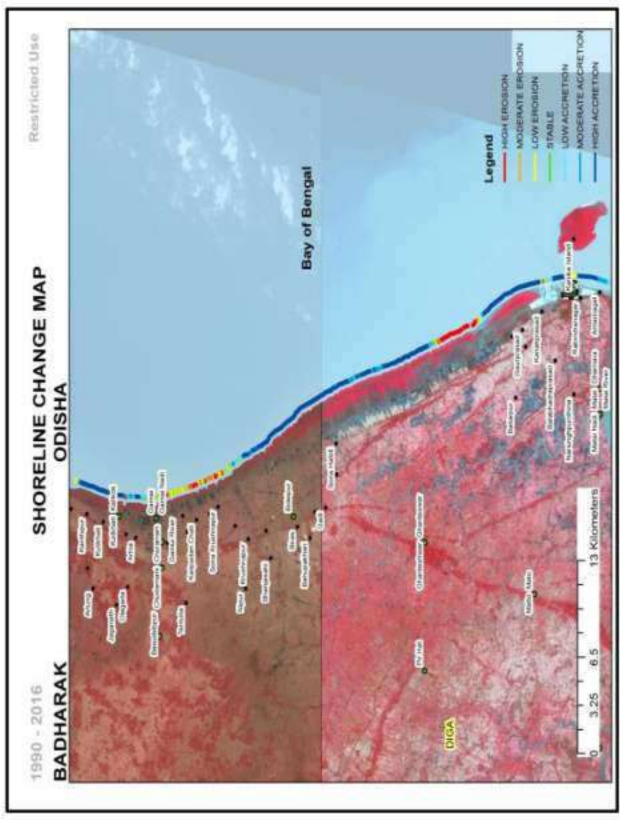
Kendrapara



Ganjam



Puri



Badharak

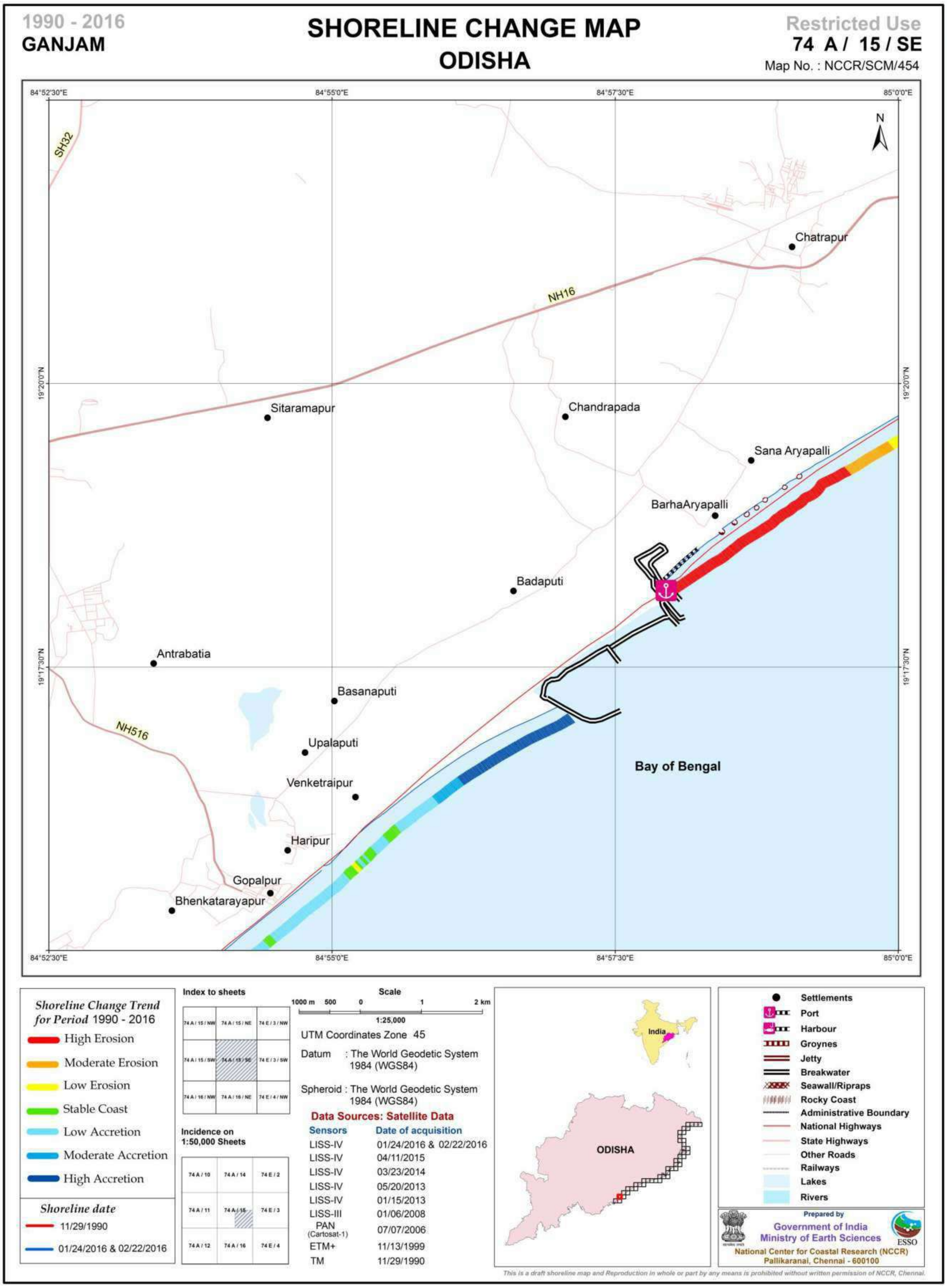


Figure 43: 1:25,000 scale map of Ganjam district, Odisha.

4.3.10 West Bengal

The coastal stretch of West Bengal is located in the eastern end of Indian Peninsula, bordering Bangladesh. The coast is one of the largest deltaic regions in the world. The Ganges, Damodar, Silali, Kasai and Hooghly are a few of the prominent rivers of the state draining into Bay of Bengal, forming the funnel shaped Hooghly estuary. Upper reaches of the creeks and coastal plain are composed of sand and mud, deposited by rivers and winds. Beaches, creeks, mangrove swamps, mudflats, coastal dunes and sand flats are some of the geomorphic features of the coastal area. It is observed that most of the sand dunes and marshy lands occur parallel to the coast. The Digha dunes lie nearest to the Bay of Bengal while the Kanthi dune is farthest from it. The Sundarban delta complex spread in the north and south Pargana districts is fed by numerous rivers and has the largest single block of tidal halophytic mangroves of the world. These regions are affected by tides, tropical cyclones and storm surges. The Sundarban has a link to the tectonic Bengal basin; a huge thickness of tertiary marine sediments is actively subsiding here. Natural processes and human interference such as salt pan, aquaculture, port construction and other developmental activities highly influence the coastline and cause changes.

Coastal length of the state is measured to be about 534 km from 2016 satellite imagery. Shoreline change analysis from 1990-2016 indicates that 63% of the coast is eroding, 13% is stable and remaining 24% is accreting. All the coastal districts of East Midnapore, South twenty-four Parganas and North twenty-four Parganas exhibit erosion with a few pockets of accretion and stable condition.

In the East Midnapore district, Old Digha, Jamra, Shyampur, Mandarmani and Bankiput beaches face erosion. In South 24 Parganas district, southeast and west of Sagar Island face severe erosion. Chumkur Island with the area of 133 hectares had gradually decreased and washed out in the span of 26 years. Same trend is observed in the case of Jumbudweep Island. Kusumtala (Baliara coast), Hendry Island, Gobardhanpur, Bulcherry and Sundarban area which fall between Gobardhanpur, Bulcherry and Kalash Island are severely eroded especially at the shore face.

Table 18: Erosion-stable-accretion status of West Bengal coastal districts.

SL No	District	Coast Length (in Km)	Coast length (in Km)						
			High Erosion	Moderate Erosion	Low Erosion	Stable	Low Accretion	Moderate Accretion	High Accretion
1	East Midnapore	55.35	6.44	5.49	15.92	8.09	9.12	2.78	7.51
2	South 24 Parganas	332.93	98.74	28.26	66.84	44.22	39.98	15.94	38.94
3	North 24 Parganas	146.07	68.46	18.21	28.16	16.47	7.16	1.07	6.54
TOTAL		**534.35**	**173.64**	**51.96**	**110.92**	**68.78**	**56.26**	**19.80**	**52.99**

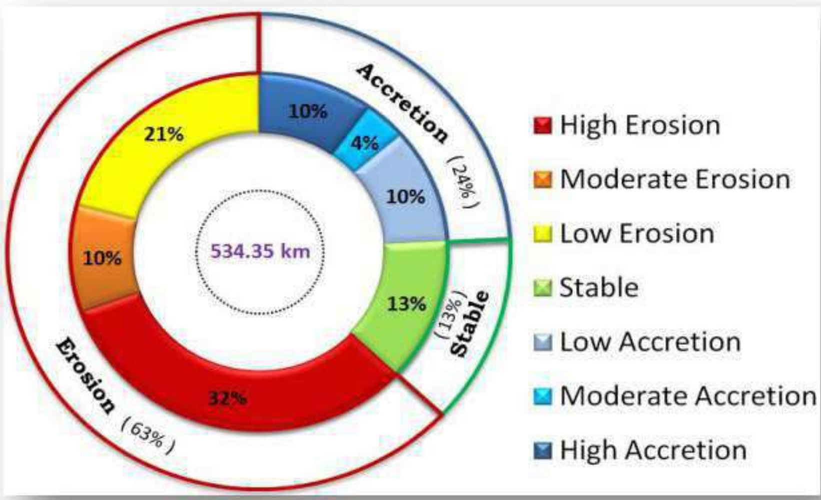


Figure 44: Percentage of shoreline change rate along West Bengal coast.

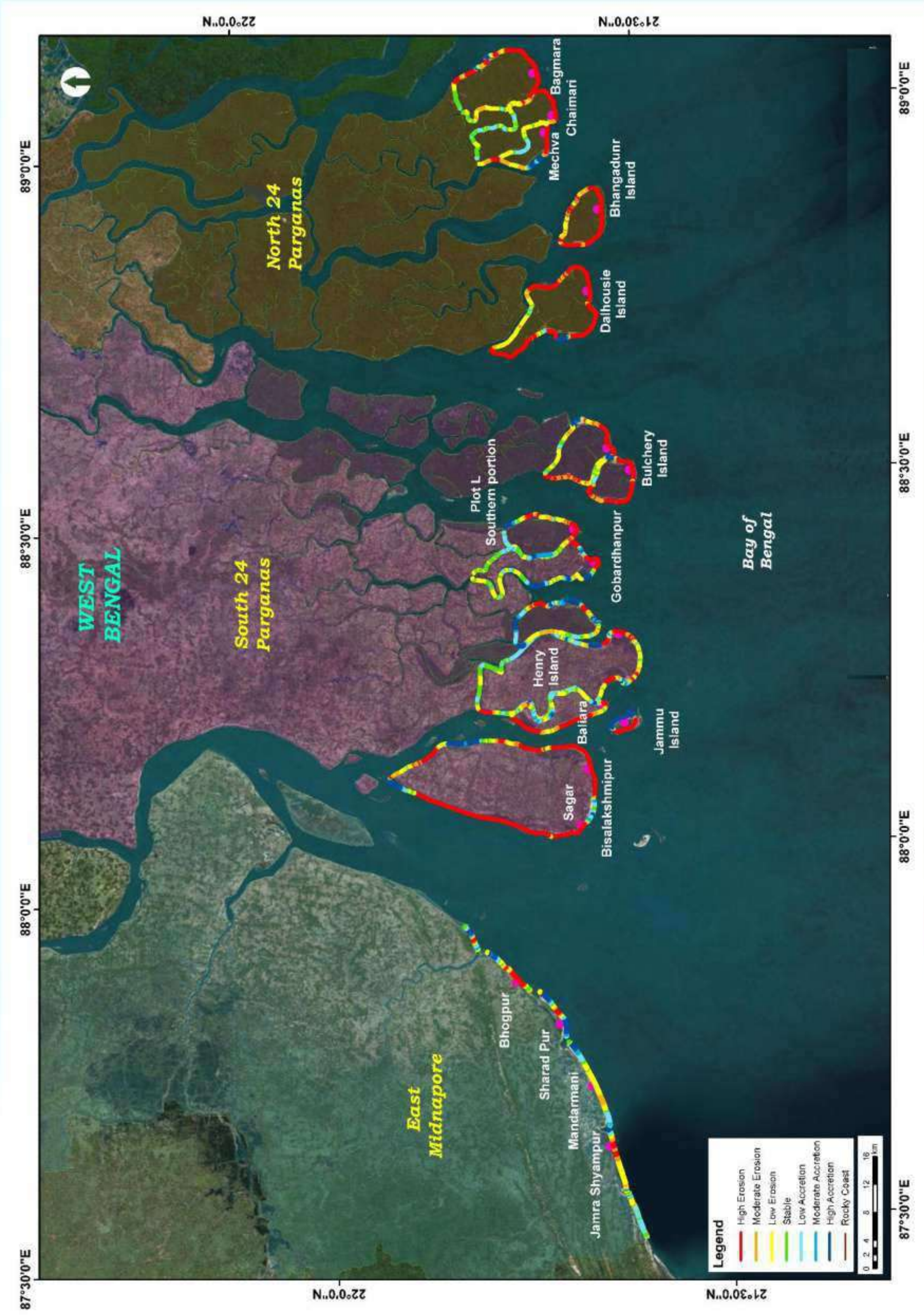
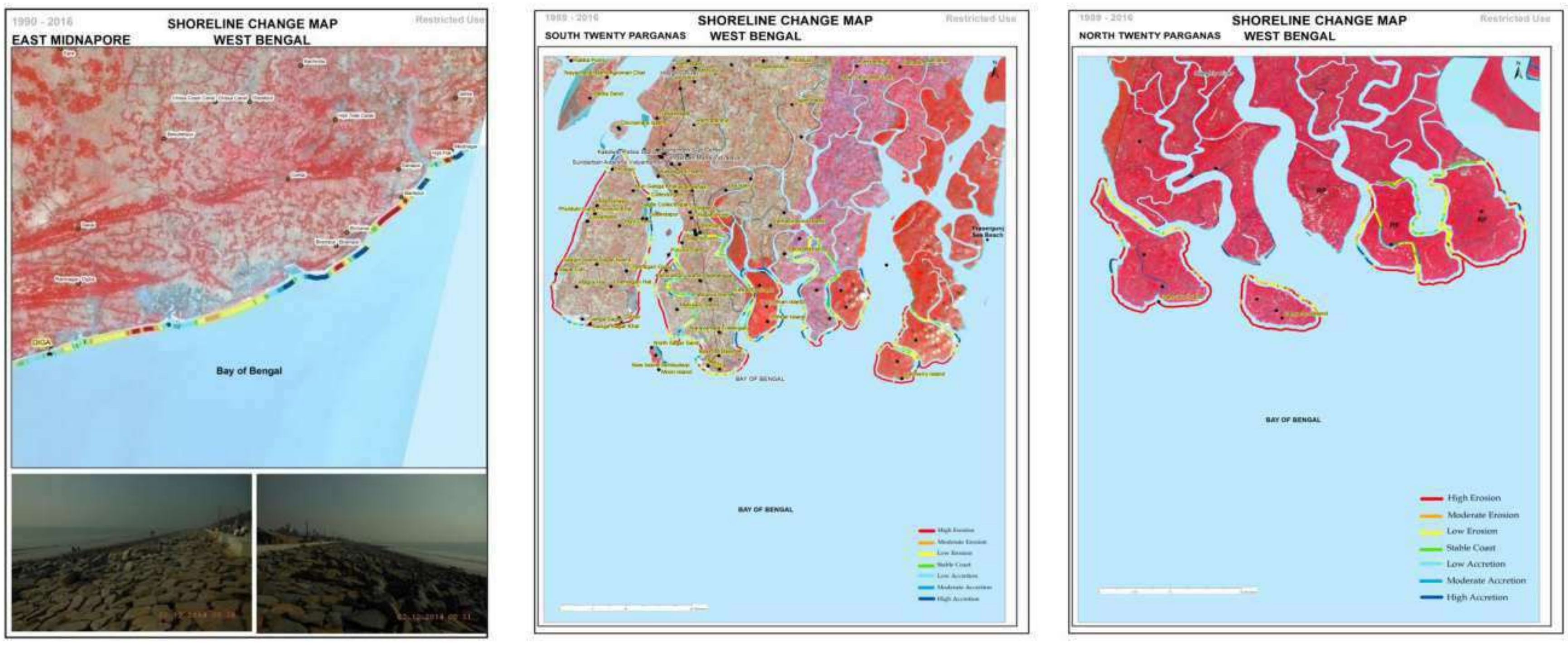


Figure 45: Shoreline change map of west Bengal coast (1990-2016).

Figure 46: Coastal district of West Bengal



East Midnapore | South Twenty Paraganas | North Twenty Paraganas

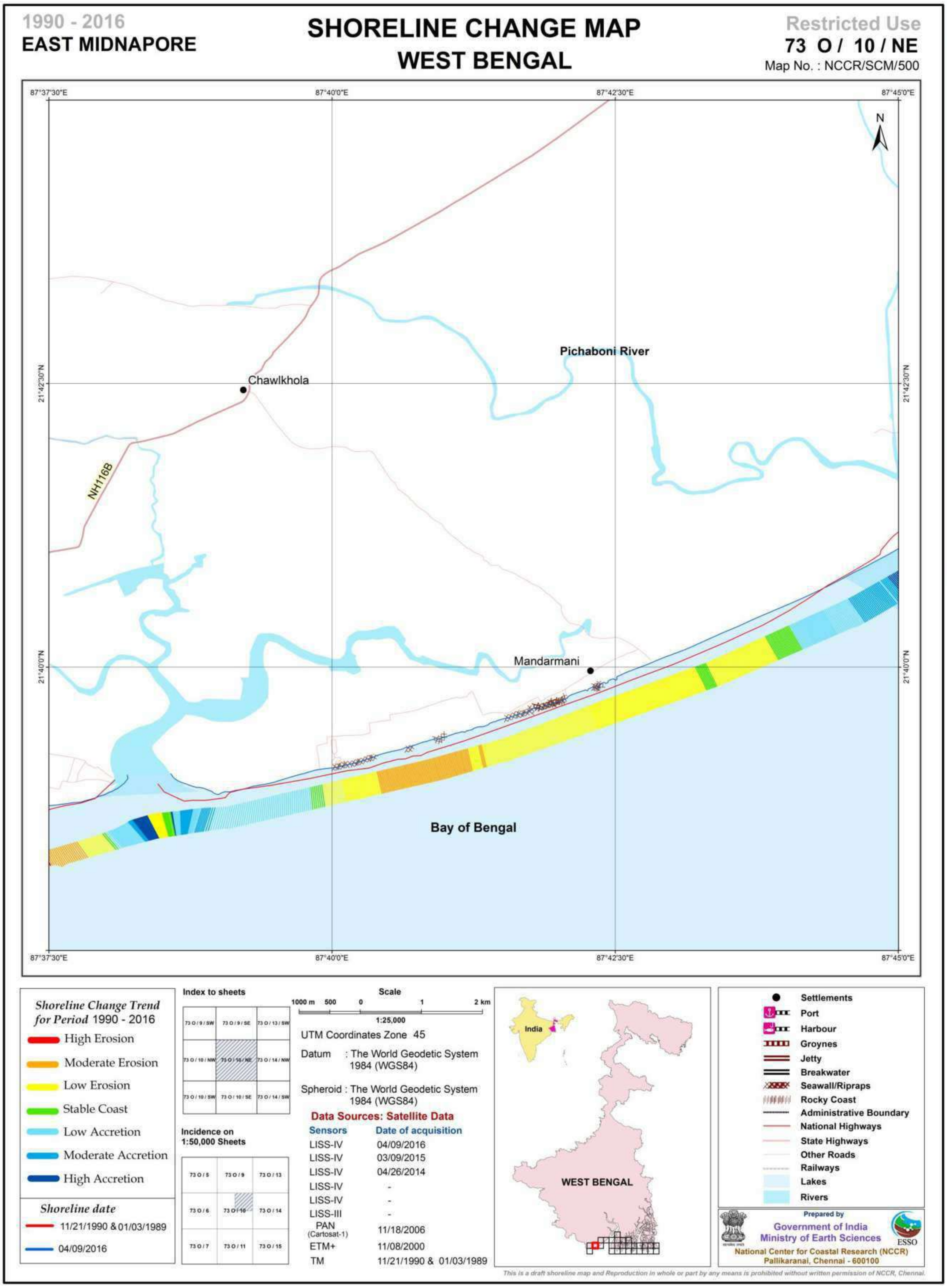


Figure 47: 1:25,000 scale map of East Midnaporedistrict, West Bengal.

4.4 Data products

The shoreline thus analysed from satellite imageries serves different data products to depict the output. Each map has different applications and used for different management purposes. These maps will be updated for every successive year. Below are the data products which are derived from final results.

1:25,000 scale maps

Indian mainland is bounded with 526 numbers of 1:25,000 scale maps at coastal region. This map will have information such as shoreline change rate with seven categories as low erosion, moderate erosion, high erosion, stable, low accretion, moderate accretion and high accretion. It also carries other particulars such as shoreline surveyed date, infrastructure details, ports, fishing harbours and industries.

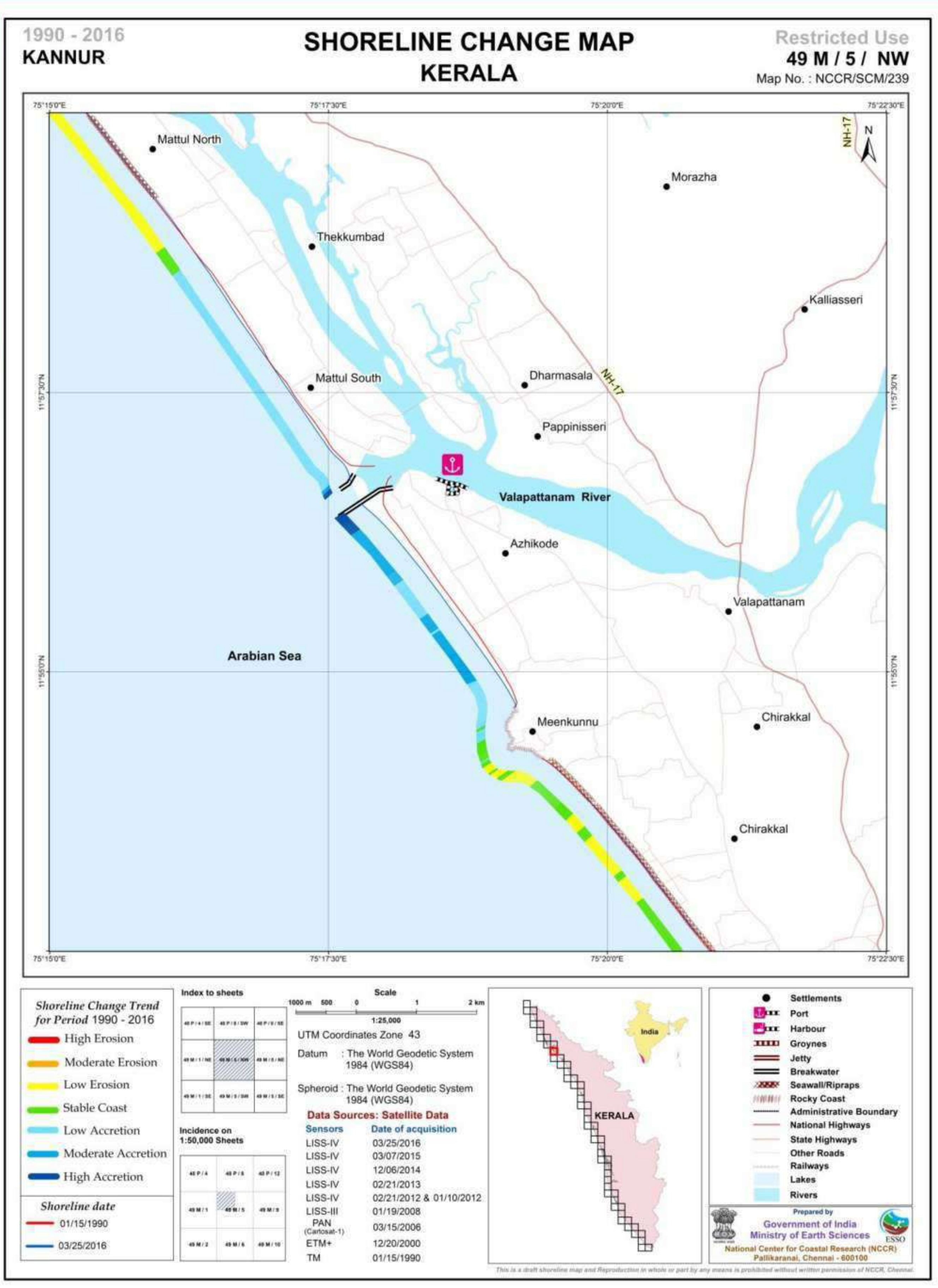


Figure 48: 1:25,000 scale map.

District maps

Indian coastal regions have sixty coastal districts and four union territories (Puducherry, Karaikal, Mahe, Daman & Diu districts). Each district map depicts shoreline change rate along with field photographs.

Figure 49: District map.

State maps

India is comprised of 9 coastal states and 2 union territories. Each state map will have information's such as shoreline change rate with seven categories as low erosion, moderate erosion, high erosion, stable, low accretion, moderate accretion and high accretion.

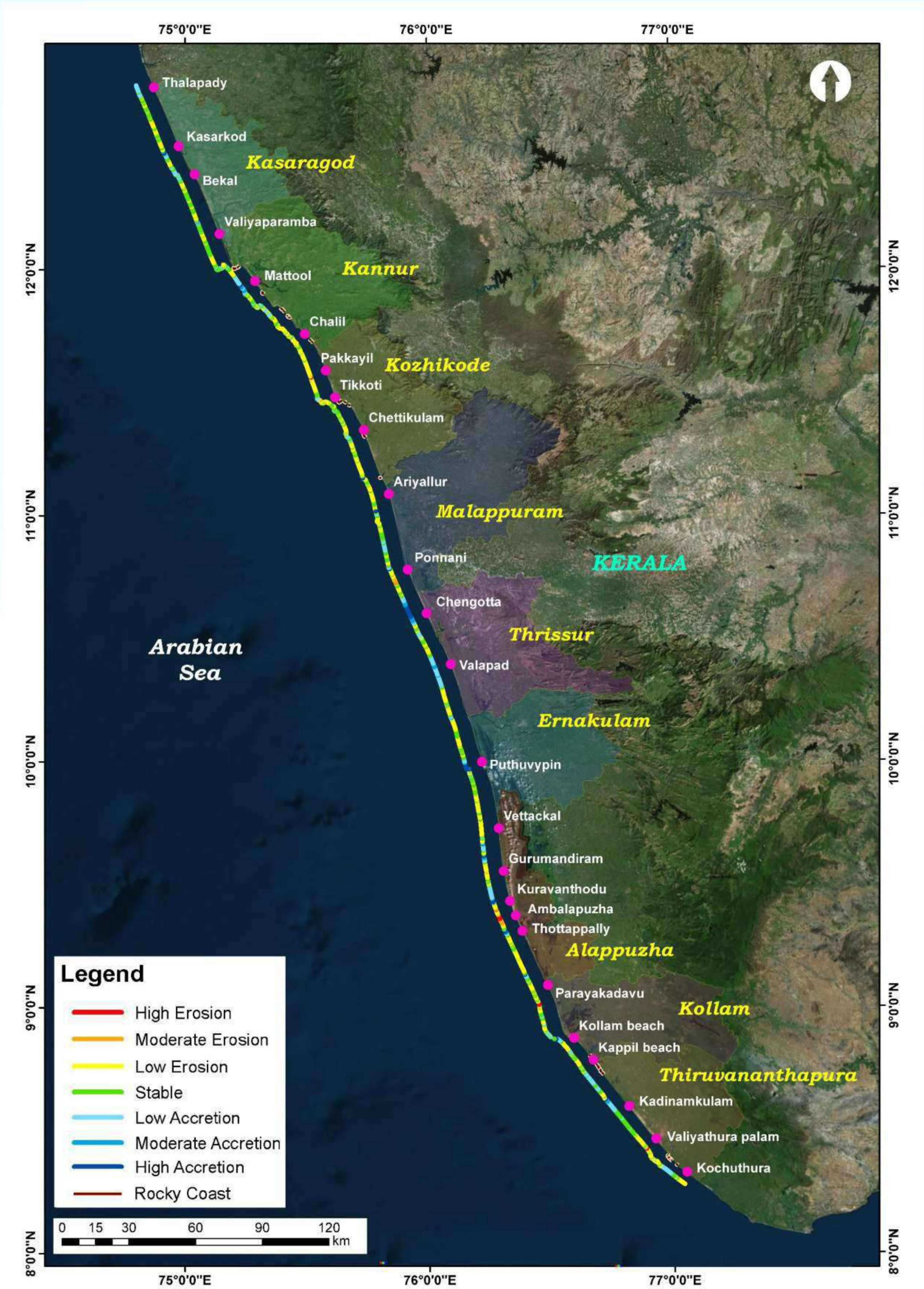


Figure 50: State map.

Hot spot locations overlaid with satellite images

From shoreline results, hot spot regions were identified for each state separately. The hot spot locations were overlaid with satellite imagery to give a clear picture of accretion/erosion change.

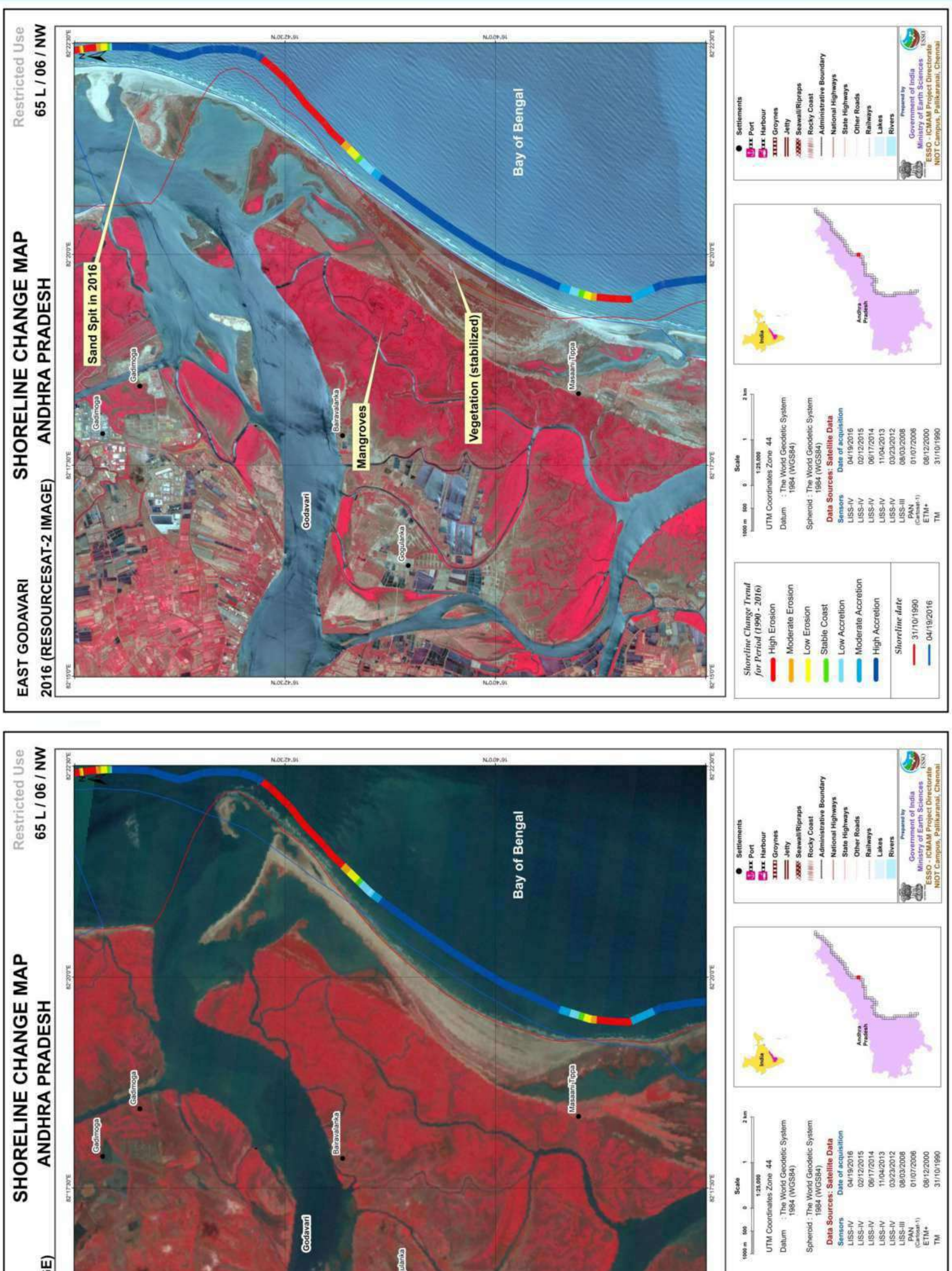


Figure 51: Hot-spot map.

5.0 References

- *Blott, S.J., Pye. K., 2001. GRADISTAT: a grain size distribution and statistics package for the analysis of unconsolidated sediments. Earth Surface Processes and Landforms, Vol. 26, No 11, 1237-1248.*
- *Braud DH, Feng W (1998) Semi-automated Construction of the Luisiana Coastline Digital Land/Water Boundary Using Landsat Thematic Mapper Satellite Imagery. Technical Report 97-002, Department of Geography & Anthropology, Luisina State University. Luisiana Applied Oil Spill Research and Development Program, OSRAPD, 1998.*
- *Ch. Guru prasad, Gaddem. Narasimha Rao (2014) Global warming affects on fishing village in India (A case study on Andhra coastal village: Uppada). Journal of Applied Geology and Geophysics. Volume 2, Issue 2 Ver. II. (2014), PP 50-56.*
- *Chalabi A, Mohd-Lokman H, Mohd-Suffian I, Karamali K, Karthigeyan V, Masita M (2006) Monitoring shoreline change using Ikonos image and aerial photographs: a case study of Kuala Terengganu area, Malaysia. In: Proceedings of the ISPRS Mid-term Symposium Proceeding. Enschede, Netherlands.*
- *COASTAL ENGINEERING RESEARCH CENTER, 1984. Shore Protection Manual, Volumes 1 and 2. Washington, DC: US Army Corps of Engineers, Waterways Experiment Station, Coastal Engineering Research Center.*
- *Ellis M Y (1978). Coastal Mapping Handbook. Department of the Interior, U.S. Geological Survey and U.S. Department of Commerce, National Ocean Service and Office of Coastal Zone Management, U.S. Government Printing Office, Washington, DC.*
- *Fenster, M.S., Dolan, R., 1999.Mapping erosion hazard areas in the city of Virginia Beach: Journal of Coastal Research, Special Issue 28, 58-68.*
- *Fisher, J.S., Overton, M.F., 1994. Interpretation of shoreline position from aerial photographs. Proceedings of the 24th International Conference on Coastal Engineering (Kobe, Japan), pp. 1998–2003.*
- *Folk, R.L., Ward, W.C., 1957. Brazos River Bar – a study in the significance of grain size parameters. Journal of Sedimentary Petrology, Vol. 27, No. 1, 3-26.*
- *Frazier PS, Page KJ (2000) Water body detection and delineation with Landsat TM data. PhotogrammEng Remote Sens 66(12): 147–167.*
- *Galgano, F.A. Leatherman, S.P., 1991. Shoreline change analysis: a case study. Coastal sediments 91 (ASCE), pp. 1043-53.*
- *Hicks SD (1984). Tide and Current Glossary. NOAA/National Ocean Service, Rockville, MD.*
- *Hoeke, R.K., Zarillo, G.A., Snyder, M., 2001. A GIS based tool for extracting shoreline positions from aerial imagery (Beachtools). Coastal and Hydraulics Laboratory Technical Note ERDC/CHL CHETN-IV-37, U.S. Army Engineer Research and Development Centre, Vicksburg, MS.*

- *Liu H, Jezek KC (2004) Automated extraction of coastline from satellite imagery by Integrating canny edge detection and locally adaptive thresholding Methods. Int J Remote Sens 25(5): 937–958.*
- *Mas JF (1999). Monitoring land-cover changes: a comparison of change detection techniques. Int J Remote Sens 20: 139-152.*
- *Moore, L.J., Benumof, B.T., Griggs, G.B., 1998. Coastal Erosion Hazards in Santa Cruz and San Diego Counties, California. Journal of Coastal Research 28, 121-139.*
- *Nayak. S. Use of satellite data in coastal mapping. Indian Cartographer. 2002. 5.*
- *Norcross, Z.M., Fletcher, C.H., Merrifield, M. 2002. Annual inter annual changes on a reef-fringed pocket beach: Kailua Bay, Hawaii. Marine Geology 190, 553-580.*
- *Overton, M.F., Grenier, R.R., Judge, E.K., Fisher, J.S., 1999. Identification and analysis of coastal erosion hazard areas: Dare and Brunswick Counties, North Carolina. Journal of Coastal Research Special Issue No. 28, 69-84.*
- *Ryu JH, Won JS and Min KD (2002). Waterline extraction from Landsat TM data in a tidal flat. A case study in Gomso Bay, Korea. Remote Sensing of Environment, 83, 442–456.*
- *Shalowitz AL (1962). Shore and Sea Boundaries, with Special Reference to the Interpretation and Use of Coast and Geodetic Survey Data. Vol 1, Pub 10-1, U.S. Department of Commerce, Coast and Geodetic Survey, U.S. Government Printing Office, Washington, DC.*
- *Stafford, D.B. Langfelder J., 1971. Air photo survey for coastal erosion. Photogrametric Engineering. No.6. 556-575.*
- *Stockdon HF, Sallenger AH, List JH, Holman RA (2002) Estimation of shoreline position and change using airborne topographic Lidar data. J Coastal Res 18(3): 502-513.*
- *Stockdon, H.F., Sallenger, A.H., List, J.H., Holman, R.A., 2002. Estimation of shoreline position and change using airborne topographic Lidar data. Journal of Coastal Research 18(3), 502-513.*
- *Thieler ER, Himmelstoss EA, Zichichi JL and Miller TL (2005). Digital Shoreline Analysis System (DSAS), http://woodshole.er.usgs.gov/project-pages/dsas/.*
- *Zhang K, Douglas BC and Leatherman SP (2002). Do storms cause long-term beach erosion along the U.S. East Barrier Coast? Journal of Geology, 110, 493–502.*

6.0 Publications made from this work

- *S. Chenthamil Selvan, R. S. Kankara, Vipin J. Markose, B. Rajan and K. Prabhu, 2015. Shoreline change and impacts of coastal protection structures on Puducherry, SE coast of India. Natural Hazards, (Springer), 83(1), 293-308. DOI10.1007/s11069-016-2332-y.*
- *Vipin J. Markose, B. Rajan, R. S. Kankara, S. Chenthamil Selvan and Dhanalakshmi.2016. Quantitative analysis of temporal variations on shoreline change pattern along Ganjam district, Odisha, east coast of India. Environmental Earth Sciences, Vol. 75, No. 10, 75:929 DOI 10.1007/s12665-016-5723-1.*
- *S. Sathish, R. S. Kankara, S. Chenthamil Selvan, M. Umamaheswari, K. Rasheed. Wave–beach sediment interaction with shoreline changes along a headland bounded pocket beach, West coast of India. Environmental Earth Sciences (2018) 77:174.*
- *R.S. Kankara, S. Chenthamil Selvan, Vipin J. Markose, B. Rajan&S. Arockiaraj. (Estimation of long and short term shoreline changes along Andhra Pradesh coast using Remote Sensing and GIS techniques). Procedia Engineering Vol 116, 2015 Pages 855–86.*
- *Sathish S, R.S. Kankara, S. Chenthamil Selvan, Manikandan M, Arockiaraj S &Rajan B. (Textural Characterization of Coastal Sediments along Tamil Nadu coast, East coast of India). Procedia Engineering Vol 116, 2015 Pages 794–804.*
- *R.S. Kankara, S. Chenthamil Selvan, B. Rajan&S. Arockiaraj. (An adaptive approach to monitor the Shoreline changes in ICZM framework: A case study of Chennai coast). Indian Journal of Marine Sciences Vol. 43(7), July 2014, pp 1271-1279.*
- *S. Chenthamil Selvan, R.S. Kankara& B. Rajan. (Assessment of shoreline changes along Karnataka coast, India using GIS & Remote sensing techniques). Indian Journal of Marine Sciences Vol. 43(7), July 2014, pp 1293-1298.*

Annexure - I

LIST OF SHORELINE CHANGE MAPS (1990-2016) in 1:25000

GUJARAT

SL NO	DISTRICT	GRIDS	SL NO	DISTRICT	GRIDS
1	Kachchh	41 A / 2 / NE	51	Jamnagar	41 J / 2 / SW
2	Kachchh	41 A / 2 / SE	52	Jamnagar	41 F / 14 / SE
3	Kachchh	41 A / 6 / SW	53	Jamnagar	41 F / 15 / NE
4	Kachchh	41 A / 6 / NW	54	Jamnagar	41 F / 15 / SW
5	Kachchh	41 A / 6 / NE	55	Jamnagar	41 F / 15 / NW
6	Kachchh	41 A / 9 / SW	56	Dev Bhumi Dwarka & Jamnagar	41 F / 11 / NE
7	Kachchh	41 A / 9 / SE	57	Dev Bhumi Dwarka & Jamnagar	41 F / 11 / SE
8	Kachchh	41 A / 10 / NW	58	Dev Bhumi Dwarka	41 F / 11 / SW
9	Kachchh	41 A / 10 / SW	59	Dev Bhumi Dwarka	41 F / 7 / SE
10	Kachchh	41 A / 6 / SE	60	Dev Bhumi Dwarka	41 F / 7 / SW
11	Kachchh	41 A / 11/ NW	61	Dev Bhumi Dwarka	41 F / 3 / SE
12	Kachchh	41 A / 11 / SW	62	Dev Bhumi Dwarka	41 F / 3 / NE
13	Kachchh	41 A / 11 / SE	63	Dev Bhumi Dwarka	41 F / 3 / NW
14	Kachchh	41 A / 12 / NW	64	Dev Bhumi Dwarka	41 B / 15 / NE
15	Kachchh	41 A / 12 / NE	65	Dev Bhumi Dwarka	41 B / 15 / SE
16	Kachchh	41 A / 12 / SE	66	Dev Bhumi Dwarka	41 B / 16 / NE
17	Kachchh	41 A / 16 / SW	67	Dev Bhumi Dwarka	41 F / 4 / NW
18	Kachchh	41 A / 16 / SE	68	Dev Bhumi Dwarka	41 F / 4 / SW
19	Kachchh	41 B / 13 / NE	69	Dev Bhumi Dwarka	41 F / 4 / SE
20	Kachchh	41 F / 1 / NW	70	Dev Bhumi Dwarka	41 G / 1 / NE
21	Kachchh	41 F / 1 / NE	71	Dev Bhumi Dwarka	41 G / 5 / NW
22	Kachchh	41 F / 1 / SE	72	Dev Bhumi Dwarka	41 G / 5 / SW
23	Kachchh	41 F / 5 / SW	73	Porbandar & Dev Bhumi Dwarka	41 G / 5 / SE
24	Kachchh	41 F / 5 / SE	74	Porbandar	41 G / 6 / NE
25	Kachchh	41 F / 9 / SW	75	Porbandar	41 G / 10 / NW
26	Kachchh	41 F / 10 / NW	76	Porbandar	41 G / 10 / SW
27	Kachchh	41 F / 10 / NE	77	Porbandar	41 G / 10 / SE
28	Kachchh	41 F / 9 / SE	78	Porbandar	41 G / 11 / NE
29	Kachchh	41 F / 13 / NW	79	Porbandar	41 G / 15 / NW
30	Kachchh	41 F / 13 / SW	80	Porbandar	41 G / 15 / SW
31	Kachchh	41 F / 13 / SE	81	Junagadh & Porbandar	41 G / 15 / SE
32	Kachchh	41 F / 13 / NE	82	Junagadh & Porbandar	41 G / 16 / NE
33	Kachchh	41 J / 1 / NW	83	Junagadh & Porbandar	41 K / 4 / NW
34	Kachchh	41 I / 4 / SW	84	Junagadh	41 K / 4 / SW
35	Kachchh	41 J / 1 / NE	85	Junagadh	41 K / 4 / SE
36	Kachchh	41 I / 4 / SE	86	Gir Somnath & Junagadh	41 L / 1 / NE
37	Kachchh	41 I / 4 / NE	87	Gir Somnath	41 L / 5 / NW
38	Kachchh	41 I / 8 / NW	88	Gir Somnath	41 L / 5 / NE
39	Kachchh	41 I / 8 / NE	89	Gir Somnath	41 L / 5 / SE
40	Kachchh	41 I / 12 / NW	90	Gir Somnath	41 L / 9 / SW
41	Morvi& Kachchh	41 I / 12 / NE	91	Gir Somnath	41 L / 9 / SE
42	Morvi	41 I / 12 / SE	92	Gir Somnath	41 L / 10 / NE
43	Morvi	41 I / 12 / SW	93	Gir Somnath	41 L / 14 / NW
44	Jamnagar &Morvi	41 J / 9 / NW	94	Diu &Gir Somnath	41 L / 14 / NE
45	Jamnagar &Morvi	41 J / 5 / NE	95	Diu &Gir Somnath	41 P / 2 / NW
46	Jamnagar	41 J / 5 / SE	96	Gir Somnath	41 P / 1 / SW
47	Jamnagar	41 J / 6 / NE	97	Diu &Gir Somnath & Amreli	41 P / 1 / SE
48	Jamnagar	41 J / 6 / NW	98	Amreli	41 P / 5 / SW
49	Jamnagar	41 J / 2 / NE	99	Amreli	41 P / 5 / SE
50	Jamnagar	41 J / 2 / SE	100	Amreli	41 P / 5 / NE

SL NO	DISTRICT	GRIDS	SL NO	DISTRICT	GRIDS
101	Amreli	41 P / 9 / NW	126	Bharuch & Anand	46 B / 12 / NW
102	Amreli & Bhavnagar	41 P / 9 / NE	127	Bharuch	46 B / 12 / SW
103	Amreli & Bhavnagar	41 O / 12 / SE	128	Bharuch	46 C / 9 / NW
104	Bhavnagar	41 O / 16 / SW	129	Bharuch	46 C / 9 / SW
105	Bhavnagar	41 O / 16 / SE	130	Bharuch	46 C / 9 / SE
106	Bhavnagar	41 O / 16 / NE	131	Bharuch	46 C / 10 / NE
107	Bhavnagar	46 C / 4 / NW	132	Bharuch	46 C / 10 / NW
108	Bhavnagar	46 C / 3 / SW	133	Bharuch	46 C / 10 / SW
109	Bhavnagar	46 C / 3 / SE	134	Bharuch	46 C / 10 / SE
110	Bhavnagar	46 C / 3 / NE	135	Surat & Bharuch	46 C / 11 / NE
111	Bhavnagar	46 C / 7 / NW	136	Surat	46 C / 11 / SE
112	Bhavnagar	46 C / 6 / SW	137	Surat	46 C / 11 / SW
113	Bhavnagar	46 C / 6 / NW	138	Surat	46 C / 12 / NE
114	Bhavnagar	46 C / 2 / NE	139	Surat	46 C / 12 / SW
115	Bhavnagar	46 C / 1 / SE	140	Navsari& Surat	46 C / 12 / SE
116	Bhavnagar & Ahmadabad	46 C / 1 / NE	141	Navsari	46 D / 9 / NE
117	Bhavnagar & Ahmadabad	46 B / 4 / SE	142	Navsari	46 D / 13 / NW
118	Ahmadabad	46 B / 8 / SW	143	Valsad &Navsari	46 D / 13 / SW
119	Ahmadabad	46 B / 8 / NW	144	Valsad	46 D / 14 / NW
120	Ahmadabad	46 B / 4 / NE	145	Valsad	46 D / 14 / NE
121	Anand & Ahmadabad	46 B / 7 / SW	146	Valsad	46 D / 14 / SE
122	Anand & Ahmadabad	46 B / 7 / SE	147	Daman & Valsad	46 D / 15 / NE
123	Anand	46 B / 11 / SW	148	Daman & Valsad	46 D / 15 / NW
124	Anand	46 B / 11 / SE	149	Valsad	46 D / 15 / SW
125	Bharuch & Anand	46 B / 12 / NE	150	Valsad	46 D / 11 / SE

MAHARASHTRA

SL NO	DISTRICTS	GRIDS	SL NO	DISTRICTS	GRIDS
1	Thane	46 D / 12 / NE	26	Ratnagiri	47 G / 2 / NW
2	Thane	46 D / 12 / SE	27	Ratnagiri	47 G / 2 / SE
3	Thane	47 A / 10 / NE	28	Ratnagiri	47 G / 3 / NE
4	Thane	47 A / 10 / SE	29	Ratnagiri	47 G / 3 / SE
5	Thane	47 A / 11 / NE	30	Ratnagiri	47 G / 4 / NE
6	Thane	47 A / 14 / SW	31	Ratnagiri	47 G / 8 / NW
7	Thane	47 A / 15 / NW	32	Ratnagiri	47 G / 8 / SW
8	Thane & Mumbai	47 A / 15 / SW	33	Ratnagiri	47 H / 5 / NW
9	Mumbai	47 A / 16 / NW	34	Ratnagiri	47 H / 5 / SW
10	Mumbai	47 A / 16 / SW	35	Ratnagiri	47 H / 6 / NW
11	Thane	47 A / 9 / NE	36	Sindhudurg & Ratnagiri	47 H / 6 / SW
12	Thane	47 A / 9 / SE	37	Sindhudurg	47 H / 7 / NW
13	Mumbai	47 B / 13 / NW	38	Sindhudurg	47 H / 7 / SE
14	Raigarh	47 B / 13 / SW	39	Sindhudurg	47 H / 7 / SW
15	Raigarh	47 B / 14 / NE	40	Sindhudurg	47 H / 8 / NE
16	Raigarh	47 B / 14 / NW	41	Sindhudurg	47 H / 8 / SE
17	Raigarh	47 B / 14 / SE	42	Sindhudurg	48 E / 5 / NE
18	Raigarh	47 B / 15 / NE	43	Sindhudurg	48 E / 9 / NW
19	Raigarh	47 B / 15 / SE	44	Sindhudurg	48 E / 9 / SE
20	Raigarh	47 B / 16 / NE	45	Sindhudurg	48 E / 9 / SW
21	Raigarh	47 B / 16 / SE			
22	Raigarh	47 F / 4 / SW			
23	Raigarh& Ratnagiri	47 G / 1 / NW			
24	Ratnagiri	47 G / 1 / SW			
25	Ratnagiri	47 G / 2 / NE			

GOA AND KARNATAKA

SL NO	DISTRICTS	GRIDS	SL NO	DISTRICTS	GRIDS
1	North Goa & Sindhudurg	48 E / 10 / NE	17	Uttara Kannada	48 J / 7 / NE
2	North Goa	48 E / 10 / SE	18	Uttara Kannada	48 J / 7 / NW
3	North Goa	48 E / 14 / SW	19	Uttara Kannada	48 J / 7 / SE
4	South Goa & North Goa	48 E / 15 / NW	20	Uttara Kannada	48 J / 8 / NE
5	South Goa	48 E / 15 / SE	21	Uttara Kannada	48 J / 8 / SE
6	South Goa	48 E / 15 / SW	22	Udupi	48 K / 10 / NE
7	South Goa	48 E / 16 / NE	23	Udupi	48 K / 10 / SE
8	South Goa	48 E / 16 / SE	24	Udupi	48 K / 11 / NE
9	South Goa	48 I / 4 / SW	25	Udupi	48 K / 11 / SE
10	Uttara Kannada & South Goa	48 J / 1 / NW	26	Udupi	48 K / 12 / NE
11	Uttara Kannada	48 J / 1 / SE	27	Udupi	48 K / 16 / NW
12	Uttara Kannada	48 J / 1 / SW	28	Dakshina Kannada & Udupi	48 K / 16 / SW
13	Uttara Kannada	48 J / 12 / SW	29	Udupi & Uttara Kannada	48 K / 9 / NW
14	Uttara Kannada	48 J / 2 / NE	30	Udupi	48 K / 9 / SE
15	Uttara Kannada	48 J / 6 / NW	31	Udupi	48 K / 9 / SW
16	Uttara Kannada	48 J / 6 / SW	32	Dakshina Kannada	48 L / 13 / NW

KERALA

SL NO	DISTRICTS	GRIDS	SL NO	DISTRICTS	GRIDS
1	Kasaragod	48 L / 13 / SW	29	Thrissur	58 B / 3 / NW
2	Kasaragod	48 L / 14 / NE	30	Thrissur	58 B / 3 / SE
3	Kasaragod	48 L / 14 / NW	31	Thrissur	58 B / 3 / SW
4	Kasaragod	48 L / 14 / SE	32	Thrissur & Ernakulam	58 B / 4 / NE
5	Kasaragod	48 L / 15 / NE	33	Ernakulam	58 B / 4 / SE
6	Kasaragod	48 P / 3 / NW	34	Ernakulam	58 C / 1 / NE
7	Kasaragod	48 P / 3 / SW	35	Alappuzha & Kollam	58 C / 12 / SW
8	Kannur & Kasaragod	48 P / 4 / NE	36	Ernakulam &Alappuzha	58 C / 5 / NW
9	Kasaragod	48 P / 4 / NW	37	Ernakulam & Alappuzha & Kottayam	58 C / 5 / SW
10	Kannur & Kasaragod	48 P / 4 / SE	38	Alappuzha	58 C / 6 / NW
11	Kannur	48 P / 8 / SW	39	Alappuzha	58 C / 6 / SW
12	Kozhikode	49 M / 10 / SW	40	Alappuzha	58 C / 7 / NW
13	Kozhikode	49 M / 11 / NE	41	Alappuzha &Pathanamthitta	58 C / 7 / SE
14	Kozhikode	49 M / 11 / NW	42	Alappuzha	58 C / 7 / SW
15	Kozhikode	49 M / 11 / SE	43	Alappuzha	58 C / 8 / NE
16	Kozhikode	49 M / 15 / SW	44	Alappuzha & Kollam	58 C / 8 / SE
17	Malappuram & Kozhikode	49 M / 16 / NW	45	Thiruvananthapuram	58 D / 10 / NE
18	Malappuram	49 M / 16 / SW	46	Thiruvananthapuram	58 D / 14 / NW
19	Kannur	49 M / 5 / NW	47	Thiruvananthapuram	58 D / 14 / SE
20	Kannur	49 M / 5 / SE	48	Thiruvananthapuram	58 D / 14 / SW
21	Kannur	49 M / 5 / SW	49	Thiruvananthapuram	58 D / 15 / NE
22	Kannur	49 M / 6 / NE	50	Thiruvananthapuram	58 D / 15 / SE
23	Malappuram	49 N / 13 / NE	51	Kollam	58 D / 9 / NW
24	Malappuram	49 N / 13 / NW	52	Kollam &Thiruvananthapuram	58 D / 9 / SE
25	Malappuram	49 N / 13 / SE	53	Kollam	58 D / 9 / SW
26	Malappuram & Thrissur	49 N / 14 / NE	54	Kannur & Kozhikode &Mahe	49 M / 10 / NW
27	Thrissur	49 N / 14 / SE	55	Thiruvananthapuram & Kanyakumari	58 H / 3 / SW
28	Thrissur	58 B / 2 / SW			

TAMIL NADU

SL NO	DISTRICTS	GRIDS	SL NO	DISTRICTS	GRIDS
1	Cuddalore	58 M / 14 / NW	41	Ramanathapuram	58 K / 15 / SE
2	Cuddalore	58 M / 14 / SW	42	Ramanathapuram	58 K / 15 / SW
3	Cuddalore	58 M / 15 / NW	43	Ramanathapuram	58 K / 16 / NE
4	Kancheepuram	57 P / 16 / SE	44	Ramanathapuram	58 K / 16 / NW
5	Kancheepuram	66 D / 1 / SE	45	Ramanathapuram	58 K / 8 / NE
6	Kancheepuram	66 D / 2 / NE	46	Ramanathapuram	58 K / 8 / SE
7	Kancheepuram	66 D / 2 / SE	47	Ramanathapuram	58 O / 7 / SW
8	Kancheepuram	66 D / 3 / NE	48	Ramanathapuram	58 O / 2 / NW
9	Kancheepuram	66 D / 3 / NW	49	Ramanathapuram	58 O / 3 / SE
10	Kancheepuram	66 D / 3 / SW	50	Ramanathapuram	58 O / 3 / SW
11	Kancheepuram	66 D / 4 / NW	51	Ramanathapuram	58 O / 8 / NE
12	Kancheepuram	66 D / 5 / NW	52	Ramanathapuram	58 O / 8 / NW
13	Kancheepuram	66 D / 5 / SW	53	Ramanathapuram&Thoothukudi	58 K / 8 / SW
14	Kanniyakumari	58 H / 12 / SW	54	Thanjavur	58 N / 4 / NE
15	Kanniyakumari	58 H / 3 / SE	55	Thanjavur	58 N / 7 / SW
16	Kanniyakumari	58 H / 4 / NE	56	Thanjavur	58 N / 8 / NW
17	Kanniyakumari	58 H / 8 / NW	57	Thiruvallur	66 C / 7 / SW
18	Kanniyakumari	58 H / 8 / SE	58	Thiruvallur	66 C / 8 / NW
19	Kanniyakumari	58 H / 8 / SW	59	Thiruvallur	66 C / 8 / SW
20	Karaikal	58 N / 13 / NW	60	Thiruvarur	58 N / 11 / SW
21	Nagapattinam	58 M / 15 / SW	61	Thiruvarur&Thanjavur	58 N / 7 / SE
22	Nagapattinam	58 M / 16 / NW	62	Thoothukudi	58 L / 1 / SE
23	Nagapattinam	58 M / 16 / SW	63	Thoothukudi	58 L / 1 NE
24	Nagapattinam	58 N / 14 / NW	64	Thoothukudi	58 L / 2 / NE
25	Nagapattinam	58 N / 14 / SW	65	Thoothukudi	58 L / 2 / SE
26	Nagapattinam	58 N / 15 / NW	66	Thoothukudi	58 L / 2 / SW
27	Nagapattinam	58 N / 15 / SE	67	Thoothukudi	58 L / 3 / NW
28	Nagapattinam	58 N / 15 / SW	68	Thoothukudi	58 L / 3 / NE
29	Nagapattinam&Karaikal	58 N / 13 / SW	69	Thoothukudi	58 L / 3 / SW
30	Nagapattinam&Thiruvarur	58 N / 11 / SE	70	Thoothukudi	58 L / 5 / NW
31	Pudukkottai	58 N / 4 / SE	71	Thoothukudi& Tirunelveli	58 H / 15 / SE
32	Pudukkottai	58 N / 8 / SW	72	Thoothukudi& Tirunelveli	58 H / 15 / SW
33	Pudukkottai	58 O / 1 / NE	73	Tirunelveli	58 H / 12 / NE
34	Pudukkottai	58 O / 1 / NW	74	Tirunelveli	58 H / 16 / NW
35	Pudukkottai &Ramanathapuram	58 O / 1 / SW	75	Tirunelveli &Kanniyakumari	58 H / 12 / NW
36	Ramanathapuram	58 K / 12 / NE	76	Villupuram	57 P / 16 / SW
37	Ramanathapuram	58 K / 12 / NW	77	Villupuram & Kancheepuram	57 P / 16 / NE
38	Ramanathapuram	58 K / 14 / NE	78	Cuddalore& Puducherry	58 M / 13 / SW
39	Ramanathapuram	58 K / 14 / SE	79	Puducherry & Villupuram	58 M / 13 / NW
40	Ramanathapuram	58 K / 15 / NE	80	Thiruvallur& Nellore	66 C / 7 / NW

ANDHRA PRADESH

SL NO	DISTRICT	GRIDS	SL NO	DISTRICT	GRIDS
1	Nellore	66 C / 6 / SW	46	East Godavari	65 L / 3 / NW
2	Nellore	66 C / 2 / SE	47	East Godavari	65 L / 3 / NE
3	Nellore	66 C / 2 / NE	48	East Godavari	65 L / 2 / SE
4	Nellore	66 C / 5 / SW	49	East Godavari	65 L / 6 / SW
5	Nellore	66 C / 1 / SE	50	East Godavari	65 L / 6 / NW
6	Nellore	66 C / 1 / NE	51	East Godavari	65 L / 5 / SW
7	Nellore	66 B / 4 / SE	52	East Godavari	65 L / 5 / NW
8	Nellore	66 B / 4 / NE	53	East Godavari	65 K / 8 / SW
9	Nellore	66 B / 3 / SE	54	East Godavari	65 K / 8 / SE
10	Nellore	66 B / 3 / NE	55	East Godavari	65 K / 8 / NE
11	Nellore	66 B / 2 / SE	56	East Godavari &Vishakhapattinam	65 K / 12 / NW
12	Nellore	66 B / 2 / NE	57	Vishakhapattinam	65 K / 11 / SW
13	Nellore	66 B / 2 / NW	58	Vishakhapattinam	65 K / 11 / SE
14	Nellore	66 B / 1 / SW	59	Vishakhapattinam	65 K / 15 / SW
15	Nellore &Prakasam	66 B / 1 / NW	60	Vishakhapattinam	65 K / 15 / NW
16	Prakasam	66 A / 4 / SW	61	Vishakhapattinam	65 K / 15 / NE
17	Prakasam	66 A / 4 / NW	62	Vishakhapattinam	65 O / 3 / NW
18	Prakasam	66 A / 3 / SW	63	Vishakhapattinam	65 O / 2 / SW
19	Prakasam	66 A / 3 / SE	64	Vishakhapattinam	65 O / 2 / SE
20	Prakasam	66 A / 3 / NE	65	Vishakhapattinam	65 O / 2 / NE
21	Prakasam	66 A / 2 / SE	66	Vishakhapattinam	65 O / 6 / NW
22	Prakasam	66 A / 2 / NE	67	Vishakhapattinam	65 O / 5 / SW
23	Prakasam	66 A / 6 / NW	68	Vishakhapattinam&Vizhiyanagaram	65 O / 5 / SE
24	Prakasam& Guntur	66 A / 5 / SW	69	Vizhiyanagaram	65 O / 5 / NE
25	Guntur	66 A / 5 / SE	70	Vizhiyanagaram	65 O / 9 / NW
26	Guntur	66 A / 9 / SW	71	Vizhiyanagaram	65 N / 12 / SW
27	Guntur	66 A / 9 / SE	72	Vizhiyanagaram& Srikakulam	65 N / 12 / SE
28	Guntur	66 A / 9 / NE	73	Srikakulam	65 N / 12 / NE
29	Guntur & Krishna	66 A / 13 / SW	74	Srikakulam	65 N / 16 / NW
30	Krishna	66 A / 14 / NW	75	Srikakulam	65 N / 16 / NE
31	Krishna	66 A / 14 / NE	76	Srikakulam	74 B / 4 / NW
32	Krishna	66 A / 13 / SE	77	Srikakulam	74 B / 3 / SW
33	Krishna	66 E / 1 / SW	78	Srikakulam	74 B / 3 / SE
34	Krishna	66 E / 1 / NW	79	Srikakulam	74 B / 3 / NE
35	Krishna	66 E / 1 / NE	80	Srikakulam	74 B / 7 / NW
36	Krishna	65 H / 4 / SE	81	Srikakulam	74 B / 6 / SW
37	Krishna	65 H / 4 / NE	82	Srikakulam	74 B / 6 / SE
38	Krishna	65 H / 3 / SE	83	Srikakulam	74 B / 6 / NE
39	Krishna	65 H / 7 / SW	84	Srikakulam	74 B / 10 / NW
40	Krishna	65 H / 7 / SE	85	Srikakulam	74 B / 9 / SW
41	Krishna & West Godavari	65 H / 11 / SW	86	Srikakulam	74 B / 9 / NW
42	West Godavari & East Godavari	65 H / 11 / SE	87	Srikakulam	74 B / 9 / NE
43	East Godavari	65 H / 15 / SW	88	Srikakulam &Ganjam	74 A / 12 / SE
44	East Godavari	65 H / 15 / NW	89	Ganjam& Srikakulam	74 A / 16 / SW
45	East Godavari	65 H / 15 / NE			

ODISHA

SL NO	DISTRICTS	GRIDS	SL NO	DISTRICTS	GRIDS
1	Balasore	73 K / 15 / NE	24	Jagatsinghpur	74 I / 5 / NE
2	Balasore	73 K / 15 / SE	25	Jagatsinghpur&Kendrapara	73 L / 11 / SE
3	Balasore	73 K / 15 / SW	26	Jagatsinghpur&Kendrapara	73 L / 15 / SW
4	Balasore	73 O / 2 / SE	27	Kendrapara	73 L / 11 / NE
5	Balasore	73 O / 2 / SW	28	Kendrapara	73 L / 14 / NE
6	Balasore	73 O / 3 / NW	29	Kendrapara	73 L / 14 / SE
7	Balasore	73 O / 6 / SW	30	Kendrapara	73 L / 14 / SW
8	Bhadrak	73 K / 16 / SE	31	Kendrapara	73 L / 15 / NW
9	Bhadrak	73 K / 16 / SW	32	Kendrapara	73 P / 2 / NW
10	Bhadrak	73 L / 13 / NE	33	Kendrapara&Bhadrak	73 L / 13 / SE
11	Bhadrak	73 P / 1 / SW	34	Puri	74 E / 10 / NE
12	Bhadrak&Balasore	73 K / 16 / NW	35	Puri	74 E / 10 / NW
13	Ganjam	74 A / 15 / SE	36	Puri	74 E / 13 / SE
14	Ganjam	74 A / 16 / NE	37	Puri	74 E / 13 / SW
15	Ganjam	74 A / 16 / NW	38	Puri	74 E / 6 / NE
16	Ganjam	74 E / 3 / NE	39	Puri	74 E / 6 / SE
17	Ganjam	74 E / 3 / NW	40	Puri	74 E / 6 / SW
18	Ganjam	74 E / 3 / SW	41	Puri	74 E / 9 / SE
19	Ganjam&Puri	74 E / 2 / SE	42	Puri	74 I / 1 / NE
20	Jagatsinghpur	73 L / 12 / NE	43	Puri	74 I / 1 / SE
21	Jagatsinghpur	73 L / 12 / NW	44	Puri	74 I / 1 / SW
22	Jagatsinghpur	73 L / 8 / NE	45	Puri&Jagatsinghpur	74 I / 5 / NW
23	Jagatsinghpur	73 L / 8 / SE	46	Balasore&East midnapore	73 O / 6 / SE

WEST BENGAL

SL NO	DISTRICTS	GRIDS	SL NO	DISTRICTS	GRIDS
1	East midnapore	73 O / 10 /SW	16	South 24 parganas	79 C / 6 /NE
2	South 24 parganas	79 C / 2 /SE	17	South 24 parganas	79 C / 10 /NW
3	South 24 parganas	79 C / 6 /SW	18	North 24 parganas	79 C / 10 /NE
4	South 24 parganas	79 C / 6 /SE	19	North 24 parganas	79 C / 14 /NW
5	South 24 parganas	79 C / 10 /SW	20	North 24 parganas	79 C / 14 /NE
6	North 24 parganas	79 C / 10 /SE	21	North 24 parganas	79 G / 2 /NW
7	North 24 parganas	79 C / 14 /SW	22	East midnapore	73 O / 13 /SW
8	North 24 parganas	79 C / 14 /SE	23	East midnapore	73 O / 13 /SE
9	North 24 parganas	79 G / 2 /SW	24	South 24 parganas	79 C / 1 /SW
10	East midnapore	73 O / 10 /NW	25	South 24 parganas	79 C / 1 /SE
11	East midnapore	73 O / 10 /NE	26	South 24 parganas	79 C / 5 /SW
12	East midnapore	73 O / 14 /NW	27	South 24 parganas	79 C / 5 /SE
13	South 24 parganas	79 C / 2 /NW	28	South 24 parganas	79 C / 1 /NE
14	South 24 parganas	79 C / 2 /NE	29	South 24 parganas	73 C / 2 / SW
15	South 24 parganas	79 C / 6 /NW			

सत्यमेव जयते

Contact Us:

National Centre for Coastal Research
2nd Floor, NIOT Campus,
Velacherry-Tambaram Main Road,
Pallikkaranai,Chennai - 600100, India
Tel: +91 44 66783589 Fax: +91 44 66783487
Email: kankara@nccr.gov.in