MODELING OF SHORELINE CONFIGURATION ALONG RAMESHWARAM ISLAND, EAST COAST OF INDIA

Thesis

Submitted in partial fulfillment of the requirements for the degree of

DOCTOR OF PHILOSOPHY

by

GOWTHAMAN, R.

DEPARTMENT OF APPLIED MECHANICS AND HYDRAULICS

NATIONAL INSTITUTE OF TECHNOLOGY KARNATAKA

SURATHKAL, MANGALURU-575 025

FEBRUARY 2016

D E C L A R A T I O N

By the Ph.D. Research Scholar

I hereby declare that the Research Thesis entitled **Modeling of Shoreline Configuration along Rameshwaram Island, East Coast of India,** which is being submitted to the **National Institute of Technology Karnataka, Surathkal,** in partial fulfilment of the requirements for the award of the Degree of **Doctor of Philosophy** in the Department of **Applied Mechanics and Hydraulics** is a *bonafide report of the research work* carried out by me. The material contained in this Research Thesis has not been submitted to any University or Institution for the award of any degree.

GOWTHAMAN, R.

Register No. 092026AM09P01

Department of Applied Mechanics and Hydraulics

Place: NITK, Surathkal

Date:

C E R T I F I C A T E

This is to certify that the Research Thesis entitled **Modeling of Shoreline Configuration along Rameshwaram Island, East Coast of India,** submitted by **GOWTHAMAN, R.** (Register Number: 092026AM09P01) as the record of the research work carried out by him, is accepted as the Research Thesis submission in partial fulfilment of the requirements for the award of degree of the **Doctor of Philosophy**.

Dr. G.S. Dwarakish
Research Guide and Head of the Department
Department of Applied Mechanics and Hydraulics

Chairman - DRPC
(Signature with Date and Seal)

ACKNOWLEDGEMENT

I would like to express my heartfelt thanks and gratitude to my supervisor, **Prof. G.S. Dwarakish,** for insightful guidance, continued inspiration and support, and great patience throughout the duration of this research, which made this study possible. It is a valuable experience to learn many aspect from him, both a teacher and a perfect human being. I also thank **Dr. V. Sanil Kumar,** Senior Principal Scientist, Head Ocean Engineering Division (OED),CSIR- National Institute of Oceanography (NI0), Goa, India for his invaluable guidance, constant encouragement and support at every stage right from the commencement of my research career. His constant motivation and suggestions have immensely helped in completing the thesis within the stipulated time frame.

I am greatly indebted to Research Progress Appraisal Committee Members, Prof.Arkal Vittal Hegde, Department of Applied Mechanics and Hydraulics and Prof.N.N. Murulidhar, Department of Mathematics and Computational Science, for their critical evaluation and very useful suggestions during the progress of the work.

I would like to sincerely thank Prof. M.K. Nagaraj, Prof Subba Rao, and Prof. Kiran G. Shirlal, Department of Applied Mechanics and Hydraulics, and Prof. Katta Venkataramana, Dr. C.Rajasekaran and Ms. R. Shree Vidhya, Department of Civil Engineering, NITK, Surathkal, Mangalore.

I am thankful to Dr. S.W.A.Naqvi, Director, CSIR- National Institute of Oceanography, Goa, for encouragement and support. I wish to express my gratitude to, Dr. S. Mandal, Dr. S. Jaya Kumar, Mr. D. Ilangovan, Dr. V.J. Loveson, Mr. JaiSingh, Mr. P.Pednekar, and Mr. B. Satish Chitari, CSIR-NIO, Goa, for the suggestions and help.

I am grateful to Dr. Basanth Kumar Jena, Scientist, National Institute of ocean Technology (NIOT), Chennai, for his help and encouragement while using LITPACK model. I am thankful to Dr. P. Chandramohan, Managing Director, Indomer Coastal Hydraulics (P) Ltd, India, for his encouragement.

I sincerely acknowledge to Mr. Jagadish, Foreman, Mr. Balakrishna, Mr. Harish, Mrs. Prathima,, Mr. Gopal, Mr. Anand and Mr. Niranjan, Department of Applied Mechanics and Hydraulics fir their support and help during the research work.

I gratefully acknowledge the support and help rendered by Research Scholars of the Department of Applied Mechanics and Hydraulics at NITK, Surathkal, Dr. Raju Adla, Ms. B.P. Ganasri and Ms. Geetha S Kuntoji during the research work.

My thanks are also to each and everyone who has directly or indirectly helped and help during the reach work.

Without the support, patience and encouragement from my lovely family I could never have been able to submit the thesis. My most gratitude goes to my wife S. Uma Gowthaman, my two daughters, G. Devi Preetha and G. Divya Janani.

- GOWTHAMAN, R.

DEDICATED

TO

MY FAMILY

ABSTRACT

The shoreline, a line of contact between the land and ocean, undergoes continuous changes mainly due to the action of waves and longshore current. The geographical formation of Tamil Nadu coast plays a vital role in the movement of littoral drift around the Indian peninsular tip across the east and west coasts of India. Rameshwaram Island is one of the most ecologically sensitive island ecosystems of India and is surrounded by Palk Bay (PB) in the north and the Gulf of Mannar (GoM) in the south. Wave characteristics around Dhanushkodi are studied based on the measured data in the GoM and in the PB. Wave spectra are mainly double-peaked in the GoM and single peaked in the PB. High waves are observed in the GoM compared to PB. Wave heights are more in the GoM during the southwest monsoon period and the waves are from south-southwest. In the PB, high waves are found during the northeast monsoon period. Swells dominate the GoM, except during the southwest monsoon period, whereas wind seas exist in the PB as distant swells cannot reach the bay due to the protection by Indian peninsula and northern extremity of Sri Lanka. Wave-induced Longshore Sediment Transport (LST) plays an important role in the dynamics of the Dhanushkodi sand spit located southeast of Rameshwaram. The LST along the Dhanushkodi coast is studied based on data collected simultaneously in GoM and PB using directional wave rider buoys. The numerical model REF/DIF1 was used to calculate the nearshore waves and the LST rate was estimated using three different formulae. The model validation was done based on the measured nearshore waves using InterOcean S4DW. Examination of shoreline changes indicates that accretion was more compared to erosion. A comparison between the 1953 toposheet and the 2010 satellite image shows accretion at the eastern tip of land, leading the sand spit along Dhanushkodi to grow by 1.03 km during this period. Numerical model LITPACK was also used for simulating non-cohesive sediment transport and the LITLINE module was used to study the shoreline evolution over 5 years. Low net annual LST along PB (~ 0.01 x 10^6 m^3), compared to the GoM region (0.3 x10^6 m^3), was due to the weak waves. Accretion in the region led to the growth of the Dhanushkodi sand spit by 65 m during the period 2010-2015.

TABLE OF CONTENTS

Contents

CHAPTER 2. LITERATURE REVIEW

CHAPTER 3. MATERIALS AND METHODOLOGY

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

CERC	=	Coastal Engineering Research Center
CSIR	=	Council Scientific Industrial Research
DHI	=	Danish Hydraulic Institute
EIA	=	Environment Impact Assessment
GIS	=	Geographic Information System
GoM	=	Gulf of Mannar
INCOIS	=	Indian National Centre for Ocean Information Service.
ICMAM	=	Integrated Coastal and Marine Area Management
IHH	=	Institute of Hydraulics and Hydrology
IMD	=	India Meteorological Department
LITPACK	=	LITtoral Processes and Coastline Kinetics
NEERI	=	National Environmental Engineering Research Institute
NIO	=	National Institute of Oceanography
NHC	=	Naval Hydrographic Chart
NRSC	=	National Remote Sensing Center
REF/DIF 1	=	Refraction/Difraction-1
PB	=	Palk Bay
SoI	=	Survey of India

CHAPTER 1

INTRODUCTION

1.1 GENERAL

India has a long coastline of more than 7500 km and the maritime trade plays a vital role in the development of the economy. There are 13 major ports and over 150 intermediate and minor ports situated along the east and west coasts of India. The coastal zone is subjected to multiple uses like construction of ports and harbours, transportation, extraction of living and non-living resources, land reclamation for commercial and industrial development, agriculture, human habitation, military, tourism and waste disposal. The stability of this coastal zone is influenced by a number of environment factors, primarily due to geological, biological, meteorological and oceanographical parameters, which distinctly vary from one sector of the coast to another. The most influencing factors in coastal waters are the tides, waves and currents, and they interact with each other to produce an energy input, which shapes and modifies the coastline.

The coastal zone, where land, air and sea meet, is the region of high physical energy and biological diversity and is different from the open ocean as it is from land. It extends from the shorelines, beaches and estuaries to continental shelves and slopes, where exchanges and interactions occur with deep ocean. Over two-thirds of the marine biological activities take place at or near the coast and mostly in estuaries. Mangrove swamps in the coastal zones play an indispensable role in regulating tides, floods and erosion, trapping nutrient rich sediment and providing refuge for living marine resources. The marine resources as well as equal valuable coral reefs are under threat due to human activities, coastal mismanagement, ship anchoring, everything from poaching of corals for commercial sale, to polluting discharge from coastal constructions, change in land use patterns, coastal mining, over exploitation of natural resources etc. All these may contribute to aggravation of naturally existing problems like sea level changes, coastal erosion, migration of river mouth and shoreline realignment.

The shoreline, a line of contact between the land and ocean, undergoes continuous changes mainly due to the action of waves and longshore current. The shoreline is strictly the water's edge that migrates back and forth with the tide, but it is difficult to capture since the water level is always changing. The accurate demarcation and monitoring of a shoreline are necessary for understanding coastal processes (Natesan, 2008). The vastest coastal zone has played a major role in the economic development of the country since ancient times by its contribution to sea trade, fishing, ocean industry and human settlement. The coastal zone, the link between ocean and land margins, constantly experiences dynamic processes, which at times, result in various hazards to human beings. Such processes include erosion, accretion, upliftment, subsidence, submergence and their combined influence. The nearshore regions are usually the areas of high energy environs where the waves and currents have sufficient strength to influence the geomorphology. The beach and nearshore environs have been studied from time to time along many coasts of the world by various researchers namely Geologists, Oceanographers, Coastal Engineers and Management personnel.

The geographical formation of the Tamil Nadu coast plays a vital role in maintaining the stability of Indian shoreline. It determines the extent of sources and sinks for the littoral drift moving around the Indian peninsular tip across the east and west coasts of India. Based on the characteristics of the sedimentary processes and the various influencing parameters, the Tamil Nadu coastline can be classified into 6 segments viz., i) open coast in the Bay of Bengal - Pulicat to Pondicherry, ii) partly protected coast in the Bay of Bengal - Pondicherry to Vedaraniyam, iii) protected coast in Palk Bay (PB) - Vedaraniyam to Dhanuskodi, iv) protected coast in the Gulf of Mannar - Dhanuskodi to Tuticorin, v) partly protected coast in Indian Ocean - Tuticorin to Ovari and vi) open coast in the Indian Ocean - Ovari to Thengaipattinam (Rao, 2003.). The typical formation of the Tamil Nadu coast comprises of long sandy beaches on the northern part. The stretch between Pondicherry and Vedaraniyam has been experiencing a recession of coastline since historical period.

The coastlines between Vedaraniyam and Rameshwaram in Palk Bay, and between Rameshwaram and Tuticorin in Gulf of Mannar are substantially protected from monsoon waves due to the proximity of Sri Lanka Island. Palk Bay is very shallow and is largely occupied by sandbanks and submerged shoals. Abundant growth of corals, Oysters, Sponges, and other sea bottom communities flourish in the relatively calm waters of the Gulf of Mannar (GoM). Rameshwaram Island, the geological formation of coral atoll with a huge sand cover between India and Sri Lanka, plays a vital role in the exchange of littoral drift between the east and west coasts of India (Rao, 2003). The GoM receives sediment from the east-flowing rivers of the state of Tamil Nadu. In addition to this, it also receives sediments from the west coast of India via Kanyakumari (southern tip of India) and from PB (Chandramohan et al., 2001). Ships travelling between the west and east coasts of India go around Sri Lanka because the sea channel between them is blocked by the Adam's Bridge (AB) and the islands of Mannar (to the east of this bridge) and Rameshwaram (to the west of this bridge) due to the geological formation of a shallow ridge, Adam’s Bridge, between India and Sri Lanka. Consequently, the entire coastal traffic from the east coast of the country to the west coast and vice versa has to go around Sri Lanka entailing additional distance of nearly 400 nautical miles and requiring additional navigational time of nearly 36 hours. To shorten the shipping distance between the two coasts of India, a number of engineering proposals were floated to cut a ship channel to connect the Palk Bay (PB) with the Gulf of Mannar (GoM). Prestigious national project Sethu Samudram Canal, the navigational passage between India and Sri Lanka, has been initiated in this region.

1.2 COASTAL EROSION IN INDIA

Coastal erosion is a universal problem. It has been estimated that about 70% of all the coastline in the world are eroding due to natural processes and human induced activities (Bird 1985). Erosion and siltation problems are frequently faced near harbors and close to existing coastal structures. The important factor governing the beach erosion is the coastal processes which are controlled mainly by the wave characteristics and near shore sediment transport.

Coastal erosion is a constant problem along most open-ocean shores of India. Coastline comprises of headlands, promontories, rocky shores, sandy spits, barrier beaches, open beaches, embayments, estuaries, inlets, bays, marshy land and offshore islands (Table 1.1). According to Naval Hydrographical Chart, the Indian mainland consists of nearly 43% sandy beaches, 11% rocky coasts with cliffs, and 46% mud flats and marsh coast. The erosion along the Indian shoreline is seasonal, since some of the beaches regain their original profiles during the fair weather season .About 50% of the beaches do not regain their original shape over an annual cycle and undergo net erosion (Chandramohan et al., 1991; Chandramohan et al., 2001).

The coastal geomorphological processes along the Indian coast are influenced by a number of environmental factors, primarily due to geological, meteorological and oceanographical factors which vary from one sector of the coast to another. The primary source of the sediments deposited on the beaches is the weathering of the land and the sediments are transported through rivers to the ocean. The contribution of the shelf erosion to suspended sediments in the ocean is unknown which appears to be of a very low order. The quantities of materials contributed by headland erosion and aeolian transport are less than 2% of river transport. Another main source of sand for a particular region can be an eroding upcoast cliff and beach.

Many coastal zones in India are ephemeral in nature, only acting to store sediment for a short geological span before it moves further down slope. The time span for which the sediment remains in coastal sink varies from only a few minutes or hours in the case of some tidal beaches, to several million years in the case of coastal rock formation. In many areas, sand is transported short or for a distance alongshore from its source before being deposited at one or more semi-permanent locations known as sinks. Harbour, bay and estuary with generated flow can trap large quantify of sediment to jetties/breakwaters constructed to stabilize the entrance channel if there is a littoral drift. Lagoon and estuaries act as long-term sediment sinks for marine sand. Wind might cause a new seaward transport of sand from the dunes to the littoral zone. (Kumar et al. 2006)

Ta le 1.1 State wise length of Indian coastline Source Kumar et al., 2006

State	Length of coastline (km)	Sandy beach (%)	Rocky coast	Muddy coast (%)	Marshy coast (%)	Coastline to subject erosion	Coastline protected (Km)
Gujarat	1214.7	28	21	29	22	36.4	4.0
Maharashtra	652.6	17	37	46	-	263.0	127.0
Goa	160.5	44	21	35	-	10.5	3.0
Karnataka	280.0	75	11	14	-	249.6	56.0
Kerala	569.7	80	5	15	-	480.0	369.0
Tamil Nadu	906.9	57	5	38	-	36.2	14.0
Andhra Pradesh	973.7	38	3	52	7	9.2	0.5
Odisha	476.4	57	-	33	10	107.6	10.0
West Bengal	157.5	-	-	51	6	49.0	14.0
Daman and Diu	9.5	-	-	-	-	-	
Pondicherry	30.6		-	-	-	6.4	
Andaman and Nicobar	1962.0	-	-	-	-	-	
Lakshadweep	132.0	-	-	-	-	132.0	44.0
Total length of Indian coastline with Island	7526.1					1379.8	641.5
Total length of Indian coastline without Island	5432.1	396	103	313	45	1247.8	597.5

1.3 COASTAL EROSION IN TAMIL NADU

The coastline of Tamil Nadu is formed at the south coast of India. Tamil Nadu coast stretches for about 906.9 km. Compared to the west coast, the east coast has large sediment movements and high erosion during the cyclones in Bay of Bengal. The shoreline changes along Tamil Nadu coast were studied using remote sensing data for the past 28 years i.e. from 1972 to 2000 by India National Centre for Ocean Information Service (INCOIS 2009). Considering the maximum and minimum values of the shoreline change rate, the shoreline is divided into three categories as accretion, low erosion and high erosion. The study reveals that the area experiences both erosion and accretion. The dominant class is the low erosion with rate up to 5m/y observed over a length of 500km. The coastlines along Chennai-Ennore, Devipattinam and Kanyakumari are experiencing high erosion with a rate more than 5 m/yr with total length of coastline 70km, whereas the remaining 375km coastline is under accretion. Murthy et al (2008) studied Ennore port to determine the shoreline oscillation due to the construction of new port and concluded that the coastline was eroding at 46 m /yr on the northern side , while it was accreting at the rate of 44 m/yr near the south breakwater. The accretion extended up to 2.6 km to the south led to the rapid silting of Ennore creek.

The study provides overall information about the coastal erosion at regional scale. The beach width of 30 sites covering about 77 km long coastline spreading along the Tamil Nadu coast was monitored at monthly intervals during 1978 to 1988 by Institute of Hydraulics and Hydrology (IHH) Poondi, Govt. of Tamil Nadu, to estimate the erosion and accretion rates. It was reported that on an average 0.419 m/m run of beach length/ year is taking place along the Tamil Nadu coast, which is an alarming figure. Erosion was reported along Pulicat, Royapuram, Eliot, Kovalam, Ennore, Cuddalore, Rameshwaram and Muttom.

The erosion rate observed at Poompuhar, Tarangampadi, Nagapattinam, Mandapam, Manapadu, Ovari, Kanyakumari, Pallam, Manavalakurichi and Kolachel is about 0.15, 0.65, 1.8, 0.11, 0.25, 1.1, 0.86, 1.74, 0.60 and 1.2 m/yr, respectively (Kaliasundaram et al. 1991). The maximum rate of erosion along Tamil Nadu coast is about 6.6 m/yr near Royapuram, between Chennai and Ennore port (IHH Poondi,2002). The accretion rate at Cuddalore, Point Calimere, Ammapattinam, Kilakarai, Rameshwaram, Tiruchendur, Manakudi and Muttam is observed to be about 2.98, 3.4, 0.72, 0.29, 0.06, 0.33, 0.57 and 0.17 m/yr, respectively. Natesan and Subramanian (1993) reported that the coast near Ovari is exposed to severe erosion in June, where alternate erosion and accretion trend has been noticed at Kanyakumari. It was also stated that the accretion had taken place in Palk Bay, Viz Ammapattinam, Mandapam and Rameshwaram. This is also one of the reasons for deposition of sediments in Palk Bay and formation of shoals and spits as Palk Bay is well protected from southerly waves. Natesan and Subramanian (1993) analysed the berm crest data collected at 22 stations from January 1979 to December 1988 to know the eroding and accreting sites. The eroded and accreted area along with the shoreline change rates for all the stations were given in a tabular form. This study over a decade shows that coastline of Tamil Nadu was prograding from Pulicat to Kanyakumari at the rate of 0.28m/metre length of beach/ year.

1.4 SEDIMENT TRANSPORT

Coastal erosion is a universal problem and it has been estimated that about 70% of all the coastline in the world is eroding due to natural processes and human induced activities (Bird 1985). Erosion and siltation problems are frequently faced near harbors and close to existing coastal structures. The important factor governing the beach erosion is the coastal processes which are controlled mainly by the wave characteristics and near shore sediment transport.

Longshore transport also plays an important role in the stability of inlets and estuaries. Normally, the average net longshore transport rate is used to determine the dredging requirements or the beach evolution at a particular site. This is usually followed by a sensitivity analysis to see what the effect would be, if the net longshore transport is considerably higher or lower than the assumed average rate, or even if a reversal in the transport direction would occur. This average rate is an estimate of the true long-term net longshore transport rate at the site. In order to obtain the long-term mean net longshore transport rate at a site, it is necessary to assess the annual variation in the net transport rates. This annual variation can be determined either by computing the longshore transport rates with a reliable formule from wave data spanning number of years, or by measuring continuously the longshore transport over a number of years. The estimated sediment transport rates based on the measured wave and current at a few locations are presented by Kumar et al. (2006) and represented in Table 1.2. This study showed that along the east coast, the longshore transport is southerly from November to February, northerly from April to September and variable in March and October. Along the west coast, the longshore sediment transport is generally towards the south from January to May and in October. It was found that the annual gross sediment transport rate was high ($\sim 1 x 10^6$ m^3) along the coast of south Odisha and south Kerala. Estimated longshore sediment transport rates show that the net transport along the east coast of India is towards the north, whereas along the west coast it is mostly towards the south.

1.5 GEOMORPHOLOGY

Coastal geomorphological features of the east and west coasts of India are complex. Long sandy beaches with dunes along the almost straight and low-lying east coast and the pocket beaches between the headlands and promontories along the highly indented west coast are the main features. Tamil Nadu coast comprises of long sandy beaches. There are a number of coral banks and islands present in the Gulf of Mannar (Krishnamurthy, 1991). The large beach storage of sand between Manapad and Tiruchendur, Vembar and Valinokkam and Rameshwaram Island indicates the depositional features of littoral sediments. This formation of spit indicates seaward progradation of the coast between Tuticorin and Mandapam. The coast between Point Calimere and Tuticorin is protected from the monsoon waves due to the proximity of the island of Sri Lanka. The northern part of Rameshwaram Island, which is occupied by a raised coral plain, is made up of undulatory sand bodies with relief upto 21 m above Mean Sea level (MSL). This zone is flat and shows the presence of dead corals and numerous minor circular depressions. These depressions are liable to get filled with water during the rainy season and are entirely devoid of vegetation. Huge sand dunes of medium grain and white sand are found in the central part of the island.

Ta le 1.2 Longshore sediment transport at few location along Indian coastline

Source Kumar et al., 2006

Location	Net Transport (10^6 x m^3/yr)	Direction	Gross Transport (10^6Xm^3/yr)
West coast of India			
Kalbadevi	0.118	South	0.147
Ambolgarh	0.189	South	0.299
Vengurla	0.053	South	0.120
Calangute	0.090	South	0.120
Colva	0.160	North	0.160
Arge	0.069	North	0.200
Gangavali	0.142	South	0.177
Kasarkod	0.040	North	0.077
Maravanthe	0.025	North	0.029
Malpe	0.014	South	0.106
Padubidri	0.089	South	0.385
Ullal	0.036	South	0.038
Kasargode	0.736	South	0.958
Kannur	0.019	South	0.561
Kozhikode	0.114	South	0.256
Nattika	0.192	North	0.660
Andhakaranazhi	0.202	South	0.599
Alleppey	0.016	North	0.062
Kollam	0.383	South	0.805
Thiruvananthapuram	0.099	North	1.231
Kolachel	0.302	West	0.946
East coast of India			
Ovari	0.002	South	0.251
Tiruchendur	0.064	North	0.087
Kannirajapuram	0.117	North	0.145
Naripayur	0.036	South	0.122
Muthupettai	0.005	South	0.008
Pudhuvalasai	0.005	South	0.042
Vedaranivam	0.051	North	0.094
Nagore	0.096	South	0.433
Tarangampadi	0.200	North	0.369
Pommpuhar	0.146	North	0.478
Pondicherry	0.134	North	0.234
Periyakalapet	0.486	North	0.657
Tikkavanipalem	0.177	North	0.405
Gopalpur	0.830	North	0.949
Prayagi	0.887	North	0.997
Puri	0.735	North	0.927

The pattern of dunes is well developed here by active Aeolian processes, resulting in migration of the dunes with frequent changes and patterns from time to time. In spite of these changes, the dunes, in general, extend from east to west. The sand sheet covers the southwestern zone of the island. Within this unit, on the western part, there is localized sand mound about 19 m high (Loveson, 1993). The beach in this area are broader with wide inter tidal zones. The tail portion of Rameshwaram occupying the southeastern part of the island has coral swampy plain, which is considered to be of recent in age. This vast flat and low lying plain is embedded with recent pink corals with clay sand deposits. Upper layer of the sandy plain is essentially composed of a thin sheet of silt and clay materials in which coral fragments are impregnated. Invariably, this zone is often inundated by seawater during high tides, monsoons and storm seasons. The beach berm is found to be elevated along the sand spit boarding GoM, but is low and flat along the side bordering PB. There is marked depression in the sand spit level between PB and GoM and between Dhanushkodi and Arichamunai. Water overflows during spring tide from PB to GoM, carrying fine sediment to the backshore regions. Most of the time, the water in the trough of the spit is stagnant. The low-lying region of the spit is covered by water during the rainy season (Anonymous, 2005).

1.5.1 GEOLOGY

Trapping of sand in this under-sea barrier led to the formation of Rameshwaram island, which Subbarao et al. (2008) called a geological formation of coral atoll with appreciable sand cover, and movement of sediment along the island's coast led to the formation of the spit on which Dhanushkodi town is located. The rocks on the mainland, west of Rameshwaram island are older. Geologically, the hinterland area of the coastal strip between Mannapad in the south, and Point Calimere in the north consists, in general, of Precambrian crystalline rocks represented by a vast array of igneous emplacement of anorthosites, granites, synites carbonatites, ultra mafic, basic sills, and dykes. The coastal strip of the above area, including Rameshwaram island upto the tip of Dhanushkodi, consists of Phanerozoic and Cenozoic formations. These are, by and large, arenaceous and calcareous formations, with patches of weathered lateritic red soil resting upon upper Gondwana and Cuddalore sandstone. Deposits of marine origin also occur close to the coast . The landform features formed during the Quaternary along the coast include beaches, beach ridges, spits, creeks, estuaries, lagoons and tidal flats (Subramanian and Selvam, 2001)

1.6 STUDY AREA

Rameshwaram Island along Tamil Nadu coast, east coast of India is situated between PB in the north, the GoM in the south, and Sri Lanka in the east. The study area is located between the latitude of 9° 25′ to 9° 31′ N and the longitude of 79° 05′ to 79° 31′ E (Figure 1). The length of the island is about 28 km in the east-west direction and it has a maximum width of 8 km in the north-south direction. The eastern end of Dhanushkodi, called the "Arichamunai Tip", acts as a mixing point of the two water bodies (PB and the GoM) with different hydrodynamic conditions (Natesan et al., 2014). Dhanushkodi is on the eastern side of Rameshwaram Island, and this narrow strip of land is a few meters wide and is surrounded on all other sides by seas (the GoM in the south and PB in the north; Gowthaman et al., 2013). High intensity storms and cyclones attacked this area in 1964 and led to vast material and human losses. The beach berm is highly elevated (~ 2 m) along the sandspit bordering the GoM, but it is very low (< 1 m) and flat along the side bordering PB. There is a marked depression in the sandspit level between PB and the GoM between Dhanushkodi and Arichamunai. Most of the time, the water is stagnant and remains along the trough of the spit. Loveson et al. (1990) have indicated that large amounts of sediments are removed constantly by rainfall, carried by minor rivers, and dumped into PB. Natesan et al. (1993) observed the accretion pattern in PB at Ammapattinam, Mandapam, and Rameshwaram.

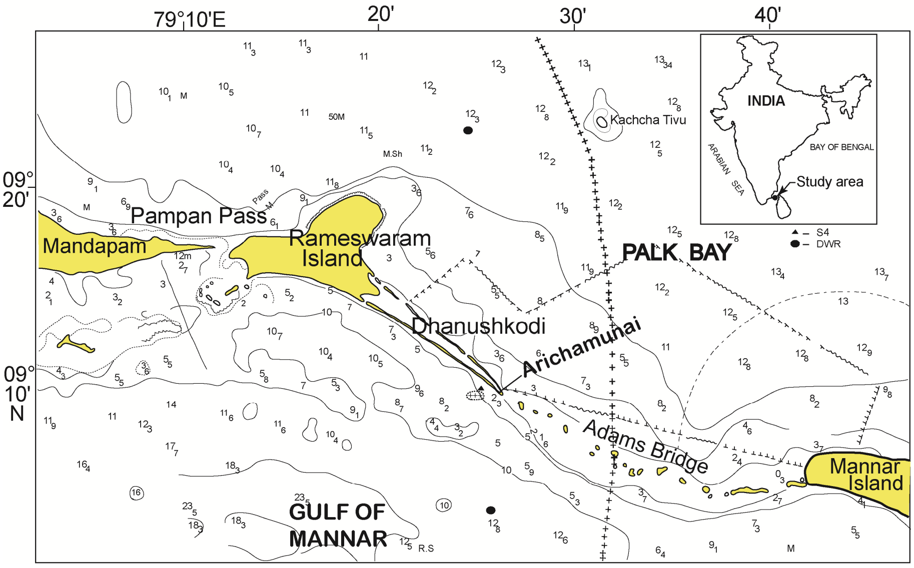


Figure 1. Location map of the study area

1.6.1 REASONS FOR SELECTING THE STUDY AREA

The Rameshwaram Island and its associated shoreline is selected as study area due to the following reasons

1. Dhanushkodi sand spit was growing.
2. Nearshore wave characteristic along Gulf of Mannar and Palk Bay are not known
3. Due to sedimentation problem between Gulf of Mannar and Palk Bay

1.6.2 OCEANOGRAPHY

The oceanography of the Indian coastal region is dominated by three seasons viz., southwest monsoon (June to September), northeast monsoon (October to January) and fair weather period (February to May). While southwest and northeast monsoon have equal impact along the southern part of the east coast and only the southwest monsoon has the significant effect on the west coast of India.

Tides: In general tides in the Indian coastal region are semi diurnal, with tidal ranges varying from place to Place . While Sundarban, Gulf of Khambhat and Gulf of Kachchh experience large tidal variation exceeding 6 m, the peninsular tip of India is subjected to relatively low variation of tides around 0.5 m. However, tidal range at the study area is semi-diurnal with a spring tidal range of 0.6 m and a neap tidal range of 0.16 m (Anonymous, 2011

Wa es The west coast of India experiences high wave activity during the southwest monsoon with relatively calm sea conditions prevailing in the rest of the year. On the east coast, the wave activity is significant both during southwest monsoon and northeast monsoon. Extreme wave conditions are, however, found to occur under several tropical cyclones frequencies in the Bay of Bengal during the northeast monsoon period (Chandramohan, et al., 1989). CSIR-National Institute of Oceanography (NIO) Goa has carried out the wave measurements at different places along the Indian coast which are presented in Table 1.3.

Ta le 1.3 Wa e characteristics at different locations   ased on measured data

Location along Indian coast	Range Significant wave height (m)	Average wave period (s)
West coast		
Mundra	0.1-2.2	2-6
Kandla	0.1-2.8	3-11
Dahej	0.1-2.0	2-10
Hazira	0.1-2.9	2-14
Daman	0.1-6.0	3-15
Umbergaon	0.2-4.8	3-16
Vadhavan point	0.3-2.8	3-15
Bombay high	0.4-5.1	3-16
Uran	0.2-2.5	4-16
Dahbol	0.4-4.6	3-8
Jaitapur	0.1-3.3	3-15
Mormugao	0.1-3.3	3-9
Karwar	0.5-3.6	3.5-11.9
Malpe	0.5-4.2	3.5-11.1
Kavarttai	0.4-1.9	3.5-11.1
East coast		
Kannirjaapuram	0.3-1.9	3-9
Nagore	0.2-2.0	2-9
Porto Novo	0.3-2.1	3-12
Machalipattanam	0.5-2.3	3-15
Narasapur	0.2-4.2	4-15
Yanam	0.3-2.8	3-15
Tikkavanipalem	0.3-3.9	3-14
Visakhapatnam	0.5-3.3	4.2-8.8
Gopalpur	0.2-2.5	3-9
Paradip	0.1-3.7	3-10

Currents The currents near river mouths are greatly influenced by tides, the region along the open coast within 2km from the coastline are mostly dominated by wind and seasonal circulation pattern. Currents in the Gulf Kachchh and Gulf of Kahambat are highly influenced by tides. The measured current speed is found to vary from about 1.4 m/s in the open ocean to about 3.2 m /s in the Gulf of Kahambat. The magnitude and direction of the current velocity measured at a few locations along the Indian coastline are given in Table 1.4.Currents bey km distance from the coastline are once again significantly by tides. The current speed of 0.1 to 1 m/s are reported for the Gulf of Mannar and Palk Bay (Rao 2003).

Ta le 1.4 Current at Shallow water along the Indian coast

Place	Year	Current Speed (m)	Current Direction(deg)
Kharo creek	1994	0.3-1.0	240-300
Poistra	1993	0.4-0.5	180-360
Kandla	1996	0.05-1.6	180-360
Vadinar	1994	0.2-0.8	60,270
Muldwaraka	2000	0.1-.0.8	290, 120
Dahej	2003	0.01-3.2	189, 360
Mormugao	1998	0.02-1.2	180, 360
Karwar	1998	0.02-0.6	180-270
Mangalore	1999	0.05-0.4	180,360
Kochi	1998	0.05-0.4	170-220
Kannirajapuram(Tuticorin),	1997	0.01-0.3	215
Nagapattinam	1995	0.12-0.6	30, 330
Chuinnakuppam	1998	0.03-0.5	180-225
Mahsbalipuram	1996	0.1-0..3	30-360
Tikkavanipalem	1998	0.02-0.03	90, 270
Gopalpur	1994	0.1-0.4	225
Paradip	1996	0.1-0.8	30,65

1.6.3 METEOROLOGICAL CONDITIONS.

Winds: Based on India Meteorological Department (IMD) wind speed is 2.56 to 4.0 m/s in the study region. Wind direction is predominantly southwest during SW monsoon, northeast during NE monsoon and has no predominant direction during the fair weather period.

Rainfall The study region receives rainfall during the NE monsoon which lasts before October-December. The average annual rainfall is about 91 cm, with more than 70% of it during the northeast monsoon from October to January.

Temperature The **a**nnual distribution of temperature at Pamban, the nearest observatory of India Meteorological Department (IMD), showed seasonal variations. The 30 years average showed the highest monthly mean temperature as 34.2 ºC in the month of May. The lowest monthly temperature was 21.3 ºC in the month of January

Cyclones Cyclones frequently occur in the Bay of Bengal either in May, i.e., before the onset of the summer monsoon, or during October-January, following the withdrawal of the summer monsoon. 64 cyclones have crossed the Tamil Nadu coast during 1891 – 2000. 55% (36) out of these cyclones happened to be Severe Cyclonic Storms (wind speed more than 89 kmph). Out of the 61 cyclones that have crossed the Tamil Nadu coast during the period between 1891–1995 A.D., 6 have directly crossed the Palk Bay; 14 have crossed the Nagapattinam coast, and 3 have crossed the Gulf of Mannar. The coast of Tamil Nadu is vulnerable to cyclones during October-January. An examination of the cyclones that crossed the study area indicates that the cyclone of December 1964 is one of the severest storms to occur in the Indian seas and the most severe storm to affect the Rameshwaram area. During this cyclone, the estimated wind speed was of the order of 60 m/s in Trincomalee, Sri Lanka, on 22 December 1964. The storm struck the Rameshwaram Island on the night of 22 December 1964 and the island experienced wind speeds of 30-40 m/s (Rao and Mazumdar, 1965, Kulshrestha and Gupta, 1999). During the study period, one cyclone, Laila, was formed in the Bay of Bengal on 17th May 2010. It moved northwest towards India and turned into a severe cyclonic storm on 19th May before making landfall in Andhra Pradesh on 20th May. The CSIR-NIO AWS at Mandapam recorded a gust speed of 26 m/s and vector-averaged wind of 18 m/s during this cyclone period.

1.7 SHORELINE DETECTION AND LAND USE LAND COVER CHANGES

Remotely sensed data from satellites is a reliable source for shoreline detection and Land use/Land cover change analysis. The study of shoreline dynamics is based on temporal scales, either addressing long-term or short-term coastal changes. Long-term changes occur over periods such as decades or centuries, while short-term changes refer to movements occurring from over a season for a few years. Studies of long-term variations are better suited for large-scale coastal planning and management, since the decision maker’s goal is to identify major trends over larger areas. Historical data are used to identify the segments along the coast where the shoreline has changed.

Comprehensive information on the spatial distribution of land use/land cover categories and the pattern of their change is a prerequisite for planning, utilization and management of the land resources of the country. Land use is obviously constrained by environmental factors such as soil characteristics, climate, topography and vegetation. But, it also reflects the importance of land as a key and finite resource for most of the human activities. To improve the economic condition of any area every bit of available land has to be used in the most rational way. This requires the present and the past land use/ land cover data of the area. Identification of temporal changes in land cover has become possible in less time, at lower cost, and with better accuracy through remote sensing technology.

1. NUMERICAL MODEL

1. .1 Wa e Transformation Model REF DIF 1

The propagation of water waves over irregular bathymetry and around islands involves many processes such as shoaling, refraction, energy dissipation and diffraction. Until recently, only very approximate models existed to predict the wave behavior due to these effects. A monochromatic, finite difference wave transformation model REF/DIF 1 was used to investigate wave transformation at the site. The model REF/DIF 1 used in the present study describes the weekly non linear combined refraction and diffraction initially developed by Kirby and Dalrymble (1983). Combined refraction/diffraction model includes both effects explicitly, thus permitting the modeling of waves in the regions where the bathymetry is irregular and where diffraction is important. The model is uniquely suited for the calculation of wave heights and wave direction**.**

1. .2 Shoreline change model, LITPACK

LITtoral Processes and Coastline Kinetics (LITPACK) numerical model in MIKE-21 software package developed by the Danish Hydraulic Institute (DHI) is one among the much improved versios. LITPACK utilises the same preprocessing and post processing module as MIKE 21. This module provides an integrated work environment with convenient and compatible routines. It simplifies the tasks of data input, analysis and presentation of simulation results. The core of LITPACK is the STPQ3 sediment transport model -a deterministic description of noncohesive sediment transport in a single point. For decades, this model has been used and improved and has proven very reliable. LITPACK is proven science turned into a productive tool for coastal engineers, and it simulates a wide range of wave and current scenarios along straight or nearly straight coastlines. LITPACK combines these simulations into predictions of coastal profiles and long term coastline evolution, estimating the sediment transport of non-cohesive sediments and shoreline changes. The main modules of the LITPACK are Long-shore current and littoral drift (LITDRIFT), Coastline evolution (LITLINE), Cross-shore profile evolution (LITPROF). The LITDRIFT module was used to estimate the LST rates. The module includes important sediment transport mechanisms, such as nonlinear wave motion, the turbulent bottom boundary layer, wave breaking, and sediment grading (DHI, 2008). It is an essential combination of a one-dimensional (1D) wave model, an 1D hydrodynamic model and an intra wave sediment transport model (STP).(www.mikpoweedbydhi.com). The solution is carried out for the long and cross-shore momentum balance equation to determine longshore current, wave height and set-up for an arbitrary profile. Later the solution is made for sediment diffusion equation on an inter-wave period grid, for breaking/non breaking waves and current arbitrary profile. Later the solution is made for sediment diffusion equation on an inter-wave period grid, for breaking/non breaking waves and current.

1. OB ECTIVES OF THE STUDY

By considering the actual problems in the study area and with the available data, the following objectives were framed for the present work.

1. To study the near shore wave characteristic along Rameshwaram Island
2. To estimate longshore current and sediment transport pattern
3. To find the shoreline change using Remote Sensing and GIS.
4. To modeling the shoreline changes using Numerical model LITPACK.

1.10 ORGANISATION OF THE THESIS

The present thesis is divided into five chapters.

Chapter 1: Provides a brief introduction of coastal process, coastal erosion and sediment transport along Indian coast. It also gives study area details and objectives of the study.

Chapter 2: Review the literature pertaining to a variety of techniques used to monitor the shoreline changes and modeling of shoreline change.

Chapter 3: Describes the data products used, their analysis and significance.

Chapter 4: The results obtained from various data analyses are provided in chapater-4

Chapter 5: Summarizes the conclusions of the present study and suggestions for the future work.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

The coastal zone is an area of interaction between land and sea and thus both terrestrial and marine environments influence this zone. The interaction between various natural processes and human activities is an important factor. Coastal zone in India assumes its importance because of high productivity of its ecosystems, development of industries, concentration of population, exploration of living and non-living resources, discharge of industrial waste effluents and municipal sewage, and spurt in recreational activities. Thus, there is a need to protect the coastal environment while ensuring continuous production and development. Shorelines are generally more or less in dynamic equilibrium and their evolution due to changes in winds, waves, currents, and sediment transport, is rather seasonal, characterized by alternate erosion and accretion. Additional changes occur when the perturbations are introduced by anthropogenic factors/activities such as construction of structures in coastal waters. Shoreline change is a natural process of evolution of coastal areas. The shoreline evolution of a given site depends on the interaction of these processes with the geological setting and may result in a great variety of shoreline forms and features on different scales of time, from a single tidal event, two decades or centuries. However, three time scales of shoreline change, evolution can be distinguished: i) Geological evolution- takes place over the centuries and affects a large area ii) Long-term evolution- annual to decadal shoreline changes affecting a limited stretch of the shoreline iii) Short-term evolution- seasonal variations of shoreline at the local scale. The understating the cause and pattern of erosion/accretion is very essential and attracts added importance in the case of the Indian coast, which is thickly populated and where lot of developmental activities are taking place along the coast. As coastal population continues to grow, and community infrastructures are threatened by erosion, there is an increased demand for accurate information regarding the past and present trend in the shoreline changes.

2.2 GLOSSARY OF THE COASTAL ONE

According to Coastal Engineering Manual (CEM 2002: CEM 2006), the coastal zone is the transition zone where the land meets and the region which is directly influenced by marine and coastal hydrodynamic processes. It extends from offshore to the continental shelf and from onshore to the first major change in topography above the reach of major storm waves, The definition of some of the terms in the coastal zone is provided in the following section and the schematic diagram is shown in Figure 2.1.

Backshore The zone of the shore or beach lying between the foreshore and the coastline and acted upon by waves only during severe storms, especially when combined with exceptionally high water.

Bar A submerged or emerged embankment of sand, gravel or other unconsolidated material builds on the sea floor in shallow water by means of waves and currents.

Beach The zone of unconsolidated material extending landward from the mean low water line to the place where there is a change in material or physiographic form, for example, the zone of permanent vegetation or a zone of dunes or a sea cliff.

Berm crest The seaward limit of berm.

Berm A nearly horizontal part of the beach or backshore formed by the deposition of material by wave action

Foreshore The part of the shore lying between the crest of the seaward berm and the low water mark line. The low water line is traversed by the uprush and backwassh of the waves as the tides rise and fall.

Nearshore The region seaward of the shore from approximately the step at the base of the surf zone extending offshore to the toe of the shore face. Nature is a general term used loosely by different authors to mean various areas of the coastal zone.

Surf one The area between the outermost breaker and the limit of wave uprush.

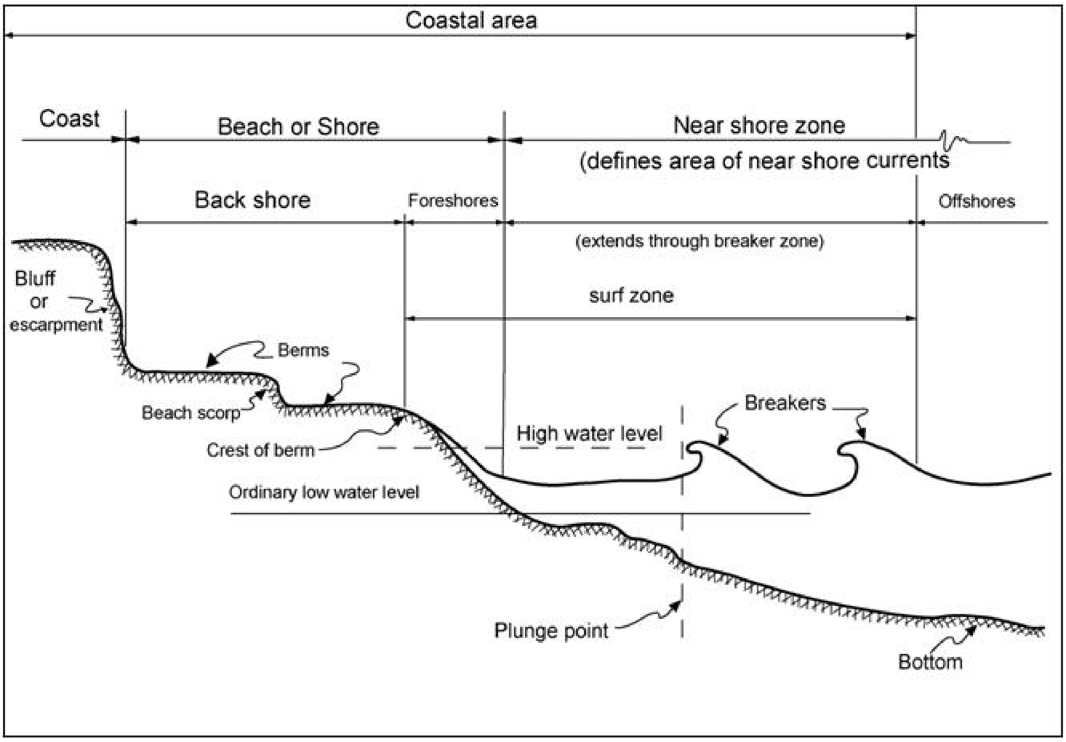


Figure 2.1 A schematic diagram showing the different ones of the coast.

Coastal area is driven by external forces, such as coastal currents, tides and tidal currents, surface waves, storm surges, tsunamis and others. Wind, waves, storm surges and tsunamis bring powerful hydrodynamic forces to the shallow area of a coast. Once generated by atmospheric disturbances and submarine earthquakes, storm storages and tsunamis can cause devastation on a coast. However, because of their infrequent occurrences, they are less important than a wind wave from the viewpoint of the coastal sedimentary processes. Some of the important causes of coastal erosion are discussed in the following section.

2.3 CAUSES OF COASTAL EROSION

Coastal erosion occurs when wind, waves and long shore currents move sand from the shore and deposit it somewhere else. The sand can be moved to another beach, to the deep ocean bottom, into an ocean trench or onto the landslide of a dune. The removal of sand from the sand-sharing system results in permanent changes in beach shape and structure. While the effects of waves, currents, tides and wind are primary natural factors that influence the coast the other aspects eroding the coastline include the sand sources and sinks, changes in relative sea level, geomorphologic characteristics of the shore and sand, etc. Other anthropogenic factors that trigger beach erosion are construction of artificial structures, mining of beach sand, offshore dredging, and reduction in sediment supply from the rivers.

2.3.1 NATURAL CAUSES

1. **Wa es**. Waves are generated by offshore and nearshore winds, which blow over the sea surface and transfer their energy to the water surface. As they move towards the shore, waves break and the turbulent energy released stirs up and moves the sediments deposited on the seabed. The wave energy is a function of the wave heights and the wave periods.

2. **Winds** Winds are acting not just as a generator of waves, but also as a factor for sand transport, called Aeolian transport. Aeolian transport is an important process for soil erosion, dune formation and alternation, and re-deposition of soil particles. Dune formations established with dune vegetation are an important defense system for low lying sandy coasts like Karnataka, Kerala and Goa.

3. **Tides** Tides result in variation of 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 or the cliff base (cliff undercutting). Macro-tidal coasts (i.e. coasts along which the tidal range exceeds 4 meters), all along the Atlantic sea are more sensitive to tide induced water elevation than meso-or-tidal coasts (i.e. tidal range below 1 m can be seen in India).

4. **Near-shore currents** Sediments scoured from the seabed are transported away from their original location by currents. In-turn 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 the action of the tides (ebb and flood currents), waves breaking at an oblique angle with the shore (long-shore currents), and the backwash of waves on the foreshore (rip currents). All these currents contribute to coastal erosion processes.

5. **Storms.** Storms result in raising water levels (known as storm surge) and highly energetic waves induced by extreme winds (Cyclones). Combined with high tides, storms may result in catastrophic damages along the coast, for example east coast of India. Besides damages to coastal infrastructure, storms cause beaches and dunes to retreat tens of meters in a few hours, or may considerably undermine cliff stability. In the past 30 years, a significant number of cases have been reported and extreme historical storm events that severely damage the coast. Most of the sediment transport in the form of cross shore or alongshore occurs along the Indian coast during storms.

6. **Sea Le el 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, an average rise of sea level is of the order of 1.5 to 3 mm per year. It has been observed that sea level rise of 1 mm per year could cause a recession of shoreline in the order of about 0.5 m per year (Das 2006).

2.3.2 ANTHROPOGENIC CAUSES

Human influence, particularly urbanisation and economic activities, in the coastal zone have turned coastal erosion from a natural phenomenon into a problem of growing intensity. Anthropogenic activities that trigger beach erosion are construction of artificial structures, mining of beach sand, offshore dredging, or building of dam across rivers. Human intervention can alter these natural processes through the following actions:

- Dredging of tidal entrances
- Construction of harbours in near shore
- Construction of groins and jetties
- River water regulation works
- Hardening of shorelines with seawalls or revetments
- Construction of sediment-trapping upland dams
- Beach nourishment
- Destruction of mangrove

2.4 IMPACTS OF COASTAL EROSION

Natural factors and human induced activities cause erosion in any coastal region. But the human activities impact significantly the coastal erosion processes in a variety of ways. In both cases (natural and anthropogenic), changes take place whenever one or more of the above mentioned natural causes of coastal erosion are modified. From a genetic point of view, a coastal management project is deemed to impact coastal erosion processes whenever it results in:

Impact 1: Modification of near shore bathymetry and wave propagation patterns
Impact 2: Disruption of Longshore drift
Impact 3: Removal of sediment from the sediment system
Impact 4: Reduction in river derived sediments
Impact 5: Modification of soil, weather properties
Impact 6: Land subsidence.

The impact of the event is not seen immediately as in the case of a tsunami or storm surge. But it is equally important when we consider the loss of property and it generally takes months or years to note the impact of erosion

2.5 NEAR SHORE WAVES

Wave spectra off Cochin are generally multi- peaked and wide-banded with higher frequency sides. Most theoretical spectra have a single peak, but most of the observed spectra are multiple-peaked. Multiple-peak occurs at approximately 1.5 or 2 times the frequency of the main peaks. Wave heights high around 1.8 m are observed during southwest monsoon and remain less than 1 m during the rest of the year (Baba et al., 1989)

Spectral characteristics of the nearshore waves off Paradip, India, during the monsoon and extreme events frequency-energy spectra during extreme events are single peaked, and the maximum energy distribution is in a narrow frequency band with an average directional spreading of 20°. Spectra for other seasons are multipeaked, and energy is distributed over a wide range of frequencies in different directions. The type of spectra represents the seasonal variation of wave conditions in the Bay of Bengal in the absence of extreme events (Aboobacker et al. 2009).

The waves along the west coast of India are dominated by swells during southwest (SW) and northeast (NE) monsoon seasons and wind sea during pre-monsoon season. Wave heights are generally low during NE and pre - monsoon seasons, and higher during SW monsoon seasons. The directional waves approach from west-southwest during SW monsoon and west-northwest during the NE monsoon the west coast of India. The wave activity along the east coast of India is high both during SW and NE monsoon seasons. The directional waves approach from the southeast during SW monsoon and fair weather period and from northeast during NE monsoon in the east coast of India (Kumar et al., 2006).

The waves along the east coast of India are dominated by swells during NE monsoon seasons. The frequency of occurrence of the double-peaked spectra was estimated and it was found that 40% of the data analysed was single-peaked. The double peaked wave spectra were analysed for sea and swell dominated cases and it was found that the observed spectra were mainly swell dominated. About 60% of the wave spectra observed is multi-peaked due to the presence of seas and swells and they are mainly single-peaked when the significant wave height is more than 2 m. Along the east coast, the wave heights persist 0.5 - 2.5 m during SW monsoon as well as NE monsoon at Kakinada and Gopalpur. Near Nagapattinam, the wave height is relatively low about 1.5 m in the NE monsoon and less than 1 m during the rest of the year. In the east coast, waves approach from the southeast during southwest monsoon and fair weather period, and from the northeast during the northeast monsoon (Kumar et al.,2011).

The wave heights were relatively high during May, June and September. The highest significant wave height (H_s) of 1.93 m and the highest maximum wave height (H_{max}) of 2.96, the ration of spectral energy at first and second spectral peak shows that energy of second peak was more than 50% of the energy at the first peak 57% of the data collected south Tamil Nadu. The significant wave height varied from 0.3 to 1.8 m, with an average value of 0.67 m. The ratio of spectral energy at the first and second spectral peaks shows that energy at the second peak was more than 50% of the energy at the first peak in 43%. The mean wave period predominantly varied from 3 to 8 s, with an average value of 4 s. during NE monsoon seasons at north Tamil Nadu (Kumar et al., 2000: Kumar 2011).

Berkhoff (1972) developed a formulation for the three-dimensional propagation of waves over an arbitrary bottom, which allows computation of combined refraction-diffraction. Kirby and Dalrymple (1983a) studied the propagation of obliquely incident waves over a trench. Kirby and Dalrymple (1983b) studied the propagation of weakly nonlinear waves in the presence of varying depth and currents. Ebersole et al. (1986) developed regional coastal processes numerical wave modeling system (RCPWAVE), which is a linear wave propagation model based on the parabolic model. Kirby (1986) carried out a study about higher-order approximations in the parabolic equation method for water waves. Graber and Madsen (1988) developed a finite depth, wind-wave model. Massel and Naguszewski (1991) developed a model for refraction and dissipation of water waves.

Chandramohan (1988) developed a model on wave refraction namely TARANGAM**,** which is based on small amplitude wave theory and accounts the effects of shoaling, refraction, bottom friction, bottom percolation and viscous dissipation. The model has been applied off Goa coast in Aguada Bay, where erosion is reported during southwest monsoon near Youth Hostel and part of Caranzalem beach and to identify the wave refraction and the wave energy distribution along this coast. The model output indicates concentration of wave energy leading to severe erosion of shoreline, confirming actual field observations.

DHI (2000) developed MIKE 21 **NSW** (Nearshore Spectral Wave) module, which is a spectral wind-wave model that describes the propagation, growth and decay of short period waves in nearshore areas by solving the equations for conservation of wave action. The model includes the effects of refraction and shoaling, wave generation due to wind and energy dissipation due to bottom friction and wave breaking

Kirby and Dalrymple (1994) developed a combined refraction/diffraction wave model (**REF DIF-1**) using elliptic model. Mano and Diposaptono (1995) developed a computing system for both current fields of river water efflux and wave fields in the current. Wave deformation in the current fields was computed based on the parabolic equation with a breaking model. O'Connor et al. (1995) studied combined refraction-diffraction - wave-current interaction over a complex nearshore bathymetry and concluded that the tide corrected depths, the wave height at each gride and the wave angle.

SWAN (Simulating WAves Nearshore) is a third-generation spectral wave model from which one can obtain realistic estimates of wave parameters in coastal areas, lakes and estuaries from giving wind, bottom, and current conditions. The model is based on the wave action balance equation with sources and sinks (Holthuijsen et al., 2003). The SWAN model was applied for Karwar shoreline on the West coast of India. Wave propagation and transformation was simulated in the SWAN model and analyzed followed by a validation with in-situ buoy data. The simulation was observed in parametric boundary condition as well as a 1D spectral boundary condition.

2.6 LONGSHORE SEDIMENT TRANSPORT

During the past six decades, numerous formulae and models for computing the sediment transport by waves and currents have been proposed, ranging from quasi-steady formulae to complex numerical models. Grant (1943) has suggested that the longshore current combined with the agitating action of the breaking waves provides the driving force for moving sand along the beach. A report of the Scripps Institution of Oceanography (1947) suggests that the work performed by waves might be a useful parameter for predicting the longshore transport rate of sand by wave action. This concept has been applied by Eaton (1951) to estimate the predominant direction of sand transport from hind cast wave data. Watts (1953), Caldwell (1956), and Ingle (1966) concluded that the longshore transport of sand is proportional to the longshore component of the energy flux of the waves measured at the breaking point. Inman et. al., (1969) verified that the longshore transport rate of sand is directly proportional to the longshore component of wave power for fully developed transport conditions. Komar and Inman (1970) carried out a study of longshore sand transport on beaches by simultaneous field measurements of wave and current parameters in the surf zone under a variety of conditions. The study showed that the immersed weight longshore transport rate of sand is directly proportional to the longshore component of the wave energy flux. Komar (1971) studied on the mechanics of sand transport on beaches. This study showed that on steepfaced beaches where waves break and swash at an angle to the shoreline the littoral drift of beach material results from the saw-tooth motions of the sediment in the longshore direction. Bijker (1971) takes into account both bed and suspended load transport and both waves and currents. Perlin and Dean (1983) developed a numerical model to simulate sediment transport in the vicinity of coastal structures. SPM (1984) used energy flux method to estimate the longshore sediment transport rate.

Van Rijn (1986) developed a mathematical model for sedimentation of dredged channels by currents and waves, based on a detailed representation of all relevant transport processes such as convection, mixing and settling. Zarillo and Park (1987) developed a numerical model to predict the net sediment transport rate for a shallow inlet-basin system. The predicted net sediment transport pattern agrees well with observed conditions showing convergence of transport in shoaling areas and divergence in eroded areas. Inman and Dolan (1989) carried out a study on the budget of sediment and inlet dynamics along a migrating barrier system on the outer banks of North Carolina. The study shows that, the barrier system moves as a whole, so that the sediment balance is relative to the moving shoreline. Kamphuis (1990) carried out a study of littoral sediment transport rate based on three-dimensional hydraulic model experiments performed with regular and irregular waves. An expression is developed linking sediment transport rate to wave steepness, beach slope, relative grain size and breaking angle**.**

Wang et al. (1998) studied on the total longshore sediment transport rate in the surf zone by field measurements and empirical predictions. The total rate of longshore sediment transport was measured by streamer traps. Study shows that a lower value of the empirical coefficient, 0.08 instead of the 0.78 recommended by the SPM, was determined by the trap data for low-energy coasts.

Longshore sediment transport rate estimated for the east coast and west coast of India from Dariapur to Tuticorin and Cochin to Porbandar are estimated from ship observed wave data (1968 to 1986) and found that the annual net transport northerly on the east coast and southerly on the west coast of India (Chandramohan 1991).

Longshore sediment transport rate estimated for the south Kerala coast India from Kasargod to Trivandrum based daily LEO (Littoral Environmental Observation) data for one year(1990 to 1991) and found that highest sediment transport rate Kasargod and low Trivandrum mostly north direction (Sajeev et al. 1997).

The annual net sediment transport rate estimated is about 0.97, 1.03, 0.63, 1.08, 0.85 and 1.07 x $10^6 m^3$/ year in the north direction at Pondicherry, Cuddalore, Thirumullaivasal, Tarangampadi, Karaikal, Nagore and Napapattinam, respectively. The sediment transport rate is high, exceeding 0.2 x $10^6 m^3$/ month during the southwest monsoon period relatively low, about 0.01 x $10^6 m^3$/ month, during pre-monsoon period (Chandrasekar 1992).

Directional waves were measured off the Nagapttinam coastline for one year to estimate the longshore sediment transport rate. It shows that the transport rate is relatively high about 0.1 x $10^6 m^3$/ month in November and December and is low showing less than 0.03 x $10^6 m^3$/ month in March, April and July. Though the annual gross transport is found to be 0.6 x $10^6 m^3$/year, the annual net transport is very low showing less than 0.006 x $10^6 m^3$/ year towards north. The temporary rise in wave activities during the cyclonic days, often increase the southerly drift, which partly get deposited in the Palk Bay and causes deficit for the northerly drift (Jena et al., 2001).

The Longshore sediment transport rate was estimated along the surf zone at a 4-km-long beach on the central west coast of India. Both the lateral and vertical distributions of the sediment transport rate were measured with traps deployed on a line spanning the surf zone. The measured values were compared with those calculated from three selected empirical formulas. Overall, the correlation coefficient between the longshore sediment transport rates measured and those calculated by CERC, Walton-Bruno, and Van Rijn formula were 0.38, 0.71, and 0.74 x $10^6 m^3$/ year respectively (Kumar et al. 2003).

Estimated of sediment transport rates on the Mediterranean Coast of Israel, employing an analytic expression based on the CERC, Kamphuis formula and are compared with the results of numerical simulations using the LITPACK model and found that sediment transport 0.64, 0.17 and 0.15 x $10^6 m^3$/ year respectively (Perlin and Kit 1999).

Longshore currents along the spit, particularly between Dhanuskodi and Arimunai facing GoM, remained weak (<0.1 m/s) during southwest monsoon and northeast monsoon. Consequently, strong currents (≈0.2 m/s) were observed between Mukkuperiyar and Dhanuskodi (Rao, 2003).

2.7 SHORELINE CHANGE DETECTION THROUGH RS AND GIS

Shoreline, a line of contact between the land and ocean, undergoes continuous geomorphologic changes, in response to natural force and human activities. Natural processes such as continental drift, tide, waves, currents etc., are always at work, but they hardly induce major morphological changes in a relatively short span of time. On the other hand, anthropogenic activities cause immense geomorphologic changes at rapid rate. The extraction of shoreline is useful for several applications like coastal processes, coastline change detection and coastal zone management, but this task is difficult, time consuming, and sometimes impossible for the entire coastal system when using traditional ground survey techniques (Cracknell, 1999). Due to the preference and huge effort involved in manual detection, quite a few automatic shoreline change detection methods were proposed. Advanced remote sensing and Geographical Information System (GIS) techniques overcome these difficulties in detecting shoreline position and shoreline change analysis. A number of satellite image processing techniques were developed to extract shoreline and change detection analysis such as, image enhancement, multi-temporal data classification and comparison of two independent land cover classifications, density slice using single or multiple bands, and multispectral classification, both supervised and unsupervised classification (Mas 1999; Frazier and Page 2000; Ryu et al. 2002; Braud and Feng 1998; Kuleli 2010; Kuleli et al. 2011; Zheng et al. 2011; Bouchahma and Yan 2012).

Kunte and Wagle (1991) used satellite images and topographic maps to delineate the coastal features of the southern coastal segment of the Karnataka, situated along the west coast. LandSAT images were used to locate the fifteen sand spits and coastal features, through those responsible factors for spit formation and growth are attempted to recognize. The study reveals that spit growth direction is either towards north or south depending upon monsoon waves. The bidirectional littoral drift could be the primary agent for sediment redistribution and confinement within the region, thereby keeping the coastline straight, smooth and stable.

Kumar and Jayappa (2000) carried out a comprehensive study between the New Mangalore port and Talapady of Mangalore region. Indian Remote sensing satellites IRS-IC, LISS-III images of January 1997 December 2001 and 2005 of the study area were analyzed to understand long and short-term shoreline changes. Long and short-term shoreline changes as well as erosion/accretion pattern have been estimated by comparing the topographic map of 1967 with multi-dated satellite images. The study concluded that the beach adjacent to the river mouth suffered from erosion.

Natesan (1993) carried out a study on shoreline oscillation of the Tamil Nadu coast using beam crest data spread over 22 locations along the Tamil Nadu coast, over a decade starting from 1979 to 1988. The monthly shoreline oscillation pattern for each sit depicts that erosion is moderate between June and July. October to December is the period of frequent cyclones and depression in the Bay of Bengal, severe erosion was observed at that time. The study concluded that stations located on the north of any man-made structure show an erosion pattern and vice versa for station south of it, as observed in Mahabalipuram, Tharangambadi and Nagapttimam. Similarly, due to the harbour activities at Chennai, foreshore Estate is accreting with a complementary erosion at Royapuram. Accreting pattern for sites located in the Palk Strait, Viz. Ammapttinam, Mandapam and Rameshwaram, is observed

The coastline between Dhanushkodi and Tuticorin, erosion and accretion areas have been estimated and identified. The areas of erosion and accretion have been estimated as 4.3 $km^2$and 23.48km^2, respectively, over a period 30 years (1969-1998). Shoreline Rameshwaram Island both accretion and erosion feature were observed. The areas of erosion and accretion along the coast were approximately 4.66 and 2.01 km^3 respectively. The study concluded that the average rates of erosion and accretion are 6.23 and 6.54 m /year (Thanikachalam et al., 2003).

Natesan(2008) carried out a study on shoreline changes of Dhanushkodi from 1986 to 1996 , the area of accretion along Palk Bay 0.33 sq.km and erosion along the Gulf of mannar 0.36 sq.km, respectively. Between 1996 to 2003 the net erosion was 0.31 sq.km with the 0.51 sq.km accretion along the Palk Bay and 0.82 sq.km erosion along Gulf of Mannar. The analysis proves that the area of erosion in the recent period is enormous as the area of erosion from 1986 to 1996 is 0.004 sq km/yr whereas from 1996 to 2003 it is 0.03 sq.km/yr.

Inter-annual variation of shoreline was calculated for every year for the regions along the Palk Bay (PB) with 187 transects and Gulf of Mannar(GoM) with 257 transects. Along PB, near Arichamunai and GoM, Kodhandaramar koi accretion was more. PB shoreline change as erosion on all the region expect Arichamunai, and the pattern behaves opposite along GoM region Interannual shoreline change reveals that erosion/accretion rate of every year must change in opposite cycles over the period from 2000 to 2012, retaining the positions in successive years, which strongly confirm the coastal stability of Dhanushkodi foreland. Statistical approach of shoreline gain and loss similarity of every year from 2000 to 2012 erosion and accretion may be stabilized by linkage year which concluded shoreline position leads to sustainable island stability (Natesan et al., 2015).

Land use/ Land cover changes in the Hazira region of Gujarat were studied using IRS-1C, LISS III sensor data. Because of major industrial activities, it needs regular monitoring. 1970-72 (SOI Toposheet), 1989 and 1999- 2002 (Satellite data) have been used and visual analysis has been carried out. Trend analysis was carried out for various coastal LU/LC features with respect to time to understand the impact of human activities on various LU/LC in the coastal region of the study area. A limited field observation was taken for verifying the mapping and for accuracy checks. Results showed erosion and deposition around the newly constructed jetty. Forest area and agriculture area were found to be decreased whereas built-up area has been increased (Chauhan and Nayak. 2005).

Land use/Land cover and change detection analysis was conducted in Kolli hill, part of the Eastern Ghats of Tamil Nadu, using remote sensing and GIS. Change detection in the land use/ land cover was carried out between 1990 and 1999 using IRS- 1C LISS III digital data and Landsat TM digital data. SOI toposheets were also used in the study as secondary data. About 467 ha increase was observed in single crop category and about 434 ha decrease was observed in land with or without scrub category. The study showed that satellite remote sensing based land cover mapping is very effective. One of the remedial measures suggested is to utilize the identified wasteland suitable for agriculture so as to improve the economy of people (Jayakumar et al, 2003) .

Landuse/Landcover study of Rameshwaram Island during the December-2005 and May-2010 indicates that water body, sparse vegetation and fallow land decreased by 0.21%, 0.62% and 1.09 % respectively in the month December 2005. Dense vegetation is found to be increased by 0.97% in December 2005. The percentage of degraded land is found to be increased by 0.63 in May 2010 while the sand , mud flat and built up are slightly decreased during December- 2010 (NEERI EIA report 2012).

2. GEOMORPHIC EVOLUTION OF RAMESHWARAM ISLAND, TAMIL NADU, INDIA.

Five distinct geomorphic units are identified, viz, Highlands, with coral swamp, Sand Sheet with high dunes, Sand Sheet and Coral Swamp with Recent Sedimentary Plains. Each one is uniquely characterised by its own lithology vegetation spread and physiography. Highlands lie between Western Pamban to the East Rameshwaram area. The area comprises of stabilised sand dunes of huge dimensions with appreciable amounts of vegetation cover. Due to its stabilised nature, it has been observed that most of the settlements of islands like Ariyangundu, Akkalmadam, Tangachimadam and Rameshwaram are located in this zone. Highland with coral swamp is one of the characteristic landforms and unique in geomorphologic sense (Loveson et al. 1998). It has landforms like beaches, beach ridges, mudflats, raised coral terraces, lagoons, spit etc. along with living corals. Wide beaches are observed in the Southern coast extending to a maximum of 1 Km around Natarajapuram in further south areas. In the Northern coast, beaches are generally narrow and extend only 5 to 10 Mts. The tail like portion of Rameshwaram Island observed in the South Eastern portion is entirely made up of sandy barrier beaches (Prabakaran et al. 2010).

A Remote Sensing and GIS perspective mapping of the coastal geomophological and resource features was carried out using IRS-P6 imagery. The results indicated that presence of coastal ecosystems like sea grasses and patches of coral reefs, and beaches are extensively developed along the southern and northern coasts of Rameshwaram Island (Nobi et al., 2010).

2. SHORELINE CHANGE MODEL

Pelnard-Considere (1956) developed a mathematical model, now called the one-line model, to study the shoreline change. Grijm (1961, 1965) used the one-line theory to derive analytic solutions for delta formations from rivers discharging sand. Bakker and Edelman (1965) further investigated the possibilities of closed form solutions of river delta evolution, assuming somewhat different sand transport equation to allow for an analytical approach. In Bakker (1969), the one-line theory is extended to include two lines for describing the shoreline change one line representing the shoreline and one representing an offshore contour. Komar (1973) developed a model of delta growth due to sediment input from rivers and longshore transport. Le Mehaute and Soldate (1977) present several analytic solutions and discuss the underlying principles of the one-line and two-line theories. Walton and Chiu (1979) gave a brief review of analytic solutions, mainly concerning the dispersion of different beach fill configurations. Larson et al. (1987) compared, through the analysis of simple examples, analytic and numerical solutions of shoreline evolution.

The one-line theory was first numerically implemented by Price et al. (1973). Rea and Komar (1975) presented a technique for studying shoreline evolution for hooked beaches using a two-dimensional grid. Horikawa et al. (1977) discussed the effect of dredged holes on shoreline evolution. Willis (1977) applied the one-line model to prototype conditions, comparing the traditional CERC formula for calculating longshore sand transport with a new expression. Sasaki and Sakuramoto (1978) reported the verification of a one-line model using very precise field data. Perlin (1979) simulated hypothetical case studies involving detached breakwaters. Le Mehaute and Soldate (1980) presented an implicit numerical model and tested it against field data. Mimura et al. (1983) compared their computer simulations against high quality laboratory data. Kraus (1983) gave a brief comparison of four classes of numerical models of nearshore topographic change, namely, the shoreline (1-line) model, the multiline model, the 3-dimensional beach change model, and the macro-model. Matsuoka and Ozawa (1983) used one-line model to estimate the changes of shoreline, interaction between shoreline changes and wave deformation is also taken into consideration.

GENESIS (GENEralized model for Simulating Shoreline Change) is a generalized shoreline change numerical model, developed for calculating shoreline change caused primarily by wave action. The model is based on the one-line theory, for which it is assumed that the beach profile remains unchanged, thereby allowing beach change to be described uniquely in terms of the shoreline position. Moreover, the equilibrium beach profile concept led to the development of the so-called "n-line" or "multi-line" model, in which cross-shore sand transport, and associated changes in the bottom profile, can be characterized to some extent, as well as the cross-shore distribution of the long-shore transport rate (Gravens et al. 1991). This was first accomplished by treating two contour lines (Bakker, 1969; Bakker, et al., 1971) in terms of analytic solutions and by Horikawa et al. (1979) using a numerical model. Shoreline change was studied in and around the Thubon river mouth central Vietnam using GENNESIS model. The change in the shoreline during 1997 to 1998 was estimated and compared. In general the computed shoreline positions show good agreement with measured ones, except the shoreline sections in the area of the river mouth, which lives in the model boundaries and the in the current dominated regions. Obtained model results give a better understanding on the changing behaviour of the shoreline of the study (Le-dinh Mau etc al., 2007).

Janardanan and Sundar (1994) developed a numerical model SHORELINE based on the CERC formulation derived expression to predict shoreline evolution in the presence of shore connected structures.. Shoreline changes of Kanniyakumari near the tip of Indian peninsula using SHORELINE model measured shoreline (2007) and prediction annual shoreline changes were found about 80% more actual shoreline (Suresh etc al., 2011).

The LITPACK model can be successfully applied for simulating, calculating and forecasting orientation of coastal line changes due to erosion and sedimentation processes (Nguyen et. al., 2007).

North of Chennai city on the East coast of India is facing shoreline erosion/accretion related problems after the construction of Ennore Port during 2001. Four major categories of shoreline changes were observed in the study region, *i* . 1) Beach accretion south of Ennore Port, 2) Beach fill erosion north of the north breakwater of Ennore Port, 3) Almost stable coastline at the central part of the study region and 4) Shifting inlet of Pulicat Lake, using LITPACK model the Ennore port south is accreting at an average rate of 45 m /year and Ennore port north coast eroding at of 50 m /year (ICMAM report 2006).

Muthalapozhy fishing harbour, in Kerala on west coast of India was carried out shoreline change using LITPACK model to predict shoreline change next three years (2009 to 2011) and found that accretion on the south harbour and erosion on north harbour due to longshore sediment transport towards north direction (Arya et.al., 2014)

2.10 SUMMARY

From the literature, it is observed that Long shore sediment transport and Shoreline change model of the research work in the study area limitations literature. Therefore long shore sediment transport and prediction shoreline change are attempted in the present study. coastal processes taking place around the Rameshwaram Island and the exchange of the littoral drift between the Gulf of Mannar and Palk Bay significantly determine the supply of sediments to the rest of the east coast and in turn the stability of the region.

CHAPTER 3

MATERIALS AND METHODOLOGY

3.1 GENERAL

Coastal processes are complex and dynamic components which dependent on a large number of influencing factors such as wind velocity, storm (frequency and intensity), tidal range, nearshore currents, wave climate, water level, river discharge and so on. These components would interact with each other and produce a large amount of variation in coastal morphology. Therefore, it is difficult to isolate specific factors causing shoreline changes, for instance changes in vegetation line can be seen more easily, but large variation cannot be easily analysed without considering several factors. Therefore, in order to evaluate the various factors and their interrelationship, it is necessary to discuss not only major influencing factors but also minor factors which need to be considered.

This chapter describes a wide variety of techniques/ methods used, and reason for measuring the data and analyzing the same in order to address the objectives of the study, followed by a brief description of the selected models to near shore wave characteristics, sediment transport rate and shoreline change detection.

3.2 DATA COLLECTION AND ANALYSIS

The collection of oceanographic related data is a very laborious exercise by itself and is very much expensive. However, these measurements and observations are necessary for proper understanding and analysis of the existing problem. A variety of state-of-art equipments like Datawell directional wave rider buoys, Interocean S4 wave gauge and Smart Station Instruments are used in the present study.

3.2.1 Instruments

3.2.1.1 Datawell Directional Waverider Buoy

Datawell Directional Waverider Buoy consists of a stainless steel body of 90 cm diameter, is spherical in shape, freely floating in the sea surface, and is moored at the desired wave measurement location shown in Figure 3.1. It has a flashlight unit for navigational purpose, an antenna of 2 m length, continuously transmitting wave information. Accelerometers housed inside the hull measure the vertical, north-south and east-west accelerations of the buoy. All these accelerations are then digitally integrated to obtain displacements and filtered with a high frequency cut-off at 0.64 Hz, The signals are transmitted to a shore based waverider receiver RX-C/ recording station, with the help of 2 m long antenna mounted on top of the buoy. The personal computer interface with waverider receiver RX-C, receives and demodulates the HM signals from the directional wave rider buoy. The processor in the receiver also checks for transmission errors. The data were also recorded internally in memory of the buoy.

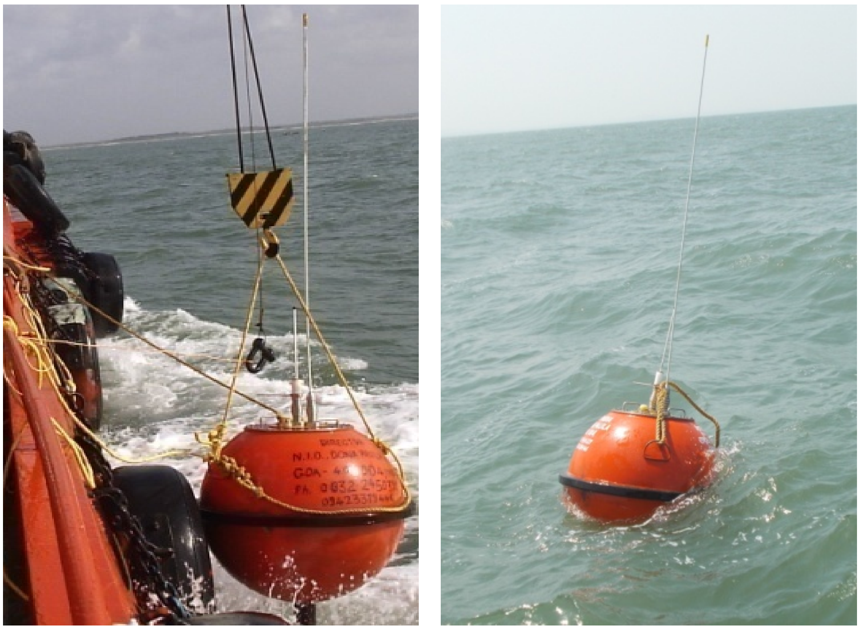


Figure 3.1 Directional wa erider uoy

3.2.1.2 InterOcean S4DW Wave Gauge

InterOcean S4DW wave gauge is of spherical shape of 35 cm diameter as shown in Figure 3.2. It has electromagnetic sensors and a fluxgate compass for wave measurement in breaking zone. It has six alkaline D type cells which give 489 hours of continuous data logging. The data is stored in CMOS static RAM, and after recovery of the moored unit, it is interfaced to personal computer through S110 interface to retrieve data. The S4DW is moored at 0.5 m above the seabed at a water depth of 1.5 m. The data are sampled at a rate of 2 Hz every three hours. The wave height and wave period are obtained from the wave spectrum.

Figure 3.2 InterOcean S4DW wa e gauge

3.2.1.3 Smart Station

Smart station is an advanced total station where it has an inbuilt real time GPS which receives data from the satellite to calculate latitude and longitude, while at the same time, it receives data from a nearby receiver operated by the movable base station. The receiver uses the data from the movable base to correct its computed position immediately or in other word in real time. It is also used to collect ground control points (GCP) for Geo-referencing the satellite images.

Figure 3.3 Smart Station

3.2.1.4 Bathymetry

Bathymetry of the GoM and PB region is digitized from the Naval Hydrographic Chart No. 358 and is used in the present the study.

3.2.2 Wa e Analysis

Time series data on three translational motions of the buoy were recorded in the memory card of the buoy. From the recorded heave data of 30 min duration, the wave spectrum is obtained through Fast Fourier Transform (FFT). FFT of eight series, each consisting of 256 measured vertical elevations of the buoy heave data, is added to obtain the wave spectrum. The high frequency cut off was set at 0.58 Hz. Heave was measured in the range of -20 to 20 m with a resolution of 1 cm and an accuracy of 3%. When the moored buoy follows the waves, the force of the mooring line may change, resulting in a maximum error of 1.5% in the measurement of surface elevation. Digital data were analyzed using spectral method for computing various statistical parameters Viz., significant wave height (H_s), mean wave period (T_z), wave period corresponding to the maximum wave spectral energy (T_p), maximum spectral energy (E_{max}), spectral width parameter (ε) and peakedness parameter (Q_p). The above statistical parameters were evaluated using the spectral moments as follows.

Significant wave height (H_{m0}) = $4\sqrt{m_0}$ (3.1)

Mean wave period (T_{m02}) = $\sqrt{m_0/m_2}$ (3.2)

Hence, m_n is the n^{th} order spectral moment and is given by $m_n = \int_{\circ}^{\infty} f^{\,n}\, s(f)\, df$, n=0 and 2, Sf is the spectral energy density at frequency f. Mean wave direction (D_p) corresponding to the spectral peak is estimated based on circular moments. Maximum wave height (H_{max}) is estimated from the 30 min time-series vertical elevation data of the buoy.

InterOcean S4DW wave gauge directional waves are measured using the principle of a analysing direction record to determine the orbital velocity components of particular frequency bands and combining that information with wave height as measured by the pressure sensor with automatic depth attenuation correction. The data is converted from the time domain to the frequency domain and analyzed using FFT.

The directional wave information, including frequency spectrum and processed results from the S4DW, are available as output from InterOcean's Wave for Windows analysis software or may be output directly from the new generation S4DW-I which processes this data internally for immediate availability to the user without the need for external software. The Wave for Windows software is a powerful processing tool that enables the user, full control over the analysis process with publication-quality graphic and tabular output. Alternatively, the direct output of pre-processed data from the S4ADW-I offers a significant advantage where Windows-based PC computers cannot be used, such as remote installations, integrated systems, and telemetry applications.

3.3 NEAR SHORE WAVE MODEL

The model REF/DIF-1 is used in the present study to estimate the nearshore waves from the measured wave data at 12 m water depth. The measured wave characteristics were given as the model input at the offshore boundary. Bathymetry of the GoM and PB region is digitized from the Naval Hydrographic Chart No.358. The model output gives the wave height at the each grid and the wave angle or the wave propagation angle at each grid point. For the GoM and PB region, the breaker heights at 1 m were extracted from the model out REF/DIF-1 model.

3.3.1 Model E uations

The problem of water waves propagating over irregular bathymetry was simplified by Berkoff (1972) using vertical integration problem. Berkoff's equation is known as mild slope equation and is written in terms of surface displacement. For monochromatic waves according to linear theory with the free surface elevation given as $\zeta(x, y, t) = \Re\{(\eta(x, y)e^{-i\omega t})\}$ and the waves propagating on a fluid layer of mean water depth $h($ $,y)$ - the mild-slope equation is

$$\nabla.\left(C_p C_g \nabla\eta\right) + k^2 C_p C_g \eta = 0 \qquad (3.3)$$

where,

$\eta($ $,y)$ is the complex-valued amplitude of the free-surface elevation $\zeta($ $,y,t)$, ($,y)$ is the horizontal position , ω is the angular frequency of the monochromatic wave motion, i is the imaginary unit, $\Re\{.\}$ means taking the real part of the quantity between braces; ∇ is the horizontal gradient operator, $\nabla\cdot$ is the divergence operator, k is the wavenumber; c_p is the phase speed of the waves and c is the group speed of the waves.

3.3.2 Model Assumtions

The REF/DIF-1 model,in parabolic form, has a number of assumptions inherent in it and it is necessary to discuss these directlty.These assumptions a

i) Mild bottom slope

The mathematical derivation of the model assumes that the variations of the bottom occur over distances which are long in comparison to a wave length. For the liner model Booij(1983) performed a comparison between an accurate numerical model and mild slop model for waves shoaling on the beach. He found that for bottom slope up to 1:3 the mild slope model was accurate and for steeper slopes it still predicts the trends of wave height changes and reflection coefficient correctly.

ii) Weak nonlinearity

The model is strictly based on a Stokes perturbation expansion and therefore is restricted to applications where Stokes waves are valid, unless the Stokes-Hedges nonlinear model dispersion relationship is selected. In this case, a heuristic dispersion relationship developed by Hedges (1976) is used. In shallow water, this relationship matches that of solitary waves. This hybrid model is discussed in more detail in Kirby and Dalrymple (1986).

iii) Wave direction

The wave direction is confined to a sector ±70° to the principal assumed wave direction.

3.3.3 Model Domain

The model domain is divided into a 100x100 grid with each grid having uniform spacing of 20 meter resolution. The Figure 3.4 below shows the bathymetry of the GoM (GoM) and PB (PB) region which has been digitized from the Naval Hydrographic Chart. REF/DIF-1 computes a grid based wave evolution over an arbitrary bathymetry and current field, an array of 100x100 grid values with regular spacing in x and y direction has been provided. The wave data were analyzed statistically to get the representative wave characteristics. These representative wave characteristics were given as the model input at the offshore boundary.

The principle effect of the depth variation will cause the wave to refraction which occurs because the part of the wave in shallow water moves more slowly than waves in deep water.

Reference grid size calculation gives the number of row and number column of the each grid. The model output gives the tide corrected depths, the wave height at the each grid and the wave angle or the wave propagation angle at each grid point. The model also provides the complex amplitude of the wave field.

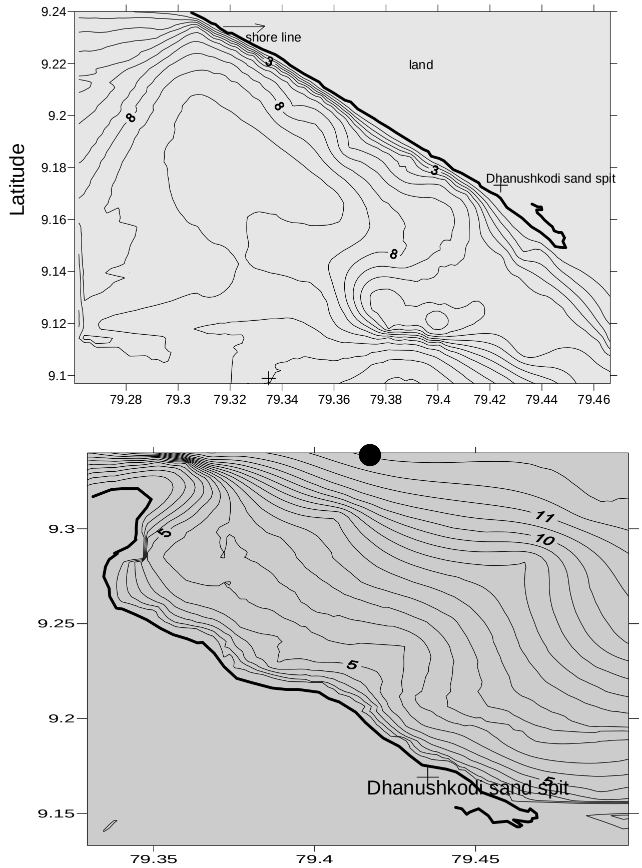


Figure 3.4 Model Domain GoM and PB.

The measured wave characteristics are given as the input at the model boundary (12 m water depth). The model output gives the wave height and the wave propagation angle at each grid point. For the GoM and PB regions, the breaker heights at 1.5 m are extracted from the model output. The model output is compared with measured wave data at 1.5 m depth for a period of 40 days during the months of November to December along the GoM. The Figure 3.5 shows to calculated LST.

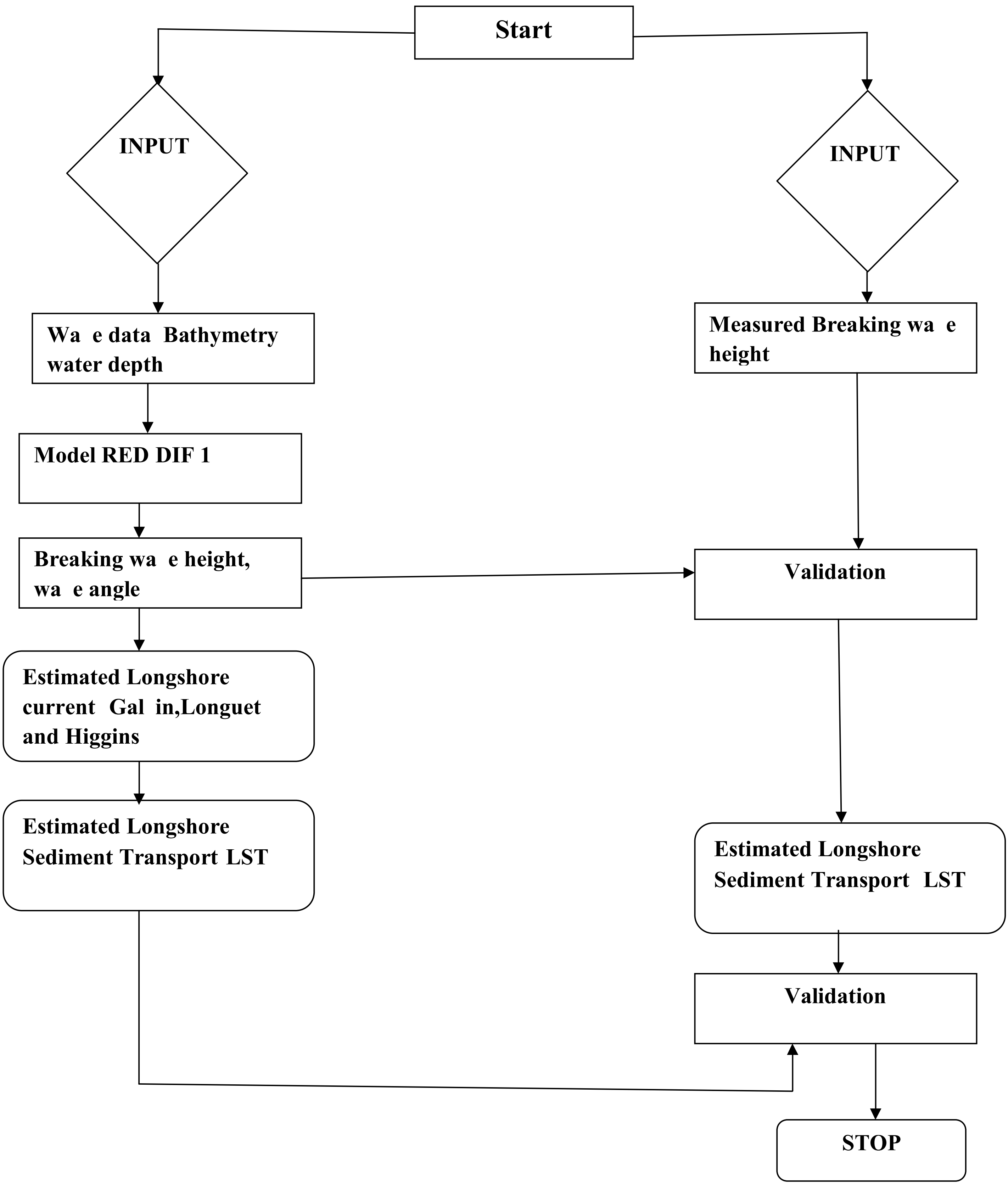


Figure 3.5 Flowchart for LST calculations

3.4 LONGSHORE CURRENTS

The longshore current is the movement of water along the shoreline. The longshore current is estimated using two commonly used equations: (i) Longuet and Higgins (1970) (Eq.3.4) and (ii) Galvin (1987) (Eq. 3.5).

$$V = 20.7m \left(gH_b\right)^{1/2} \sin\left(2\alpha_b\right) \qquad (3.4)$$

$$V = \quad m\,T \sin\left(2\alpha_b\right) \qquad (3.5)$$

where V is the longshore current velocity (m/s), g is acceleration due to gravity (m/s^2), m is the slope of the sea bottom in the surf zone (m), T is the wave period(s), H_b is the breaking wave height (m), α_b is the angle between the breaking wave crest line and the local shoreline (deg), and K is the dimensionless coefficient depending on the geometry of the breaking wave. K=1 is used in the present study.

3.5 LONGSHORE SEDIMENT TRANSPORT

The longshore sediment transport rate is usually estimated from an empirical equation relating the longshore energy flux in the breaker zone to the longshore transport rate (Komar and Inman, 1970) and it is known as Coastal Engineering Research Center (CERC) formula (SPM, 1984). Almost in all studies, the longshore transport rate has been attempted to relate with longshore energy flux. The longshore sediment transport rate (LSTR) is estimated using three different formulae viz the CERC formula, the Walton and Bruno formula, and the Kamphuis formula.

i The CERC formula

One of the simplest and, most commonly used methods for calculating the LSTR is the Coastal Engineering Research Center (CERC) formula (SPM, 1984, CERC 2006). Here, the LSTR is calculated from the empirical equation relating longshore energy flux in the breaker zone:

$$Q = \frac{K A \rho g\, H_b^{\,2}\, T \sin\left(2\alpha_b\right)}{64\pi} \qquad (3.6)$$

where Q is the LSTR (m^3/yr), K is the dimensionless empirical proportionality constant (taken as 0.39), $A = \dfrac{1}{(\rho_s - \rho) g (1 - p)}$, and ρ_s is the sediment density (kg/m^3). ρ is density of seawater (kg/m^3), g is acceleration due to gravity (m/s^2), p is porosity factor (0.4), T is wave period (s), θ_b is wave breaking angle (deg).

ii The Walton and Bruno formula

Another equation used to calculate the LSTR was put forward by Walton and Bruno (1989). Using the breaker height and longshore velocity, the LSTR is calculated by the Walton and Bruno formula as:

$$Q = \frac{K A \rho g H_b W V C_f}{0.78\left(5 \pi/2\right)\left(\frac{V}{V_0}\right)_{LH}} \tag{3.7}$$

where, V is mean longshore velocity (m/s), W is surf zone width (m), C_f is friction coefficient, $(V/V_0)_{LH}$ is the theoretical dimensionless longshore current velocity with the mixing parameters as 0.4 (Longuet-Higgins, 1970).

iii The Kamphuis formula

Kamphuis et al. (2002) developed an empirical formula that includes the nearshore slope, the wave period (Tp), and the sediment grain size (d_{50}) based on their laboratory experiments and existing field data:

$$Q = \left(\frac{2.27 H_b{}^2 T_P{}^{1.5} m^{0.75} d_{50}^{-0.25} \sin(\alpha_b)}{(\rho_s - \rho) g (1 - p)}\right) \tag{3.8}$$

i LITDRIFT

LITtoral Processes and Coastline Kinetics (LITPACK) numerical model in MIKE-21 software package developed by the Danish Hydraulic Institute (DHI) is used for estimating the sediment transport of non-cohesive sediments and shoreline changes (DHI, Version 2008). The main modules of the LITPACK are long-shore current and littoral drift (LITDRIFT), Coastline evolution (LITLINE), Cross-shore profile evolution (LITPROF). The LITDRIFT module was used to estimate the LST rates. The module includes important sediment transport mechanisms, such as nonlinear wave motion, the turbulent bottom boundary layer, wave breaking, and sediment grading (DHI, 2008).

LITDRIFT module simulates the cross-shore distribution of wave height, set-up and longshore current for an arbitrary coastal profile. It provides a detailed deterministic description of the cross-shore distribution of the longshore sediment transport for an arbitrary bathymetry for both regular and irregular sea states. The LITDRIFT module simulates the cross-shore distribution of wave height, set-up and longshore current for an arbitrary coastal profile. It provides a detailed deterministic description of the cross-shore distribution of longshore sediment transport for an arbitrary bathymetry for both regular and irregular sea. It is assumed in the model that the conditions are uniform along the straight coast.

The equation shore-parallel momentum balance determines the longshore current velocity profiles.

$$\tau_b - \frac{d}{dx}\left[\rho E D \frac{du}{dy}\right] - \frac{ds_{xy}}{dy} + \tau_{w+}\tau_{cur} \quad (3.9)$$

τ_b-bed shear strees due to the longshore current, ρ- density, E-movement exchange coefficient, D- water depth, U-longshore current, y-shore normal current. s_{xy}- shear component of the radiation street $\boldsymbol{\tau_w}$ and $\boldsymbol{\tau_{cur}}$ – driven forces due to wind and coastal current.

The suspended sediment transport is calculated as the product of sediment concentration and the mean circulation current average over the wave period (Hedegaard, 1988). The input data for the LITDRIFT module are the wave climate as a time series data, the initial coastline, and the sediment characteristics. The LITDRIFT profiles are created using bathymetry, roughness, mean grain size, fall velocity, and geometrical spreading. The profiles considered in the study are shown in Figure.3.6. The roughness used in the study is 0.004 and the geometrical spreading is 1.5.

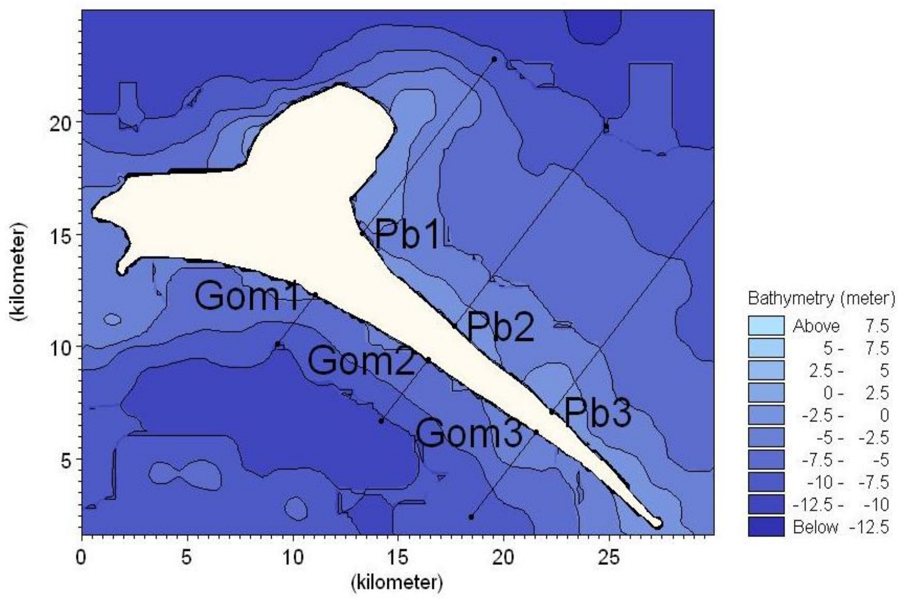


Figure 3.6 Bathymetry and cross section profile used in LITDRFIT model

3.6 SHORELINE CHANGE DETECTION THROUGH RS AND GIS

One of the most important research aims of shoreline change studies is to quantify the erosion/accretion pattern of shoreline. There are several factors affecting the shoreline change such as bathymetry, shoreface, sea level fluctuations, sediment budget, longshore sediment transport and tectonic activity. In order to ensure sustainable development of coastal zone, it is necessary to develop accurate, up-to-date and comprehensive scientific analysis for the selected region.

Generally short-term variation is induced over periods ranging from days to seasons where as long-term variability (the rise in sea level, the shift in natural sediment supply) occur over a period of decades to centuries. Because of this reason, both long-term and short-term impacts on shoreline need to be studied in a detailed manner, and hence both long-term and short-term variations are considered in the present study.

3.6.1 Remote Sensing Data

Remote sensing is a technology of acquiring data through a device which is located at a distance away from the object without any physical contact, and analysis of the data for interpreting the physical attribute of the object. Both these aspects are intimately linked to each other.

Remote sensing data could be either analog or digital form, representing the real world. Data may be acquired through a variety of devices depending upon the object or phenomena being observed. Most of the remote sensing techniques make use of emitted or reflected electromagnetic radiation of the object of interest in a certain frequency domain (infrared, visible light, microwaves). This is possible due to the fact that the examined objects (vegetation, houses, water body and so on) reflect or emit radiation in different wavelength and in different intensity according to their current conditions.

Four remotely sensed images were obtained from the National Remote Sensing Center (NRSC), Hyderabad. In addition, two topomaps were obtained from Survey of India (SoI) in order to assess the changes in the shoreline since 1953 and the details are presented in Table 3.1

3.6.2 Geographic Information System GIS

Geographic Information System (GIS) is an automated tool for assisting the capture, storage, management, analysis, display and retrieval of spatially displaced information. GIS is defined as an information system that is used to input, store, retrieve, manipulate, analyze geographically referenced data or geospatial data, in resources, environment, transportation, land use/land cover, oceanography, and other coastal administrative records.

Ta le 3.1 Details of data products used in the present study

Type of Data	Data Source	Data Period	Scale / Resolution
Wave Data	Field Data (waverider buoy)	Feb 2010 to Feb. 2011	
Wave Data	Field Data (S4DW)	Nov2010 to Dec 2010	
Shoreline	Field Data (Smart Station)	Dec 2010	
Bathymetry	NHC	2007	
Toposheet	SOI	1953	1:25,000
Toposheet	SOI	1969	1:25,000
IRS-1D LISS III	NRSC, Hyderabad	1998	23.5 m
LRS-1D LISS III	NRSC, Hyderabad	2008	23.5 m
IRS-P6 LISS III	NRSC, Hyderabad	2010	23.5 m

3.6.3 Software Tool

In order to assess the changes in shoreline at five temporal conditions, ERDAS Imagine 9.2 and ArcGIS 8.2 were used for digital image processing and for the creation of maps, respectively.

3.6.3.1 ERDAS Imagine

ERDAS (Earth Resource Data Analysis System) Imagine is the image processing software, which is designed for the purpose of accessing, interpreting, and analyzing multispectral satellite imagery. It has a wide range of features for enhancing and manipulating a large number of image files. It also enables to develop new models for satellite image processing based on earth applications. ERDAS Imagine includes an innovative set of tools for extraction of earth surface features and allows geospatial data layers to be created and maintained through the use of remotely sensed imagery.

3.6.3.2 ArcGIS 8.2

ArcGIS 8.2 is the name of group of desktop Geographic Information System (GIS) software products produced by ESRI. ArcGIS includes: ArcReader, which allows viewing query maps created with other Arc Products: ArcView is to view spatial data, create maps, and perform basic spatial analysis; ArcEditor which includes all the functionality of ArcView and consists of more advanced tools for manipulation of shape files and Geodatabase.

3.6.4 Shoreline Change Methodology

Base map of the study area was prepared using SoI toposheets. The shoreline and the outline of the area of interest was traced on to a tracing paper from the toposheets using pencil and later marked with Indian ink pen to minimize the errors and allow corrections at the initial stage itself, and the map was scanned and extracted in image format. Later registration was carried out under ArcMap GIS environment by adopting Geographic co-ordinate system as projection system and Modified Everest as a datum. All the images were later exported for mosaiking and analysis in ERDAS Imagine 9.0. Digitization was carried out using GIS software Arc map. The digitized base map was first stored in shape format and later converted into image format before importing to ERDAS Imagine for further analysis. The base map of the study area is shown in Figure 3.7 and the flowchart of the methodology is shown in Figure 3.7.

The shoreline change analysis was carried out using the SoI Toposheet (1953 and 1969) and remote sensing data (1998, 2008 and 2010). The base maps were prepared by tracing the SoI Toposheet. The base map includes the features like the road networks, railway networks, major river boundary, High Tide Line (HTL) etc. The traced sheets were scanned and registered with respect to the co-ordinates and then the features were digitized and stored in shape files. Using the rectified base map the satellite data was Geo-referenced on ERDAS platform. The shoreline was extracted from both the base map and remote sensing data and the overlay analysis was carried out by extracting the areas of erosion, accretion and stable beach using ArcGIS 9.

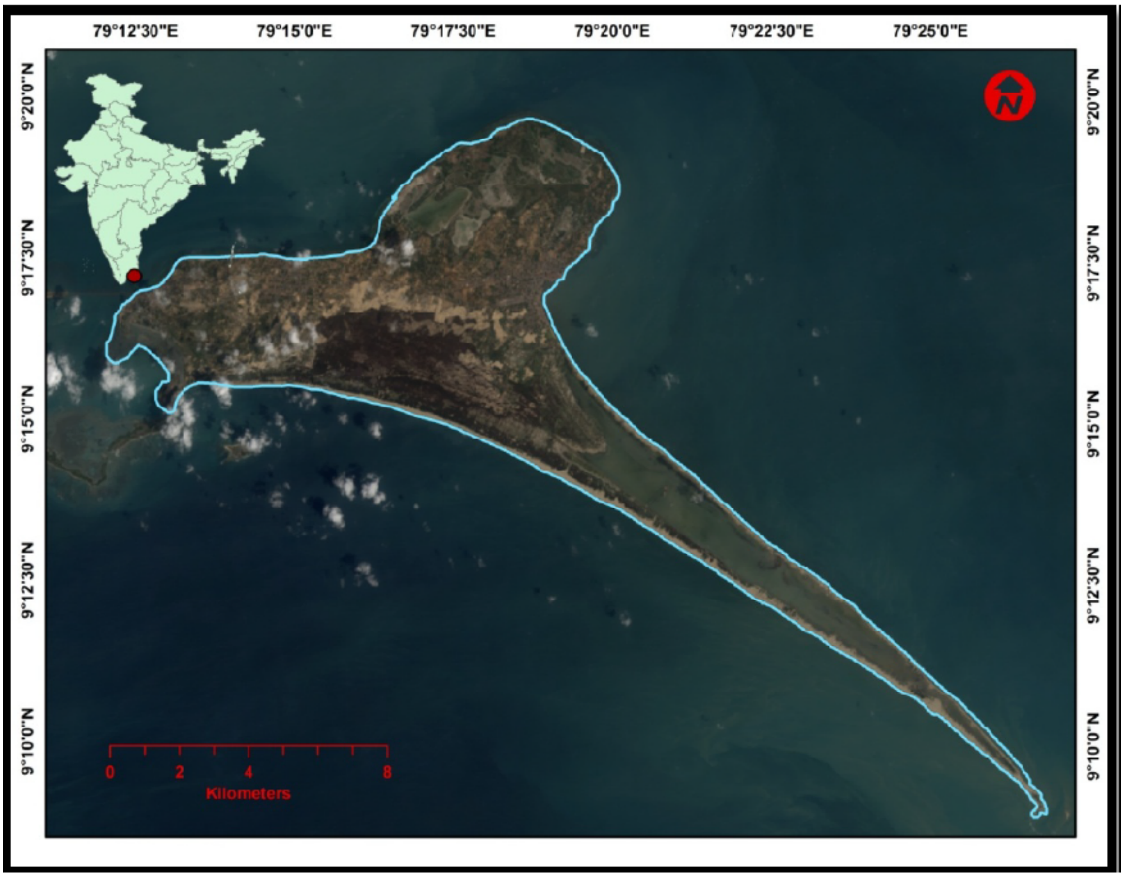


Figure 3.7 Base map of study area

3.6.5 Land Use LU Land Co er LC Map

The LU/LC map is a map showing spatial distribution of various land use/ land cover categories like built-up land, agricultural land, water bodies, wasteland, etc. Information on the existing LU/LC pattern and its spatial distribution studies is required for planning, utilization and formulation of development activities (Chauan and Nayak, 2005). In the present study IRS – 1C LISS III (1998), and IRS-P6 LISS III (2010) images were used to detect the changes in land use and land cover. The change detection was carried out upto level II classification based on the standard NRSC classification system. The ERDAS Imagine 9.0 was used to register the images, then the vector layers of various land use/land cover classifications and attributes of these areas such as area, type of land use/land cover were detailed and then the final map was composed using ArcGIS 9.3

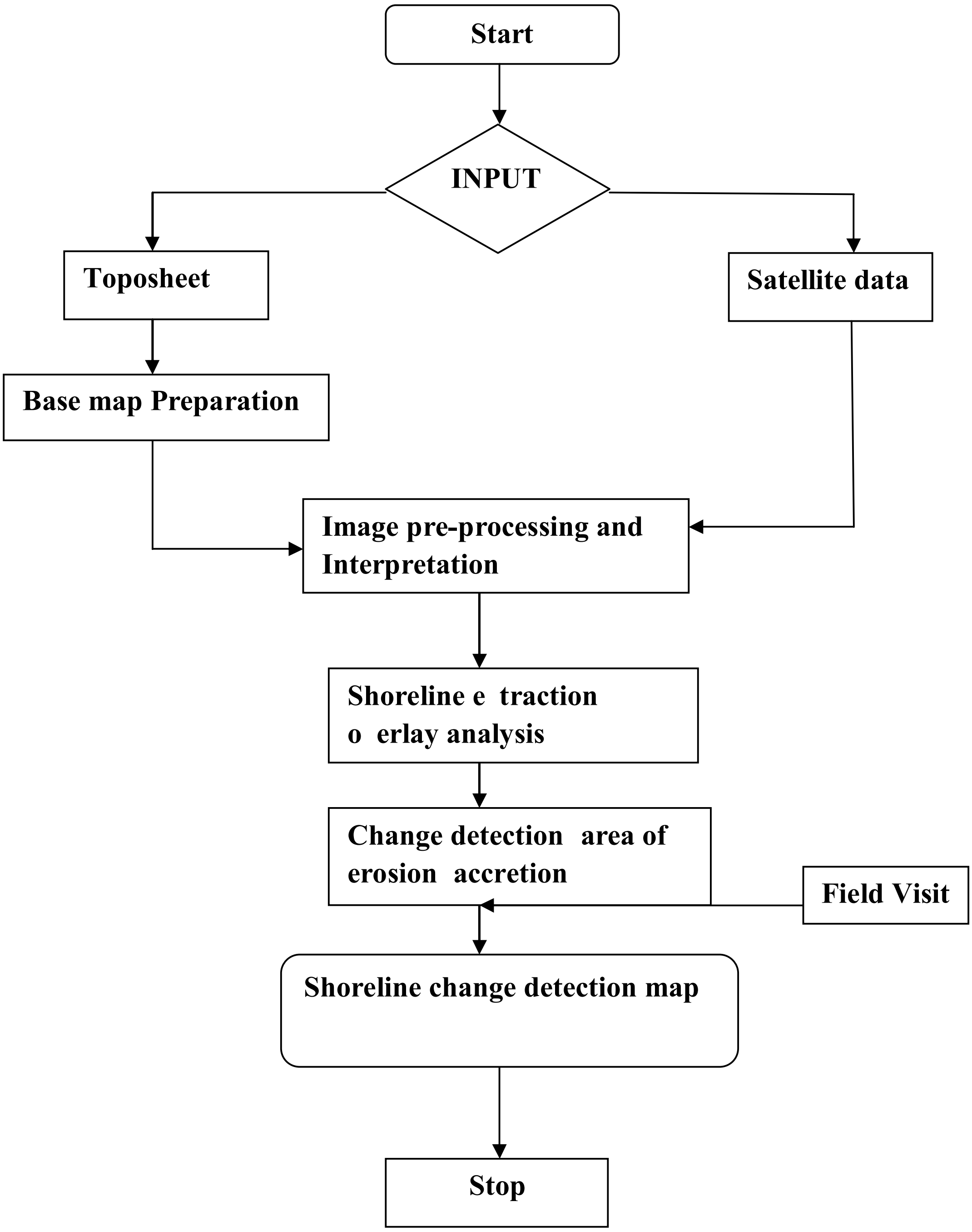


Figure 3. Flowchart of methodology for shoreline change detection analysis

3.7 SHORELINE CHANGES MODEL

The module LITLINE was used to simulate the evolution of the coastline of the study as shown in Figure 3.9. It calculates the coastline position based on the input of the wave climate as a time series data. The model is based on one ‑ line theory, in which the cross ‑ shore profile is assumed to remain unchanged during erosion / accretion. Thus, the coastal morphology is solely described by the coastline position (cross shore direction) and the coastal profile at a given long - shore position. LITLINE is applied in research on shoreline changes due to natural conditions, protected constructions and research on shoreline recovering measures by artificial beach nourishment. Based upon the results from the LITDRIFT, LITLINE simulates the coastal response to gradients in the longshore sediment transport capacity resulting from natural features and a wide variety of coastal structures. The model solves the continuity equation for coastline, as shown below.

$$\frac{\partial y_c}{\partial t} = -\frac{1}{h_{act}}\frac{\partial Q}{\partial x} + \frac{Q_{sou}}{h_{act}\nabla x} \quad (3.10)$$

y_c – distance from the baseline to the coastline, t-time, h_{act} – height of the active cross-shore profile Q - long-shore transport of sediment expressed in volumes, x = long-shore position, ∇x- long-shore discretization step. Q_{sou}–source/sink term expressed in volume/∇x.

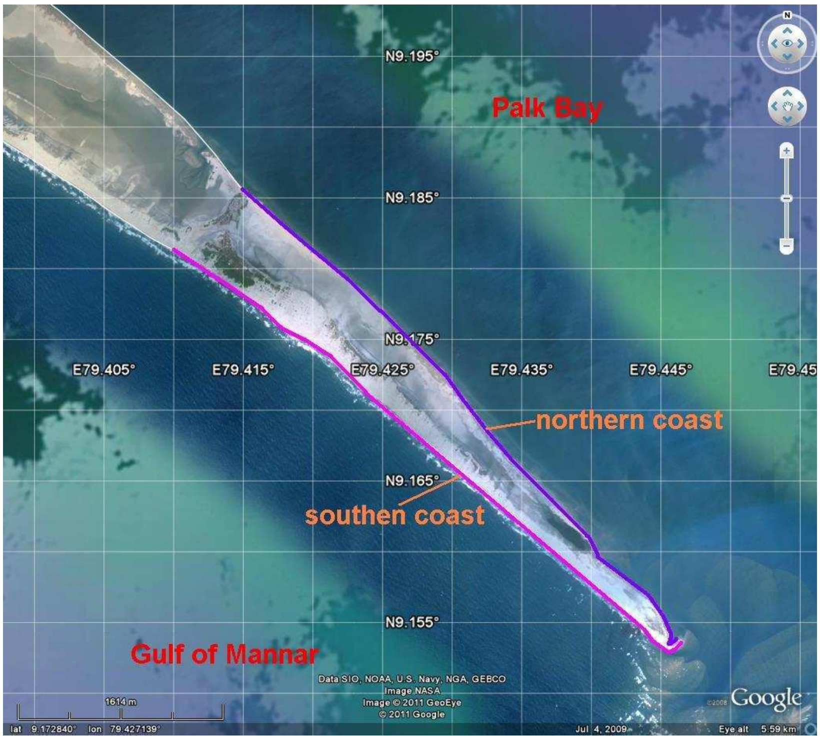


Figure 3. Initial coastline used in LITLINE model

The LITLINE simulates the coastline using the wave climate and five beach variables (i.e., beach position, sand dunes position, height of dunes, profile number, and water depth). The wave climate is prepared from the observed wave data. The simulation was carried out for the evolution of 6 km of coastline on both sides of the

GoM and PB to predict the scenario of the coastline for 3 years (2010-2013) and 5 years (2010-2015). For validating the model, the shoreline of the year 2010 was considered as the base line. The flowchart for the simulation of the coastline from the wave climate date is shown in Figure 3.10.

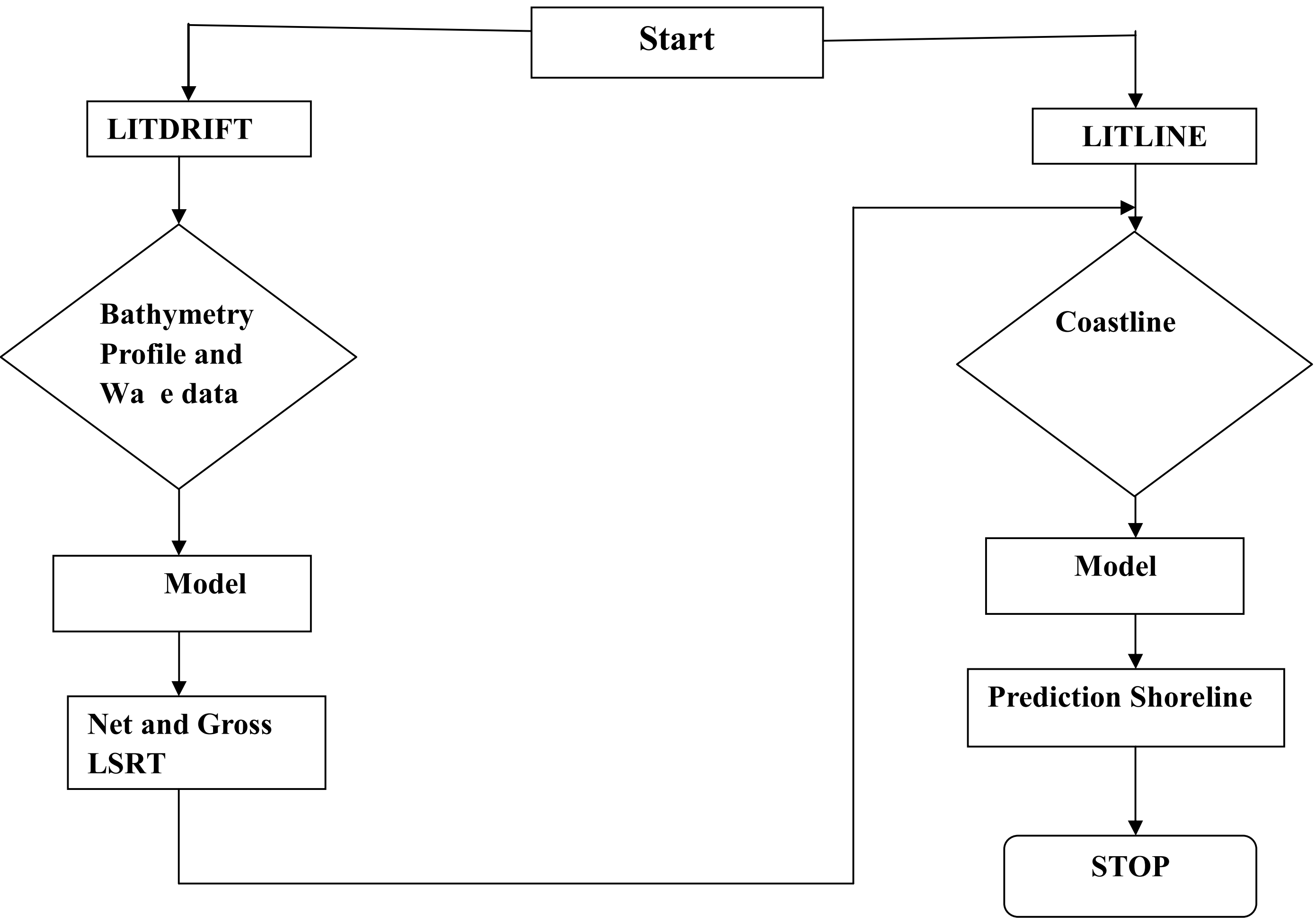


Figure 3.10 Flowchart for the simulation of coastline changes using LITPACK

CHAPTER 4

RESULTS AND DISCUSSION

4.1 GENERAL

Shoreline change is one of the very important parameters in the domain of coastal engineering in order to provide proper plan and management of coastal zones in a sustainable manner. The coast is a zone of intense energy input. This energy transported by wave, tides, and wind arrives at the coast, sets the process of sediment transport in motion that causes the morphological changes. These changes will continue indefinitely until an equilibrium condition is reached which results in no net sediment transport. The variations of longshore sediment transport rate and breaker characteristics, distribution of net longshore sediment transport rate, extent of erosion, deposition of shoreline, shoreline change under the influence of wave action, interpretation and prediction of shoreline changes are detailed in this chapter.

4.2 NEAR SHORE WAVE

Near shore waves are prominent among other oceanographic parameters such as winds, tides, and currents in modifying the coastal geomorphology. Wave forces and wave dominated processes such as wave transformation in shallow waters cause spatial variation in wave energy leading to beach erosion/accretion (Short, 1999). Longshore currents generated by the breaking waves are responsible in transporting the sediments along the surf-zone. The surfzone dynamics and the longshore sediment transport are evaluated based on the wave propagation into shallow water, if is subject to the effect of wave shoaling. If the wave crest is oblique to bottom contours, the difference in celerity along the wave crest causes the wave to bend, called wave refraction. As waves enter shallow water they slow down and they change shape, increasing in height. Longer period swells will increase more during this process than shorter period swells, which are steeper to start with. Once they reach a water depth of approximately 1.3 times their height they start to break. How rapidly this happens is affected by the local sea bed. On a gently sloping beach with light winds the wave will gradually increase in height and eventually the top starts to spill gently forward. The surface waves are measured using a Datawell directional waverider buoy for a period of one year covering different seasons of the year (2010-2011). The model REF/DIF1 is used in the present study to simulate the nearshore wave patterns from the measured wave data at a water depth of 12 . The discontinuity in the wave data collection is due to the retrieval of the buoy for maintenance and due to the entanglement.

4.2.1 Wa e Spectrum

A wave spectrum is the distribution of wave energy as a function frequency. It describes the total energy transmitted by a wave field. The potential and kinematic energy of random waves is represented by the wave spectral density function, or the 'wave spectrum'. This concept is of much significant in evaluating the statistical properties of random waves. Wave spectra are strongly influenced by the wave-producing wind and its statistical/ spatial characteristics. The significant information obtained is of the wave frequency composition in a given wave sample. The area under the wave spectrum gives the total energy of the irregular wave system per plan area and also the variance value of the water surface fluctuations. The integration of the wave spectrum involving different powers of wave frequencies yields important design statistics like significant wave height and average zero cross period. The wave spectra when multiplied by a suitable transfer function yield the response spectra that are used in structural design. The wave energy distribution with respect to the frequency along, disregarding the wave direction is known as the frequency spectrum, whereas the energy distribution represented as a function of both frequency and direction is called the directional wave spectrum. The wave energy spectra are either single-peaked or multi-peaked. In multi-peaked spectra, the peak in the low-frequency region is associated with swells and the peak in the high-frequency region is associated with wind seas.

According to the dominance of swell or wind sea, frequency of primary and secondary peaks in the spectrum varies. Wave spectra of GoM are mainly multi-peaked are shown in Figure 4.1, indicating the presence of two or more distinct wave systems prevailing in the region. During fair weather season (February–May), the sea states of GoM are swell dominated with the primary peak in the low-frequency region and a secondary peak in the high-frequency region and during monsoon, the wind sea dominates. Distant swells from different directions also propagate to this region and form a complex sea state. The spectral peak shifts from low- to high-frequency region depending on the strength of the prevailing winds. Wave spectra of PB are mainly single-peaked are shown in Figure 4.1a , except during the SW monsoon season. Because of the dominance of wind seas, the primary peak of the wave spectrum in PB is always in the high frequency region of the spectrum. Another feature observed during the spectral analysis is that the secondary peak occurred approximately at 1.9 times the frequency of the primary peak in the GoM and at 1.1 times the frequency in PB. The secondary peak of the multi-peaked observed in the GoM is similar to that (1.5-2.5 times the frequency of the main peak) reported for the open-sea locations around India (Baba et al., 1989 and Kumar et al., 2003). The low value of 1.1 observed in PB is due to the absence of swells in the region and both the peaks are in the wind-sea region.

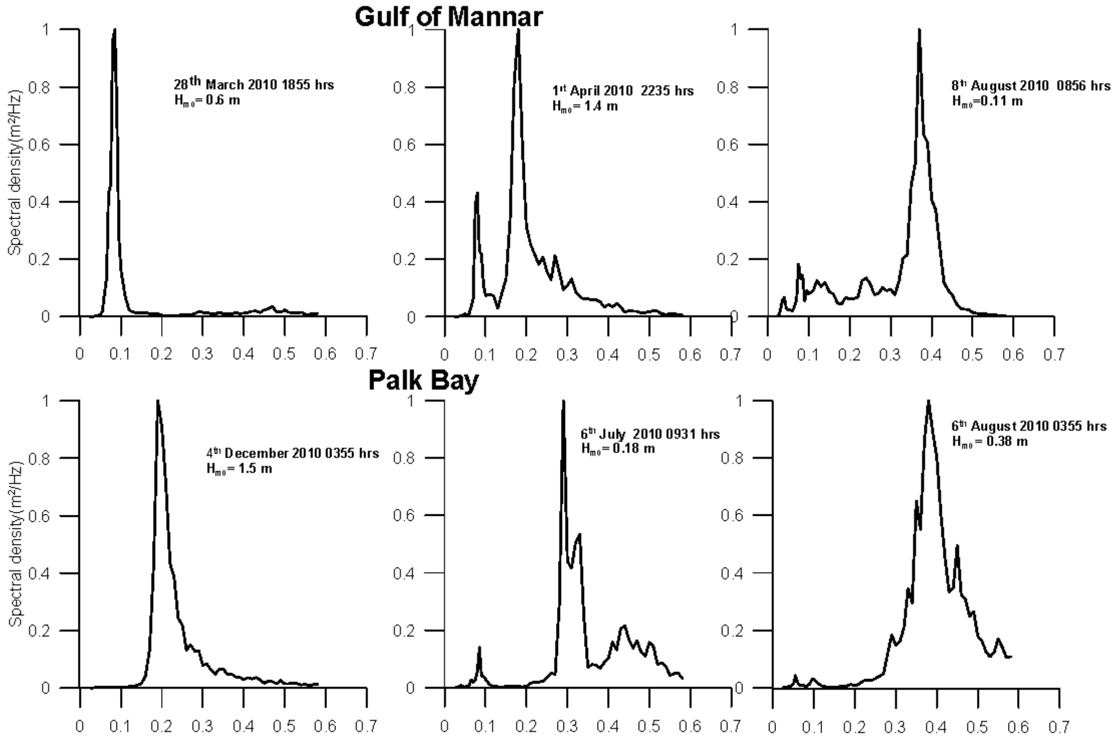


Figure 4.1 Wa e spectra at GoM and PB

4.2.2 Wa e characteristics

The wave characteristics are required for the planning of the jetty. Estimated design wave parameters have considerable importance in planning and operation of marine activities and design of coastal and offshore structures. The information wave characteristics has great importance in the study of sediment transport and coastal processes. Wave generated long shore currents are the driving force behind the littoral drift.

Wave characteristics of GoM and PB are evaluated on the basis of the data collected. The ranges and average values of significant wave height (H_{m0}) swell wave height (H_{swell}) and wind sea height (H_{sea}) during 2010 February – March 2011 for GoM and PB. Significant wave height (H_{m0}) varied from 0.2 to 2.7 m with a mean value of 0.9 m and maximum wave heights (H_{max})varied from 0.3 m to 5.4 m with mean value 1.4 m in GoM (Figure 4.2 a).

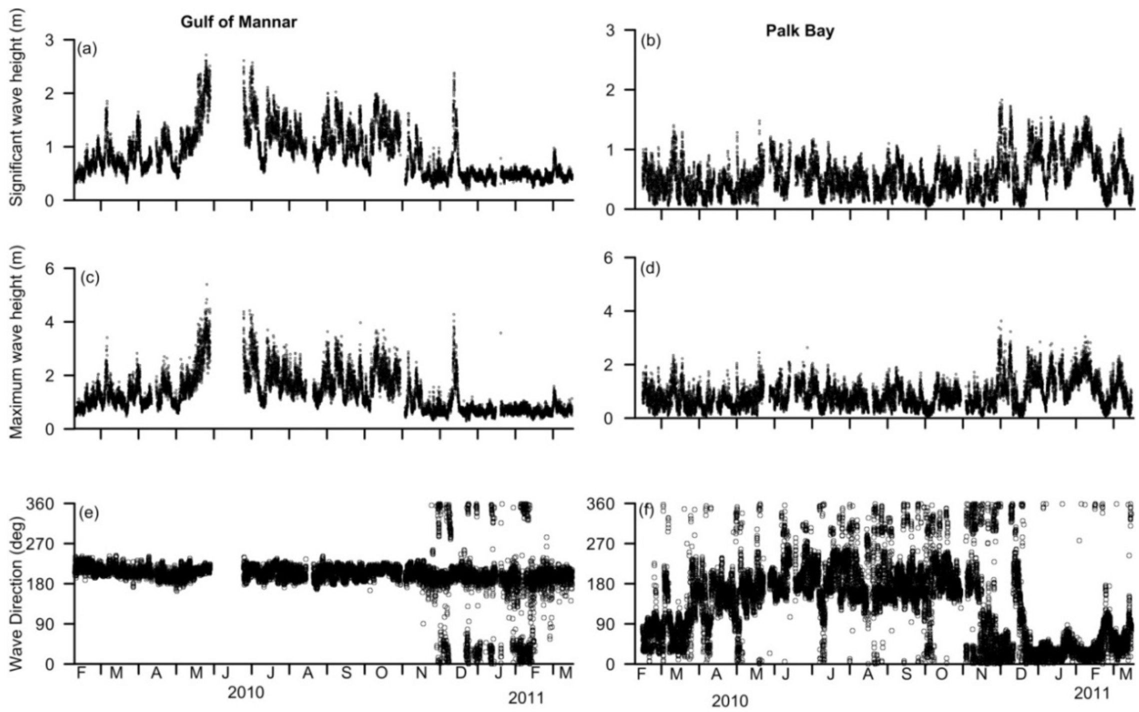


Figure 4.2 Variation of wa e parameters *a*, *b* significant wa e height *c*, *d* ma imum wa e height and *e*, *f* mean wa e direction measured at GoM and PB

Significant wave height (H_{m0}) upto 1.8 m with a mean value of 0.5 m and maximum wave heights (H_{max}) upto 3.6 m with 0.9 m is observed at PB (Figure 4.2 b). During the NE monsoon period, wave activity is comparatively low in GoM but in PB the wave activity is high. At GoM maximum average swell height (H_{swell}) of 0.9m is found during March. During the SW monsoon period, average swell heights (H_{swell}) are varies between 0.5 m –0.7 m and for the NE monsoon period varies between 0.1m – 0.4m. Wind sea heights (H_{sea})are maximum during the SW monsoon period. Average Wind Sea heights (H_{sea}) vary between 0.6m – 1.48m in this period. For NE monsoon wind sea heights vary between 0.3m – 0.4m. No swells are present in the PB. Maximum average wind sea height of 0.8m is found during January. During NE monsoon period average wave height varies between 0.5 and 0.87m. Maximum wave height varies between 1.2 and 1.7m during this period (Figure 4.2 c). The wave heights are relatively high during the SW monsoon in the GoM. PB is calm except during the northeast monsoon. Comparing with the wave action of PB, wave activity is quite intense in the GoM.

The range and average values of the mean wave period for swell and wind seas are given in Table 4.1. Wave periods are low during southwest monsoon for both regions. Mean wave periods are high in GoM during the fair-weather period and during the pre monsoon period for PB. Mean value of H_{swell} is 0.7 m. and that of H_{sea} is 0.5 m in the GoM. Swell wave heigh H_{swell} is negligible in PB with a mean value of 0.1 m. H_{m0} exceeded 1 m for 141 days in a year in GoM and 35 days in PB. Highest significant wave height (H_{m0}) of 1.9 m and maximum wave heights (H_{max}) of 3 m has been reported(Kumar et al., 2010) for the location at 12 m water depth situated north of Tuticorin in GoM during 1997–98,whereas during the present study, and maximum wave heights(H_{max}) up to 5.4 m was measured indicating the importance of site-specific data for the project. Highest significant wave height (H_{m0}) of 2.1 m and maximum wave heights(H_{max}) of 3.8 m during the NE monsoon in the area north of PB in the Bay of Bengal were observed during 1995–96 and slightly lower values were observed in the present study in PB (Jena et al., 2001).

Ta le 4.1 Range of significant wa e height H_{m0} and mean wa e period T_{m02} for the swell and wind sea in different months

Month	GoM				PB			
	H_{m0}		T_{m02}		H_{m0}		T_{m02}	
	Swell	Sea	Swell	Sea	Swell	Sea	Swell	Sea
Fe ruary-2010	0.3-1.6	0.1-0.6	10. -16.	1. -3.5	0.0-0.2	0.1-0.6	.4-21.2	1. -3.4
March-2010	0.4-2.1	0.1-1.1	6. -16.2	1. -3.6	0.0-0.1	0.1-1.0	1. -15.2	1. -3.
April-2010	0.4-1.4	0.1-1.1	5. -13.2	1. -3.6	0.0-0.5	0.0-1.4	7.5-1 .3	1. -3.3
May-2010	0.1-1.6	0.0-1.6	. -22.7	2.2-4.3	0.0-0.7	0.0-1.0	.3-24.3	2.0-4.3
une-2010	0.4-1.2	0. -1.5	11.4-17.3	3.5-5.5	0.0-0.5	0.0-1.5	5.2-20.7	2.1-4.1
uly-2010	0.4-1.7	0.3-1.6	.0-14.	2.4-4.	0.0-0.4	0.0-1.2	6.1-12.7	1. -3.3
August-2010	0.0-2.7	0.0-1.6	.0-22.3	2.4-4.3	0.0-0.1	0.0-1.2	7.7-23.3	2.0-3.7
Septem er-2010	0.3-1.2	0.3-1.6	.0-14.	2. -4.5	0.0-0.3	0.0-1.1	.2-16.1	1. -3.2
Octo er-2010	0.1-1.2	0.0-1.	. -22.1	2.2-6.2	0.0-0.2	0.0-1.1	7. -21.	1. -4.3
No em er-2010	0.2-0.	0.1-1.4	10.1-13.	2.1-4.7	0.0-0.2	0.0-1.1	.1-15.	1. -4.2
Decem er-2010	0.2-1.1	0.1-1.5	.1-14.4	1. -4.	0.0-0.2	0.0-1.7	.1-15.1	1. -4.2
anuary-2011	0.1-1.1	0.0-0.6	.1-23.6	2.1-3.6	0.0-0.6	0.0-0.6	7.2-25.0	2.2-23.2
Fe ruary-2011	0.0-0.1	0.1-0.6	.2-14.	2.1-4.5	0.0-0.7	0.0-1.1	5.2-11.4	1. -3.6
March-2011	0.0-0.7	0.0-1.1	.7-16.0	5.2-17	0.0-1.2	0.0-0.7	5.2-17.1	1. -3.7

Good correlation (correlation coefficient of 0.94) is obtained between H_{m0} and mean wave period (T_{m02}) in PB (Figure 4.3 *b*) during January to March 2011 since the only wind sea is present. But the correlation between H_{m0} and T_{m02} is poor in the GoM (Figure 4.3 *a*) due to the presence of wind seas and swells. Empirical relation between H_{m0} and T_{m02} is T_{m02} =3.5*$H^{\cdot}_{o}$ and the same expression is found valid for the data collected off Goa (Kumar 2010). Good correlation is found between H_{m0} and T_{m02} with a correction coefficient of 0.8 for the shallow water waves of the west coast of India (Swain et al., 1993). Highest waves are not associated with long period waves, similar to the earlier observation (Dattatri 1997). Maximum spectral energy density (max) is found to follow the empirical relationship proposed for normal sea states ($_{max}$ = 1.55*H^2_{mo}), with a good correlation coefficient of 0.97 for PB (Figure

4.3 *d*) and 0.72 for the GoM (Figure 4.3 *c*). Similar trends are observed for Visakhapatnam coast and the expression is found valid along the Indian coast (Kumar et al., 2004) Wave periods are low (< 8 sec) during southwest monsoon and high (> 8 sec) during pre-monsoon period in GoM.

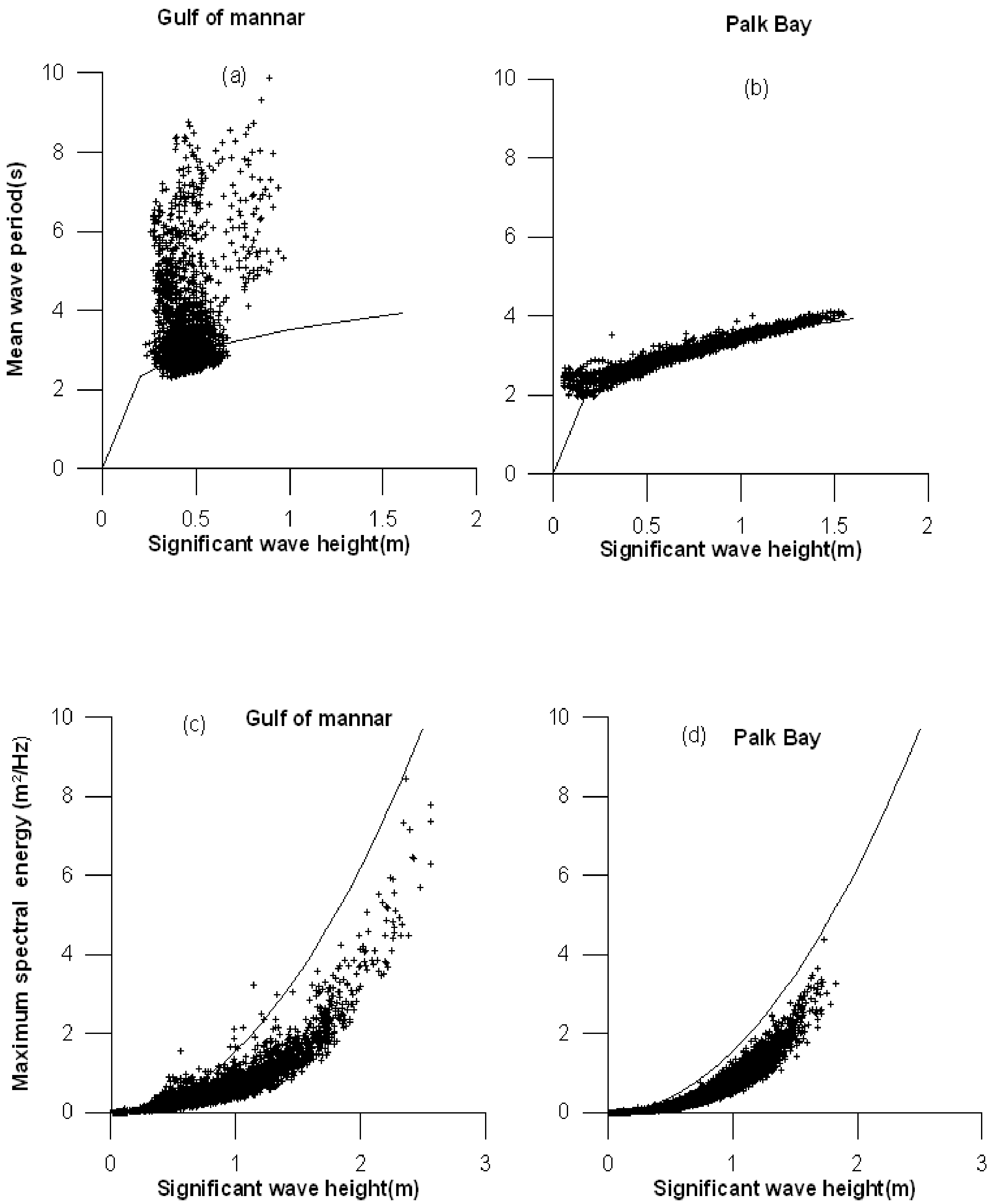


Figure 4.3 Variation of mean wa e period, ma imum spectral energy with significant wa e height

The impact of cyclone Laila is observed at both locations. Laila cyclone developed over SE Bay of Bengal on 17 May 2010 (Figure 4.4)and initially moved to the west-northwesterly direction towards south Andhra Pradesh and adjoining north Tamil Nadu coast. Cyclone Laila produced a wind speed of 17.2 m/s in the study area with high wave heights at both locations.

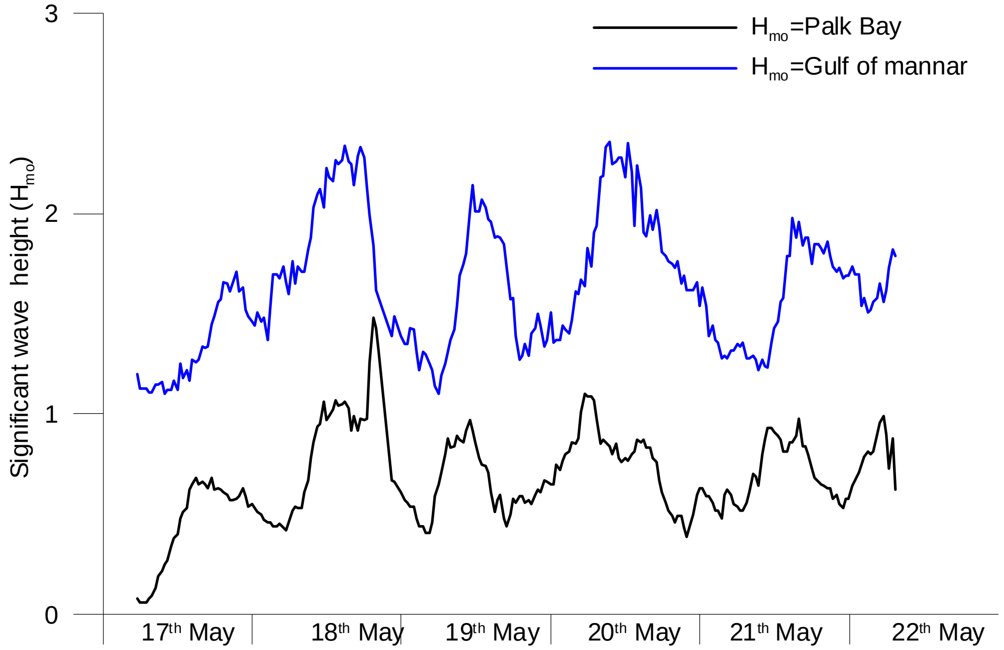


Figure 4.4 Significant wa e height H_{m0} at GoM and PB during Laila cyclone.

4.2.3 Monthly dominance of swell and wind sea

The study shows that the swells are predominant in GoM during non-monsoon period (January– April) and during the rest of the year wind sea dominates (Table 4.2). Even though wind seas are predominant during May to December, the role of swell is also significant. The dominance of swell is maximum (98%) during March and dominance of wind sea is maximum (94%) during October. Swells are insignificant in the PB region as PB is a semi-enclosed region and distant swells cannot reach this region.

Ta le 4.2 Percentage of swell and sea

Month	GoM		PB	
	Swell	Sea	Swell	Sea
February 2010	98.4	1.6	0.0	100.00
March 2010	98.9	1.1	0.0	100.0
April 2010	85.8	14.2	0.1	99.0
May 2010	28.5	71.5	6.1	94.0
June 2010	3.9	96.1	2.8	97.2
July 2010	24.3	75.7	0.1	99.9
August 2010	24.2	75.8	2.1	97.9
September 2010	36.2	63.8	0.0	100.0
October 2010	6.1	93.9	1.7	98.3
November 2010	39.5	60.5	0.0	100.0
December 2010	35.6	64.4	0.0	100.00
January 2011	52.4	47.7	0.1	99.9
February 2011	58.1	41.9	0.2	99.8
March 2011	98.7	1.2	0.8	99.3

4.2.4 Wa e Direction

At GoM, the waves are from south-southwest (Figure 4.5) and in PB, the waves prevailed in all directions (Figure 4.6), with waves from north-northeast during November to March and from SE to SW during the remaining period. For the southern region of GoM, the wave direction mostly prevailed 140–230° during SW monsoon (June to September), 85–150° during NE monsoon and 90–200°during fair weather period .The wave direction is highly variable in January and May at GoM. Wave direction mostly prevailed between 60° and 120° during the NE monsoon period, and 90° and 120° during the rest of the year north of PB1. Range of swell direction varied from 86° to 266° and wind sea from 14° to 324° in GoM. High-energy waves in GoM approach from directional sector between SE and SW and in PB the high-energy waves are from the north.

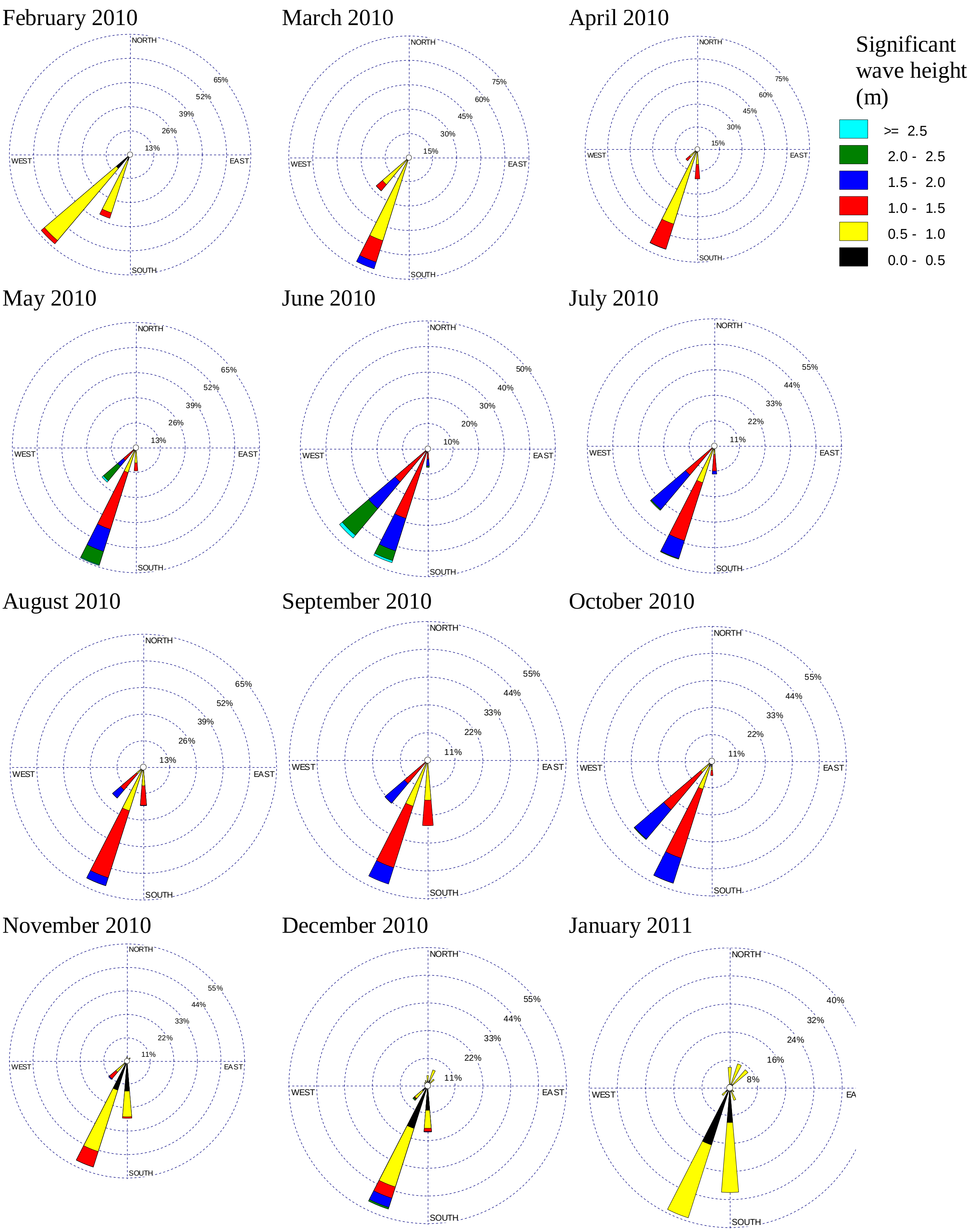


Figure 4.5 Wa e rose diagram at GoM

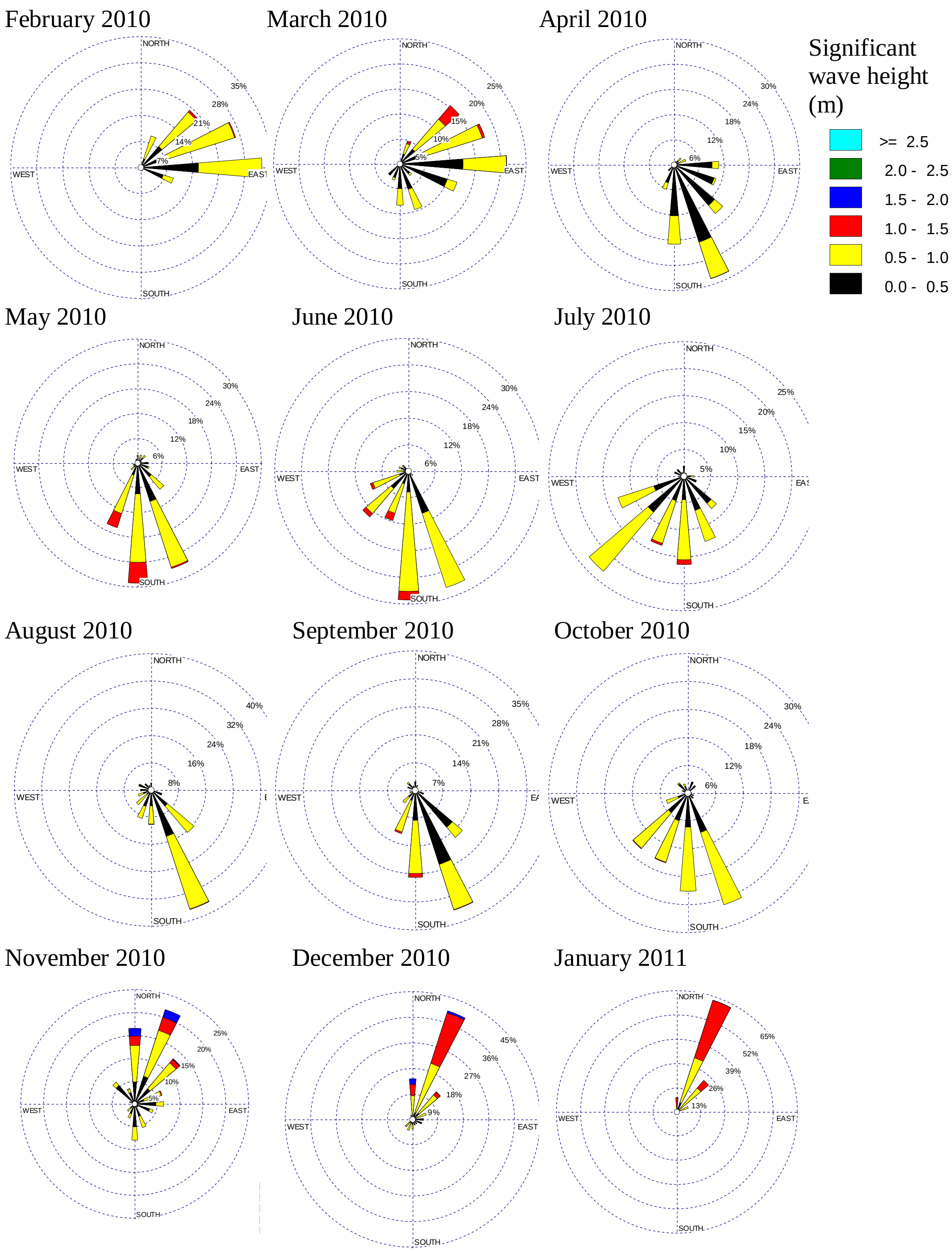


Figure 4.6 Wa e rose diagram at PB

4.3 NUMERICAL MODEL

Near shore wave heights are estimated using a REF-DIF-1 numerical model and are compared with the measured data. Measured waves at 12 m water depth are transformed by using the REFDIF-1 model and the model outputs are extracted for two locations (GoM and PB). The output of the model includes wave propagation patterns and wave height variations and directional changes in both regions. These modelling results were post processed to calculate the longshore currents, sediment transport rates. The model output gives the wave height and the wave propagation angle at each grid point. For the GoM and PB regions, the breaker heights at 1.5 m are extracted from the model output.

The results of the model output are compared with measured wave data at a 1.5 m depth for a period of 40 days during the months of November to December along the GoM . The correlation coefficient between the model estimated value and the measured value is 0.62. During 6-9 December 2010, there is a large difference between the model and measured wave height and the model estimated value is almost double of the measured value. The large difference due to the depression "BOB06" formed over the Bay of Bengal during 6-9 December 2010, which generated high waves at 12 m water depth, but the measurements at 2 m water depth shows that its influence is less at 2 m water depth may be due to the frictional dissipation and breaking. Figure 4.7 indicates that the numerical model will not give good results during tropical storm/depression.

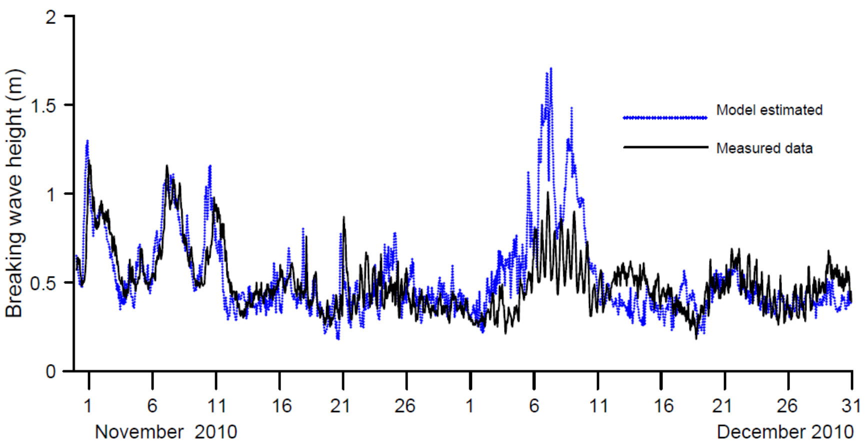


Figure 4.7 Time series plot of measured reaker height and that estimated ased on numerical model No em er-Decem er 2010

4.4 BREAKING WAVE CHARACTERISTICS

The breaking wave height varied between 0.1 and 1.7 m in the GoM (Figure. 4.8 A) with the maximum value occurring during the southwest monsoon season (June to September). In PB, the breaking wave height varied from 0.05 to 1 m(Figure 4.9 A) with maximum values during November to May. The breaker period, mostly ranged between 1.9 and 10 s in the GoM (Figure. 4.8 B) and 1.9 and 6 s in PB (Figure 4.9 B). The wave breaker angle with respect to the coast ranged from -29 to 29˚ in the GoM (Figure. 4.8 C) and -12 to 17˚ in PB (Figure 4.9 C). Negative values indicate waves approaching from the southwest and positive values indicate waves approaching from the southeast in GoM coast. Whereas in the PB coast, positive values are for northeast waves and negative values are for northwest waves.

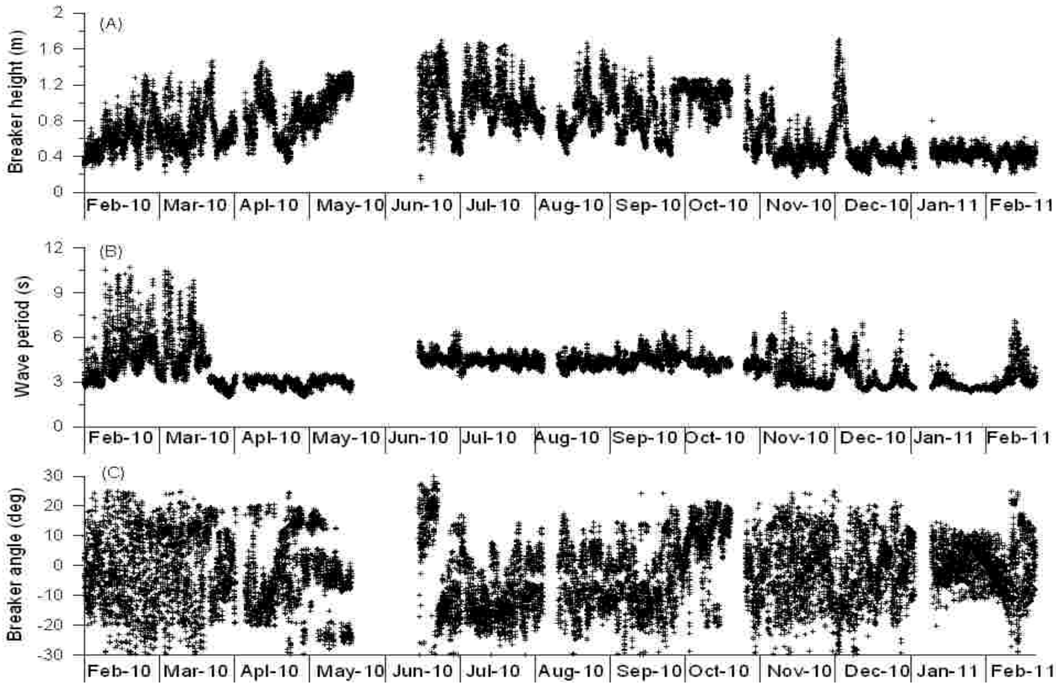


Figure 4. Breaking wa e characteristic at GoM

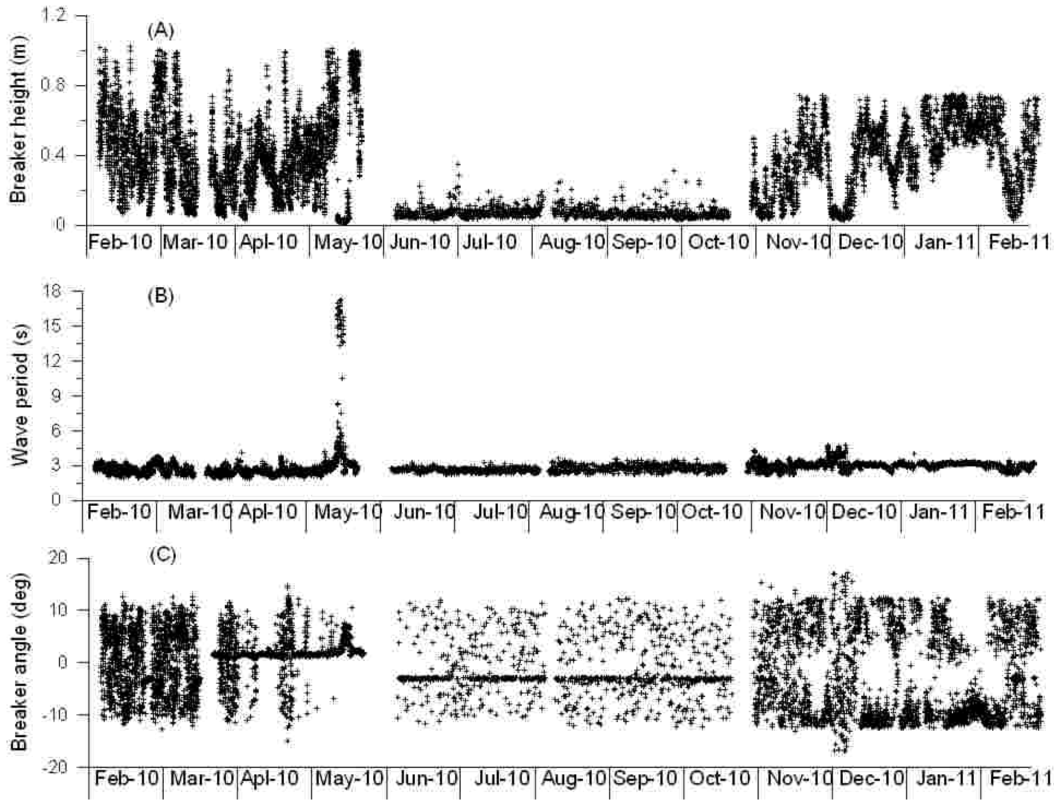


Figure 4. Breaking wa e characteristic at PB

4.5 LONGSHORE CURRENT

From Figure 4.10 (A), it is clear that along the GoM coast, the mean longshore current is predominantly in the south-eastward direction with a speed upto 0.3 m/s. Negative values in Figure 4.10 indicate longshore current towards east and the positive values indicate current towards west. Along the PB coast, the longshore current speed is less than 0.2 m/s (Figure 4.10 B). Even though the Hs is less (average value 0.7 m) during the pre-monsoon period, the longshore current is high (upto 0.3 m/s) and during the monsoon period, the Hs is high (average value 1 m) and the longshore current is less (upto 0.15 m/s). The correlation of longshore current with breaker angle is high (~ 0.9) compared to breaker height (~ 0.3). The study shows that for the locations considered, the longshore currents are more influenced by the breaker angle than the breaker height and mean wave period. Rao (2003) observed that the longshore currents along the spit remained weak (< 0.1 m/s) during the northeast monsoon, particularly between Dhanushkodi and Arichamunai facing the GoM. Consequently, strong currents (~ 0.2 m/s) are observed between Mukkuperiyar and Dhanushkodi. During the northeast monsoon period, the littoral currents move towards the south and alter the rate of change of erosion/accretion. This is similar to the observation of Thanikachalam and Ramachandran (2003). Although the longshore current is extremely weak along the Sandspit facing PB, it tends to be easterly during the southwest monsoon and the fair weather period. Similarly, at Arichamunai, the direction of the longshore current is southerly during the southwest monsoon and the fair weather period and northerly during the northeast monsoon. This indicates a phenomenon that is opposite to the phenomenon observed along the GoM coast. Such processes indicate the accumulation of littoral drift on either side of Rameshwaram Island during the southwest monsoon and the removal of sand during the northeast monsoon: making this region a sediment storage reservoir.

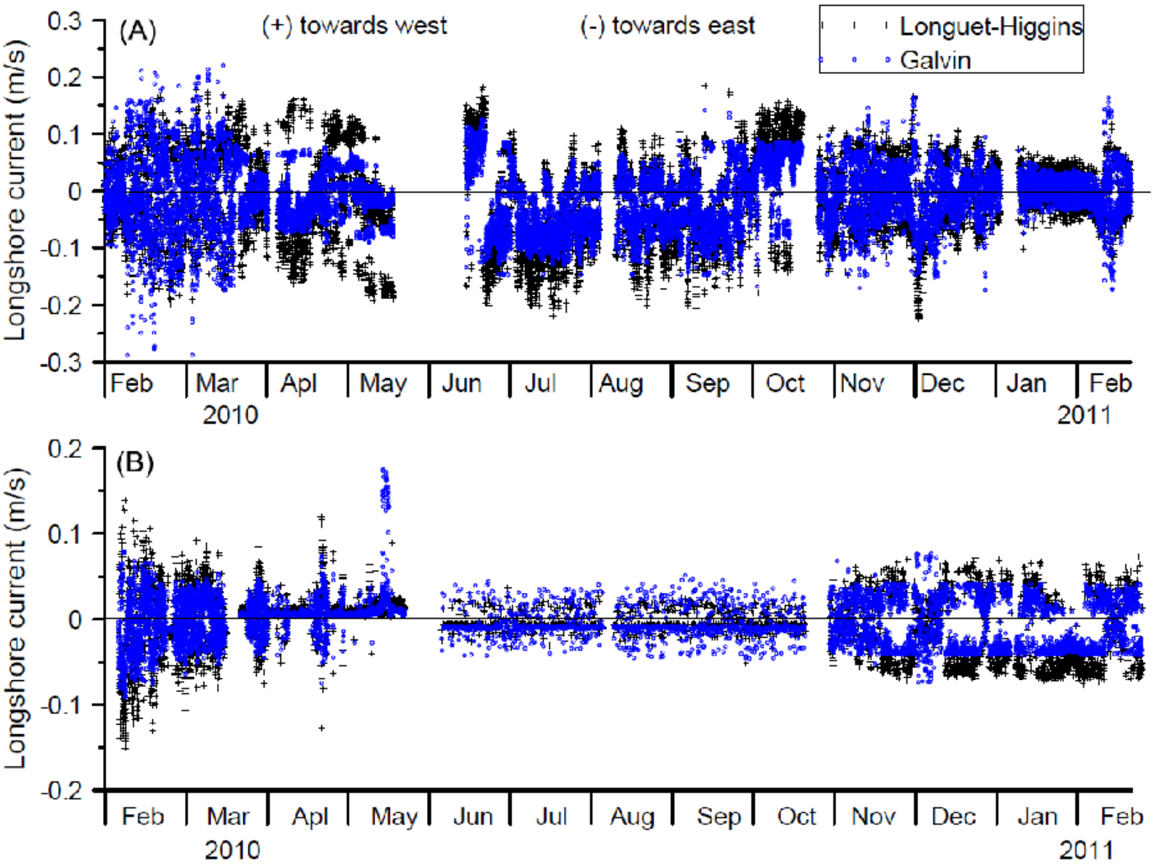


Figure 4.10 Time series plot of longshore current off A GoM B PB

4.6 LONGSHORE SEDIMENT TRANSPORT LST

The LST computed for a period of 40 days from November to December based on the numerical model is compared with the value estimated based on the measured nearshore parameters (Table 4.3). It is found that the average LST per day computed based on the measured breaker parameters are similar to that based on breaker parameters estimated from the numerical model with a least square error of less than 10%.

The monthly variation of LST is studied based on the value estimated using the CERC, Walton and Bruno, and Kamphuis formulae. The monthly LSTR is high during the southwest monsoon season and the predominant direction of transport is southeastward. The gross LSTR estimated from February 2010 to January 2011 along the Dhanushkodi Sandspit (the GoM region) is found to be 0.6 x 10^6 m^3, 0.62 x 10^6 m^3, 0.58 x 10^6 m^3 for the CERC, Walton and Bruno, and Kamphuis formulae, respectively.

The net LST along the Dhanushkodi indicates that the predominant direction of transport is southeastward. Its value based on the three formulae (CERC, Walton and Bruno, and Kamphuis) is 0.3 x 10^6 m^3, 0.28 x 10^6 m^3, 0.23 x 10^6 m^3, respectively. The sensitivity of the wave direction on the estimation of the LSTR is checked by estimating the LSTR values by increasing and decreasing the value of the wave direction by 5°. The estimated values are 13 to 20% less than the values for a 5° increase in wave direction and they are 30 to 40% more than the values for a 5° decrease. Whereas the LST along PB is negligible as compared to the LST along the GoM, the gross LSTR is only 0.047 x 10^6 m^3, 0.045 x 10^6 m^3, and 0.042 x 10^6 m^3 based on 3 formulae and the net transport is found to be northwesterly (Table 4.4). It is seen that the annual LST is relatively low along the Dhanushkodi coastline as compared to the rest of the east coast where the transport is well over 1 x 10^6 m^3 (Chandramohan et al., 1990).

Based on the monthly visual Littoral Environmental Observation, Rao (2003) reported an LSTR of 0.8 x $10^6 m^3$ along the GoM coast and an LSTR of 0.027 x 10^6 m^3 along the PB coast. The large difference in the values of the LSTRs observed in the present study compared to Rao (2003) is because the estimat es in Rao (1983) are based on a single value in a month, whereas in the present study the researcher have used values at 30 minutes interval. The longshore sediment transport rate estimated based on CERC and Walton and Bruno Kamphuis formula are similar (Figure 4.11)

LITDRIFT simulates the cross-shore distribution of wave height and long shore current for an arbitrary coastal profile. It provides a detailed deterministic description of the cross-shore distribution of the LST and the calculated net/gross littoral transport. The model calculates based on time series information as input, the wave conditions at a grid point in the profile.

Computation of littoral drift includes sediment parameters like specific gravity, mean grain diameters, fall velocity, bed roughness critical shield parameter and sediment spreading etc. Simulations are carried out for three different profiles at both the GoM and PB. Based on the simulations, the calculated annual net and gross LST are 0.45 and 0.53 x 10^6 m^3/year along the GoM and 0.05 and 0.06 x 10^6 m^3/year along PB. In contrast, the annual net and gross LSTR from the CERC equation are 0.3 and 0.6 x10^6 m^3 along the GoM and 0.015 and 0.047 x10^6 m^3 along PB. The numerical model over-estimated the net LSTR at both GoM and PB, whereas the difference in gross LSTR values estimated by numerical model and the empirical equations are less.

The net LSTR based on empirical equation depends on the direction of the breaking wave and the difference in net LSTR based on empirical equations and numerical model is due to the error in estimation of breaking wave direction.

Ta le 4.3 Longshore sediment transport rate estimated from measured reaker parameters and that ased on numerical model along GoM.

Formulae used	Sediment transport rate estimated from measured breaker parameters for 40 days x 10^4 (m^3)	Sediment transport rate computed based on wave parameters obtained from numerical model for 40 days x 10^4 (m^3)	Average sediment transport rate per day	
			Measured x 10^3 (m^3)	Computed x 10^3 (m^3)
CERC	3.1671	2.840	0.791	0.710
Walton and Bruno	3.317	3.016	0.829	0.754
Kamphuis	2.866	2.588	0.716	0.647

Ta le 4.4 Annual net and gross longshore sediment transport rate

Sediment transport formula	Longshore sediment transport rate at Dhnaushkodi along GoM in x 10^6 *year*		Longshore sediment transport rate at location at Dhanushkodi along PB in x 10^6 *year*	
	Net towards south-east	Gross	Net towards north-west	Gross
CERC	0.30	0.6	0.015	0.047
Walton and Bruno	0.28	0.62	0.010	0.045
Kamphuis	0.23	0.58	0.012	0.042
LITDRIFT	0.45	0.53	0.05	0.06

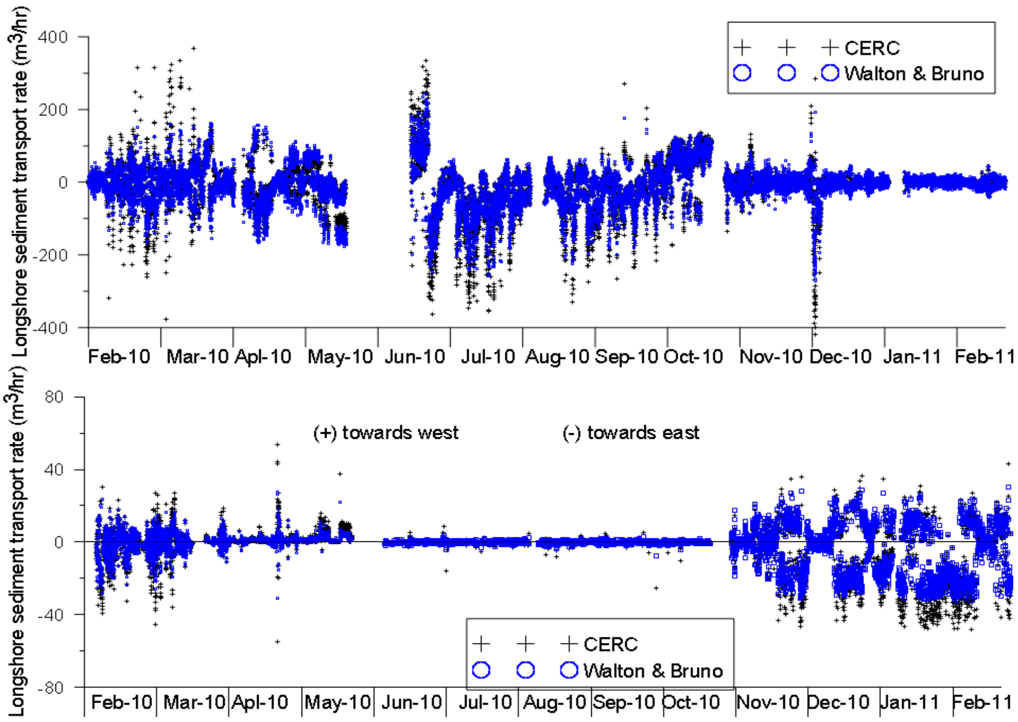


Figure 4.11 Time series plot of longshore sediment transport rate off a GoM and PB

4.7 SHORELINE CHANGE DETECTION THROUGH RS AND GIS

Remote Sensing and GIS has been found to be extremely useful for understanding the shoreline changes at various scales i.e. monthly, seasonal to decadal changes. The availability of high resolution data provides the best representation of shoreline. India has a number of remote sensing satellites to provide the data at different resolution and repeatability and to monitor the shoreline changes along the coast with reasonable accuracy to complement the field monitoring program. Remote sensing data help and / or replace the conventional survey by its repetitive, spatial coverage and less cost-effectiveness. Standard guidelines to determine the berm line on satellite imagery should be followed. Nevertheless, high resolution satellite data (<1m) should be used to map the shoreline changes as only from such a resolution the berm can be identified. Satellite imageries are useful tools for detecting the coastal morphology changes. RS data can be used to evaluate the coastal processes like erosion/ accretion and shoreline changes. Geographic Information System (GIS) is designed to work with data referenced by spatial/geographical coordinates. The major advantage of GIS is that it allows identifying the spatial relationships between features and temporal changes within an area over time. Remote sensing satellite images have been effectively used for monitoring shoreline changes of different locations. The geo-corrected data is entered into an ArcGIS environment for digitization of shoreline. High waterline shown in the satellite imageries (1998, 2008 and 2010) and topographic sheets is digitized as line feature. Shorelines representing different years are presented by overlaying together. Quantification of erosion /accretion rate is done by digitization as polygon features using ArcGIS.

4.7.1 Period of 1 53-1 6

The shoreline changes observed between 1953-1969 are shown in Figure 4.12, and these changes were estimated using the SOI toposheets. During this period, erosion was found near Dhanushkodi owing to the impact of 1964 cyclone. The area of accretion along the PB coast and erosion along the GoM coast are 1.3 sq. km and 3.2 sq. km, respectively during 1953 and 1969. In Gandhamadana parvatam area the water bodies have gradually shifted the towards south/southeast of Rameshwaram Island between 1921-1969.

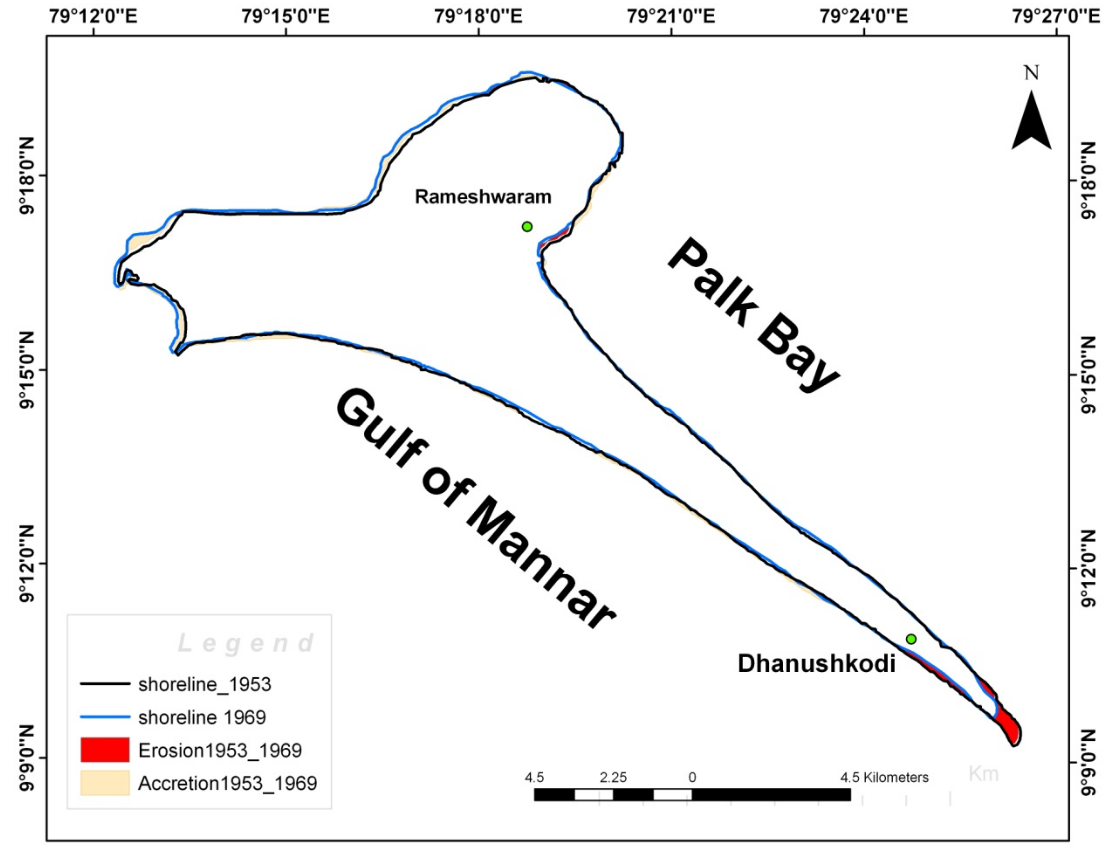


Figure 4.12 Shoreline changes from 1 53 to 1 6

4.7.2 Period of 1 6 -1

Shoreline changes were observed between Toposheet 1969 and satellite image 1998 is shown in Figure. 4.13 accretion 5.2 Sq km and erosion is 1.8 sq km , respectively. Similarly, study was done by Thanikachalam et al. (2003) along the coastline between Dhanuskodi and Tuticorin and erosion and accretion was estimated at 4.34 sq. km and 23.49 sq. km, respectively, over a period of 30 years (1969-1998).

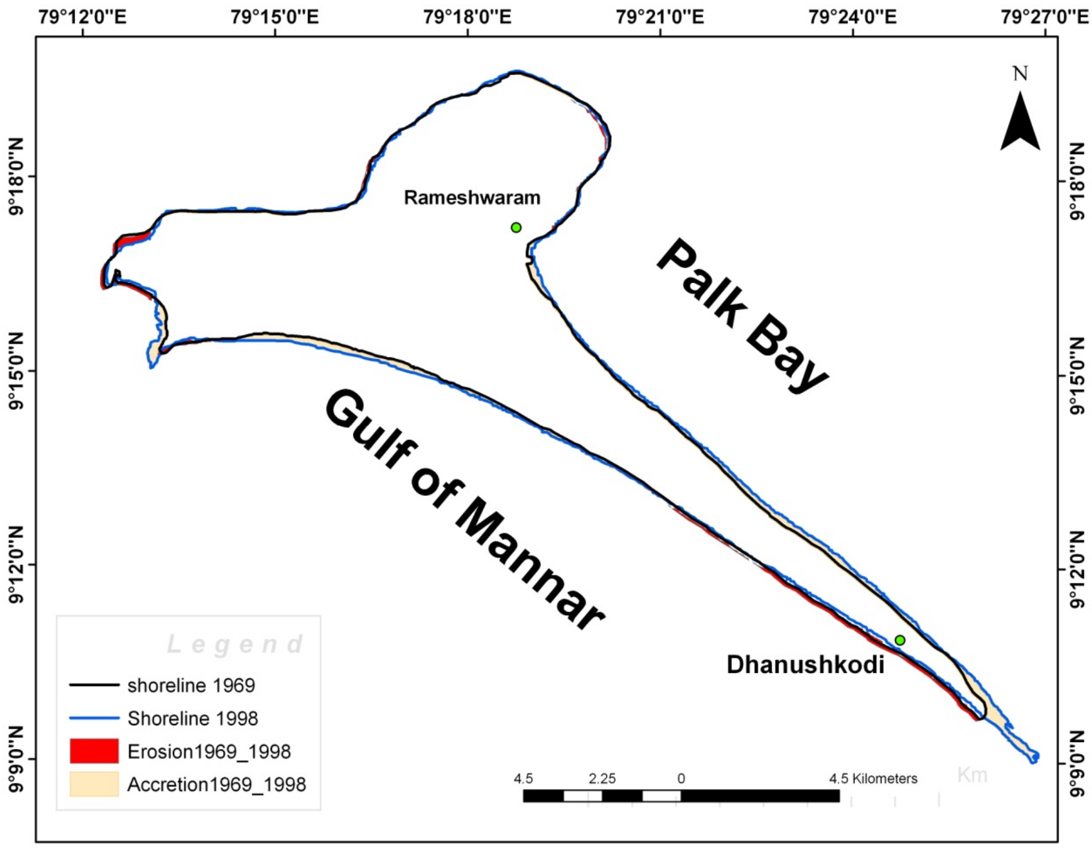


Figure 4.13 Shoreline changes from 1 6 to 1

4.7.3 Period of 1 -200

Shoreline changes were observed between Satellite images 1998 and 2008 are shown in Figure. 4.14. Accretion 1.7 sq km and erosion is 0.86 sq km respectively. Shoreline has increased a tongue-shaped spit due to littoral current from PB to GoM during northeast monsoon period (Nobi et al. 2010).

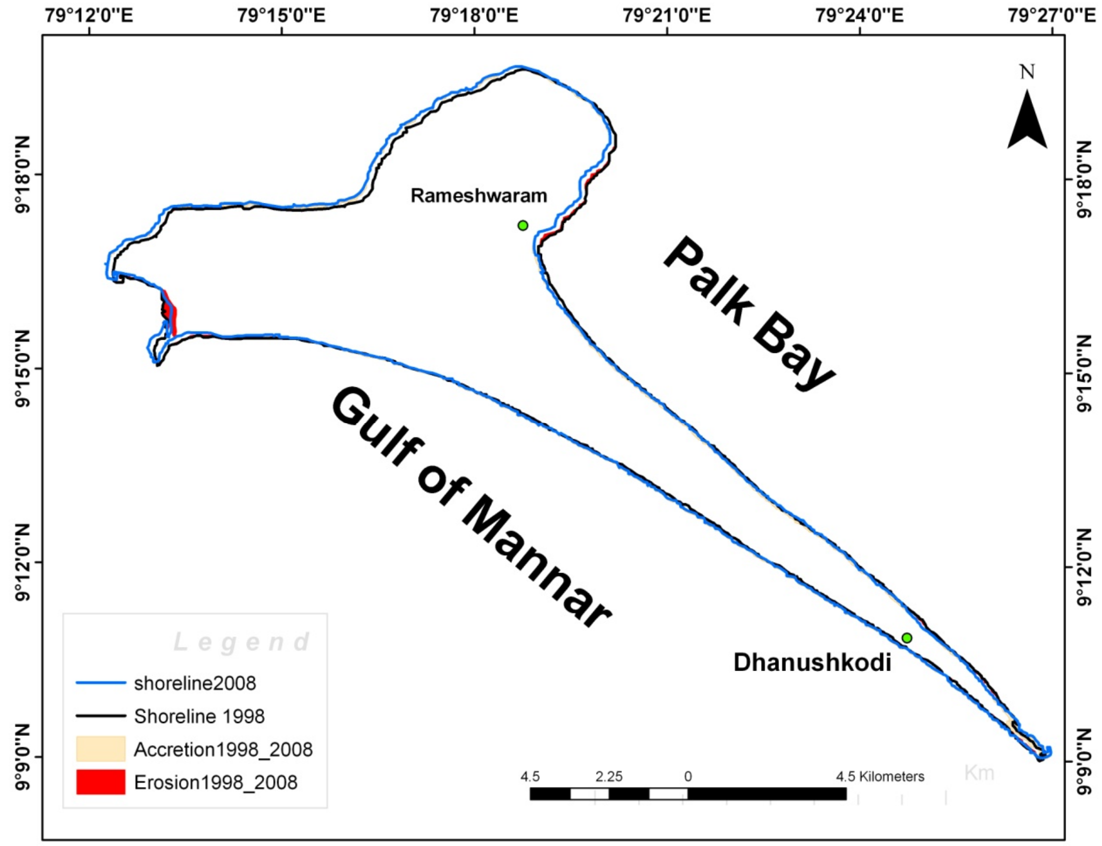


Figure 4.14 Shoreline changes from 1 to 200

4.7.4 Period of 200 -2010

Shoreline changes between 2008-2010 two satellite images erosion 2.2 sq km and accretion 0.9 sq. km are shown Figure 4.15. Similarly, at Arichamunan, the longshore current direction is southerly during southwest monsoon/fair period and northerly during northeast monsoon indicating just the opposite to the phenomenon observed in GoM. Such process indicates the accumulation of littoral drift on either side of the Rameshwarm Island during southwest monsoon and removal during northest monsoon, making this region a sediment storage reservoir (EIA report 2005).

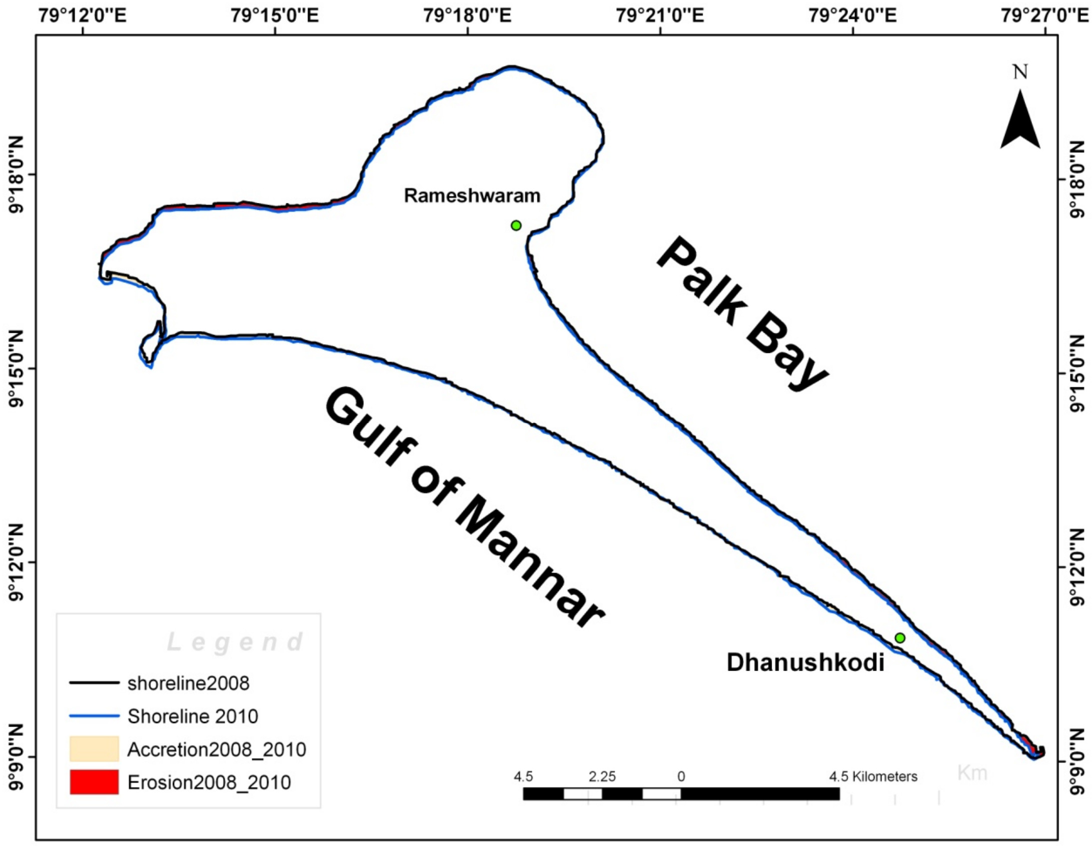


Figure 4.15 Shoreline changes from 200 to 2010

4.7.5 Period of 1 53-2010

Shoreline change between the 1953 toposheet and the 2010 satellite image, the erosion was 2.9 sq. km and accretion 6.9 sq. km. are shown in Figure.4.16. Accretion in the region has led to the sand spit along Dhanushkodi grow by 1.03 sq km during this period. The strong erosion caused by the 1964 cyclone was more than offset by the natural process of sediment deposition resulting accretion over this 57-year period. An overall shoreline change indicates that accretion was more compared to erosion.

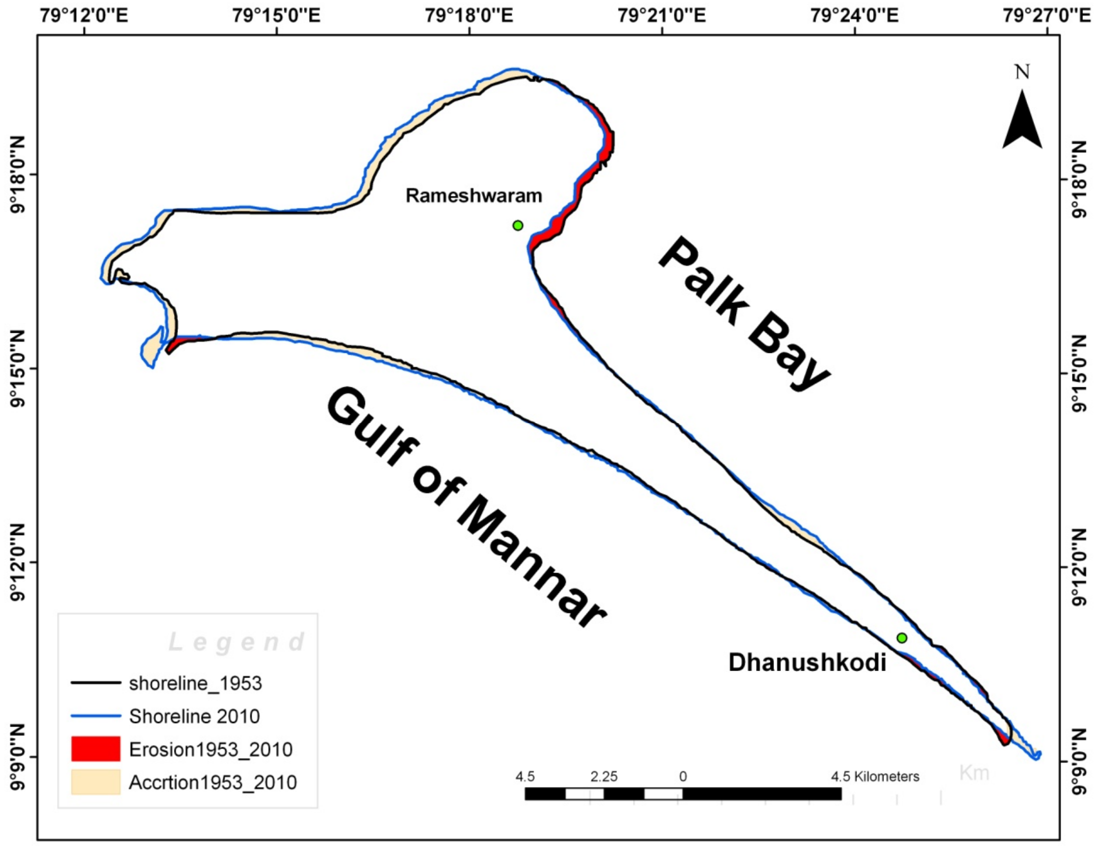


Figure 4.16 Shoreline changes from 1 53 to 2010

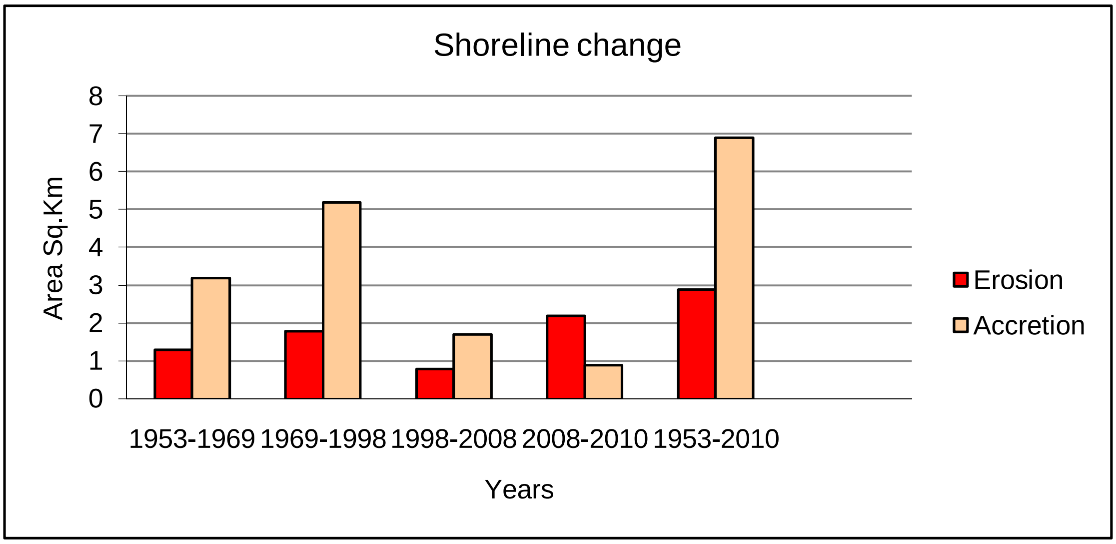
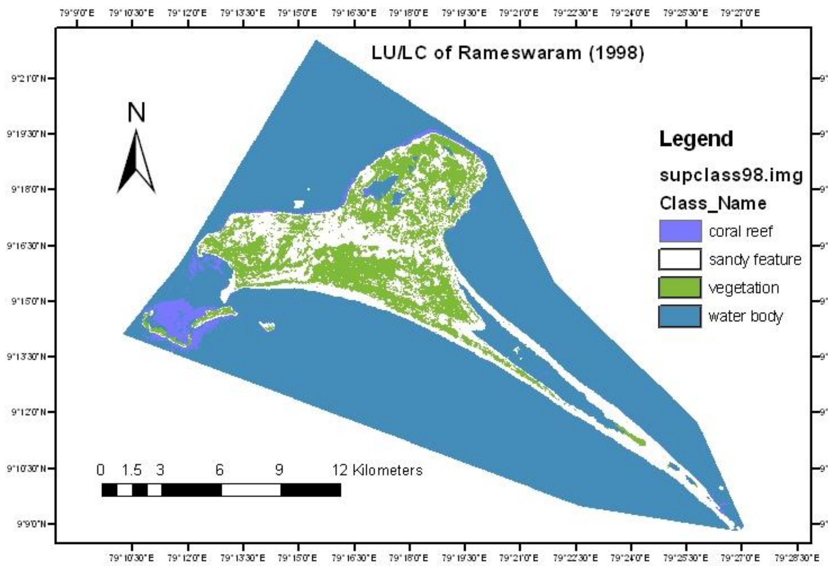


Figure 4.17 O erall shoreline changes

4. LAND USE LAND COVER CHANGES

Land use and Land cover are observed around Rameshwaram Island. Land use/Land cover maps for different years have been prepared for the study area. Changes were quantified using the post-classification of the two images are shown in the Figure 4.18. The study indicates changes in the area of different coastal features such as water body of 178 and 177 km^2, sand features of 32 and 32 km^2, vegetation of 28 and 35 km^2 and coral reefs of 5 and 6 km^2, respectively during 1998 and 2010 (Table 4.5). The reef formation mostly consists of dead coral mingled with corals rocks and live coral (Sridha et al., 2010). Suspended sediment load is the main factor which determines the coral reef growth, which, in turn, is determined by coastal erosion and accretion. The degradation of coral reefs in the GoM has been well noticed and many authors have reported that the degradation is quite severe mainly due to human stress (anthropogenic) and also natural agents (Mahadevan et al.,1972). A recent study by EIA-NIO showed that the highest percentage of coral cover was recorded in the Mandapam group of islands and lowest in the Kilakarai group, since fishing is limited in Mandapam group compared to the other Islands. Both reefs and mangroves play a role in the accretion of coastlines.

The GoM was declared as a Marine National Park (MNP) in 1986 and, in 1989, it became the first biosphere reserve in Southeast Asia. The GoM Biosphere Reserve (GOMBR) is the coastal biodiversity hotspot in India extending from Rameshwaram Island to Tuticorin in a NE-SW direction. It extends over a distance of 140 km and covers an area of about 10,500 sq. km. There are 21 islands running parallel to the coastline of the GoM with an average distance of 8 km from the coast. The GoM is inhabited by 3,600 species of plants and animals known to live within its boundaries. The core area is the MNP comprising the 21 islands, with an area of 560 km^2 covering the waters around the island up to a depth of 6 m on the bay side and 9 m on the seaward side. The buffer zone is the Gulf waters in the south and the inhabited coastline in the north. Human activities in the buffer zone are permitted within the guidelines issued by the GoM Biosphere Reserve Trust (GOMBRT) and the core zone is kept undisturbed.



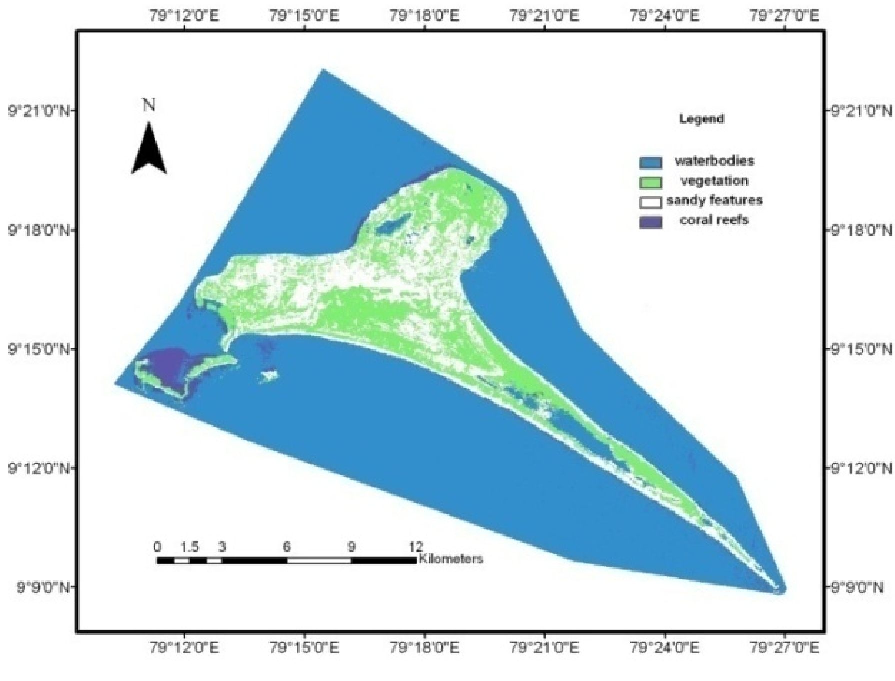


Figure 4.1 Land use Land co er changes 1 and 2010

Ta le 4.5 Area of Landuse Landco er changes during 1 and 2010

Category	1 Area Km^2	2010 Area Km ^{2}
Water ody	17	177
Sand features	37	32
Vegetation	30	35
Coral reefs	5	6
Total	250	250

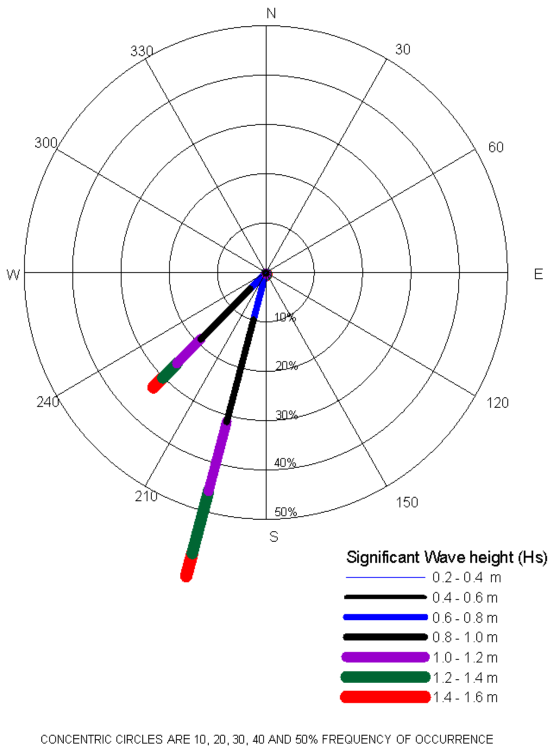
The coast process between Arichamunai (India) and Talaimannar (Sri Lanka), i.e. along Adam's Bridge, is quite complex which predominantly control the exchange of sediment between GoM and PB. Adam's Bridge is a formation of submerged coral reefs and there are around 17 islands present with bushes and plants. The average length of these islands varies between 0.8 km to 3 km. The average depth along the Adam's Bridge varies between 1 and 2 m during low tide. This is exposed to complex current pattern with the presence of quicksand. The currents near the Adam's Bridge and Pamban Pass are found to be more seasonal. Submerged sand shoals are seen shifting south of Arichamunai and remain quasi-steady. The nearshore on the northern side of the Rameshwaram Island is found to be very shallow causing the northeast monsoon waves to break far offshore. The coastal stretch between Mandapam and Arichamunai in PB shows the presence of wide beach with elevated dunes. PB coastal zone is classified into 3 groups i) uplands/highlands with scanty vegetation, comprised of Cuddalore sandstone formations, (ii) along the lower elevations sediment Cuddalore sandstones, and (iii) coastal lands mainly of micro deltas, swamps, and beach ridges based on the geomorphologic features (Loveson et. al., 1990). A large amount of sediments from those pediments are removed constantly by rainfall and minor rivers. Because the pediments are placed over the substratum which is appreciably sloping towards the sea, the erosion is found to be intensive along the coastal islands. The eroded sediments brought to the littoral zone are dumped in PB. As PB is shallow and protected from the high waves and currents, the material brought by these minor rivers is deposited in the mouth of each river/stream, leading to the formation of micro-deltas in due course, encouraging the formation of new shorelines. PB is very shallow and is largely occupied by sand banks and shoals (Agrawal, 1988). Abundant growth of corals, oysters, sponges, and other sea bottom communities flourish in the relatively calm waters of the GoM.

Figure 4.1 Coral reef at GoM and PB

4. SHORELINE CHANGE MODEL LITLINE

Shoreline changes are simulated using analytical and numerical models. The later is preferred where the interaction between the incident waves and the gradually changing shoreline is taken into account. A number of authors discussed numerical simulation model to study the performance of groin, breakwater and beach fill. (Brampton 1995, Hanson et al 1991, Kraus 1995).

LITPACK, an integrated modeling system for LITtoral Processes and Coastline Kinetics, (DHI, Version 2008) was used to study the area. A typical coastline 6 km (3 km on GoM and 3 km PB) was selected for the present study. Accuracy of shoreline response model depends on synthesis, wave data and improving the input wave climate (Bodge 1996). Hence, an estimation of wave climate at the nearshore was essential for interpretation need to be transformed from deep/intermediate water. Annual wave climate (Figure 4.20) measured wave data was used for the present study. The monthly wave climate was transformed to nearshore region using REF/DIF1 model.



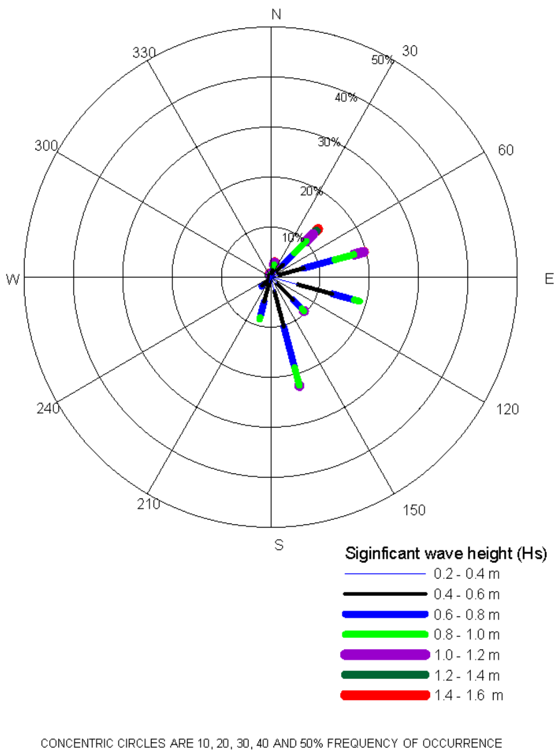


Figure 4.20 Annual wa e climate at GoM and PB

The simulation is carried out for the evolution of 6 km of coastline on both of the GoM and PB coasts for 3 (2010-2013) and 5 years (2010-2015). The initial shoreline used in the study is based on the field measurements carried out in 2010 using Smart station. The measured coastline is compared with the coastline extracted from a satellite image and the comparison results show that the measured shoreline are very compatible with the extracted coastlines using the remote sensing technique. The coastline change between 2013 and 2015 is presented in Figure 4.21. The study shows that the prediction of shoreline variation needs field observation and continuous wave and current data. If the time history of the original shoreline measurement is not available, remote sensing technology helps to monitor the shoreline. Accretion in the region led to growth of the sandspit along Dhanushkodi by 65 m during the period 2010-2015. Natesan (2008) observed a growth of small land mass along with elongation of about 0.02 sq.km near the tip during the period 1986-1996.

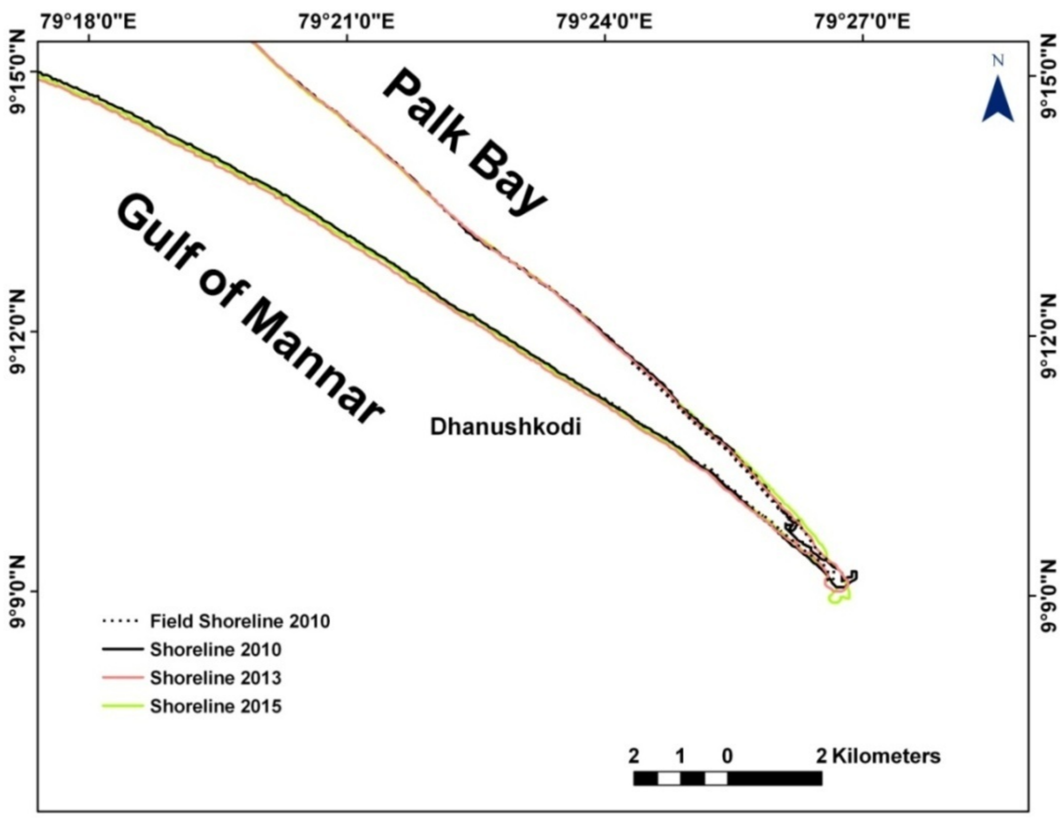


Figure 4.21 Shoreline measured during and that predicted for 2013 and 2015

CHAPTER 5

SUMMARY AND CONCLUSIONS

5.1 SUMMARY

The stability of this coastal zone is influenced by a number of environmental factors, primarily due to geological, biological, meteorological and oceanographical parameters, which distinctly vary from one sector of the coast to another. The geographical formation of the Tamil Nadu coast determines the sources and sinks for the littoral drift moving around the Indian peninsular tip across the east and west coasts of India. Rameshwaram Island is one of the most ecologically sensitive island ecosystems of India and is surrounded by PB in the north and the GoM in the south. The southeastern part Rameshwaram Island knows as Dhanushkodi is a long sand spit of about 20 km length. The southwestern shore of Rameshwaram has a tongue-shaped spit and the shoreline along this stretch is relatively straight and smooth. The wave sheltering effect due to the Sri Lanka Island, the presence of numerous offshore islands in GoM, the growing sand spit along Dhanushkodi and the Adam's Bridge largely modify the sediment movement. In view of the proposed Sethusamudram channel across the Dhanushkodi sand spit, there is an interest to know the nearshore wave characteristics, longshore sediment transport rate and shoreline change along the coast facing GoM and PB.

Wave characteristics around Dhanushkodi were studied based on the measured data for a one year period. The model REF/DIF1 was used to simulate the nearshore wave patterns from the measured wave data. Wave induced longshore sediment transport rates were estimated using three different formulae. The model validation was done based on the measured nearshore waves. Shoreline changes using Remote sensing & GIS were carried out. Numerical model LITPACK was also used for simulating non-cohesive sediment transport and the LITLINE module was used to study the shoreline evolution over 5 years

5.2. CONCLUSIONS

Directional wave data measured at 12 m water depth using Datawell directional wave rider buoys at two locations, one in the GoM and another in PB are used to study the wave characteristics around Dhanushkodi. Wave spectra are mainly double-peaked in the GoM and single peaked in the PB. Swells dominate the GoM, except during the southwest monsoon period, whereas wind seas exist in the PB as distant swells cannot reach the bay due to the protection by Indian peninsula and the northern extremity of Sri Lanka. Maximum wave height observed is 5.4 m at GoM and 3.6 m in PB. Wave heights are high in the GoM during the southwest monsoon period and waves are from south-southwest. In the PB, high waves are found during the northeast monsoon period. The influence of cyclone Laila is observed during the study period in both the GoM and the PB.

Near shore wave heights are estimated using a REF-DIF1 numerical model and are compared with the measured data. The results of the model output are compared with measured wave data at a 1.5 m depth for a period of 40 days during the months of November to December along the GoM . The correlation coefficient between the model estimated value and the measured value is 0.62. During 6-9 December 2010, there is a large difference between the model and measured wave height and the model estimated value is almost double of the measured value. The large difference is due to the depression "BOB06" formed over the Bay of Bengal during 6-9 December 2010, which generated high waves at 12 m water depth, but the measurements at 2 m water depth shows that its influence which is less at 2 m water depth may be due to the frictional dissipation and breaking. The study indicates that the numerical model will not give good results during the tropical storm/depression

Breaking wave height varied between 0.1 m and 1.7 m in the GoM with the maximum value occurring during the southwest monsoon season (June to September). In PB, the breaking wave height varied from 0.05 m to 1 m with maximum values during November to May. The breaker period, mostly ranged between 1.9 s and 10 s in the GoM and 1.9 s and 6 s in PB. The wave breaker angle with respect to the coast ranged from -29 to 29˚ in the GoM and -12 to 17˚ in PB. Negative values indicate waves approaching from the southwest and positive values indicate waves approaching from the southeast in GoM coast, whereas in the PB coast positive values are for northeast waves and negative values are for northwest waves.

Along the GoM coast, the mean longshore current is predominantly in the southeastward direction with a speed up to 0.3 m/s . Along the PB coast, the longshore current speed is less than 0.2 m/s. The annual net longshore sediment transport along the GoM coast at Dhanushkodi indicates that the predominant direction of transport is southeastward and is 0.3 $x10^6$ m^3, 0.28 $x10^6$ m^3, 0.23 $x10^6$ m^3 based on the CERC, Walton and Bruno, and Kamphuis formulae, respectively. The LSTR along the PB coast at Dhanushkodi is negligible as compared to the LSTR along the GoM. Simulations are carried out for three different profiles at both the GoM and PB uses the LITDRIFT module of the LITPACK numerical modeling software. Based on the simulations, the calculated annual net and gross LST are 0.45 and 0.53 x 10^6 m^3/year along the GoM and 0.05 and 0.06 x 10^6 m^3/year along PB. In contrast, the annual net and gross LSTR from the CERC equation are 0.3 and 0.6 $x10^6$ m^3 along the GoM and 0.015 and 0.047 $x10^6$ m^3 along PB.

Examination of shoreline changes indicates that accretion is more compared to erosion. A comparison between the 1953 toposheet and the 2010 satellite image shows accretion at the eastern tip of land, leading the sand spit along Dhanushkodi to grow by 1.03 km during this period.

The numerical model studies based on the LITLINE module of LITPACK show that, during the last 5 years (2010- 2015), the sand spit along Dhanushkodi grew by 65 m due to the net southeastward LST along the GoM coast.

5.3 SCOPE FOR FUTURE WORKS.

i) Field measurements tidal currents covering entire Palk Bay and Gulf of Mannar.
ii) Influence of Adam’s Bridge on littoral process.
iii) Movement of littoral drift across Gulf of Mannar between India and Sri Lanka.
iv) Wave and current induced sediment transport between Vedaraniyam (India) and Point Pedro (Sri Lanka).

REFERENCE

Aboobacker, V.M., Vethamony, P., Sudheesh, K. and Rupali, S.R. (2009). “Spectral Characteristics of the near shore waves off Paradip, India during monsoon and extreme events.” *at. Ha ards*, 49(2), 311-323.

Anonymous. (2005). “Indian and selected Foreign Ports.” *S r ey of ndia o ern ent of ndia* New Delhi, 238.

Anonymous. (2011). “Indian and selected Foreign Ports.” *S r ey of ndia o ern ent of ndia*” New Delhi, 238.

Arya, D.S., Santosh, K. and Vaidhy, A.M. (2014). “Simulation of shoreline changes along Muthalapozhy Harbour, India.” *cade ic orks*.

Baba, M., Dattatri, J. and Abraham, S. (1989). “Ocean wave spectra off Cochin west coast of India.” *ndian . ar. Sci*. 18(2), 106-112.

Bakker, W.T. (1969). “The dynamics of a coast with a groyne system.” *Proc. of* th *oastal n r . onf., S* , 492-517

Bakker, W.T., Klein-Breteler, E. H. J., and Roos, A. (1971). “The dynamics of a coast with a groyne system.” *Proc. of* th *oastal n r . onf., S* , 1001-1020.

Booij, N., Ris, R.C. and Holthuijsen, L.H. (1999). “A third-generation wave model for coastal regions, Part I. Model description and validation.” *eophys Res.* 104(C4), 7649 –7666.

Bird, E. C. F. (1985). “Coastline Changes A Global Review.” John Wiley, UK, p. 219.

Bouchahma, M. and Yan, W. (2012). “Automatic measurement of shoreline change on Djeba Island of Tunisia.” *o p ter nf. Sci.* 5(5), 17-24.

Braud, D. H. and Feng, W. (1998). Semi-automated construction of the Louisiana coastline digital land/water boundary using Landsat Thematic Mapper References satellite imagery, Baton Rouge, Louisiana State University, Department of Geography and Anthropology, Louisiana Oil Spill Research and Development Program, Technical Report Series, 97-002

Berkhoff, J. C. W. (1972). "Computation of combined refraction-diffraction." *Proc. of th nt. onf. on oastal n r .*, ASCE, New York, 471-490.

Berkhoff, J. C. W., Booij, N., and Radder, A. C. (1982). "Verification of numerical wave propagation models for simple harmonic linear water waves." *oastal n r* , 6, 255-279.

Caldwell , J. M. (1956)."Wave action and sand movement near Aneheim Bay, California." *Beach rosion Board .S. r y orps n ineers*, Technical Memorandum, 68, p21.

Chandramohan, P.(1988)."Longshore sediment transport model with particular reference to India coast." Ph.D. thesis. Indian Institute of Technology Madras.

Chandramohan, P., Nayak, B.U. and Raju, V.S., (1990). "Longshore-Transport model for South Indian and Sri Lankan coast. " *. aterways Port oast and cean n r .*, 116(4), 408-423.

Chandramohan, P. and Nayak, B.(1991) "Longshore sediment transport along the Indian coast." *ndian . ar. Sci.*, 20, 110-114.

Chandramohan, P., Kumar, V.S. and Nayak, B.U. (1993). "Coastal processes along shorefront of Chilka Lake, East coast India." *ndian . ar. Sci* , 2(4),268-272.

Chandramohan, P., Jena B. K. and Sanil Kumar, V. (2001). "Littoral drift and sink along the Indian Coast." *r. Sci.*, 81(3), 292-297.

Chandrasekar, N. (1992)."Beach placer mineral exploration along the Central Tamilnadu Coast." Unpublished PhD thesis, Madurai Kamaraj University, Madurai.

Chauhan, H. B. and Shailesh Nayak (2005). "LU/LC Changes near Hazira region, Gujarat using Remote sensing satellite data." *. ndian society of Re ote Sensin* , 33(3), 413-420.

CEM, (2000). "Coastal Engineering Manual." U.S. Army Corps of Engineers**.**

Dattatri, J. (1997). "Waves off Mangalore Harbor-west coast of India." . *aterways Harbors and oastal n r . di ision, S* , 9, 39-58.

Das (2006). "Coastal Erosion Management: Recent Initiatives." National Institute of Disaster Management, Central Water Commission, New Dehi.

Dolan, R, Hayen, B.P., May, P. and May, S.K. (1980). "The reliability of shoreline change measurements from aerial photographs." *Shore and beach*, 48(4), 22-29.

Dong, P., and Chen, H. (1999). "A probability method for predicting time-dependent long-term shoreline erosion." *oastal n r .*, 36, 243-261.

DHI [Danish Hydraulic Institute] (2008). "LITPACK - Noncohesive Sediment Transport in Currents and Waves." User Guide. Hersholm, Denmark: DHI Water and Environment.

Eaton, R. O. (1951). "Littoral processes on sandy coasts." *Proc. irst onf. oastal n r* Council on Wave Research, University of California, 140-154.

Frazier, P. S., and Page, K. J. (2000). "Water body detection and delineation with Landsat TM data." *Photo ra . n . Re ote Sens.*, 66 (2), 1461-1467.

Galvin, C. J. (1987). "The continuity equation for longshore current velocity with breaker angle adjusted for a wave-current interaction." *oastal n r* 11(2), 115–129.

Goda, Y. and Kobune, K. (1990). "Distribution function fitting for storm wave data." *Proc.* [nd] *nt. onf. on oastal n r* , ASCE, 18 - 31.

Gowthaman, R., Kumar,V.S., Dwarakish, G.S., Soumya, S., Mohan, Jai Singh, and Ashokkumar, K. (2013). "Waves in Gulf of Mannar and Palk Bay around Dhanushkodi, Tamil Nadu, India." *rrent Science* 104(10), 1431-1435.

Gravens, M. B., Kraus, N. C. and Hanson, H. (1991). "Genesis: Generalized model for simulating shoreline change, Report 2. Workbook and system user's manual." *Technical report* CERC-89-19.

Grant, U. S. (1943). "Waves as a sand transporting agent." *erican . Science*, 241, 117-123.

Grijm, W. (1961). "Theoretical forms of shorelines." *Proc. th oastal n r . onf.* SCE, 197-202.

Grijm, W., (1965)."Theoretical forms of shorelines." *Proc th oastal n ineerin onference*, *S* , 219-235.

Gilhousen, D.B and Hervey,R.(2011)."Improved Estimates of Swell form moored buoys." *Proc. of the fo rth nternational Sy posi S S* , Alexandria, 387-393

Griggs, G. B., Tait, J. F., and Scott, K. (1990)."The impacts of shoreline protection structures on beaches along Monterey Bay, California." *Proc. the nd nt. onf. on oastal n r .* 3 (213), 2810-2823.

Hanson, H., and Kraus, N.C. (1986a). "Seawall boundary condition in numerical models of shoreline change." *Technical Report R* US Army Engineer Waterways Experiment Station, CERC, 59p.

Hanson, H., and Kraus, N.C.(1986b). "Forecast of shoreline change behind multiple coastal structures." *oastal n r in apan*, 29, 195-213.

Hanson, H. (1989). "GENESIS - A generalized shoreline change numerical model." *oastal Res.*, 5 (1), 1-27.

Hanson, H., and Kraus, N. C. (1991). "Genesis: Generalized model for simulating shoreline change." *Report . Technical report* CERC-89-19.

Horikawa, K., Sasaki, T. and Sakuramoto, H. (1977). "Mathematical and laboratory models of shoreline change due to dredged holes." *. ac lty of n ineerin* , University of Tokyo, XXIV (1), 49-57.

Horikawa, K., Harikai, S., and Kraus, N. C. (1979). "A physical and numerical modeling of waves, current and sediment transport near a breakwater." *nn al Report of the n ineerin Research nstit te*, University of Tokyo, No. 38, 41-48.

Hedegaard, I.B.(1988)."Wave generated ripples and resulting sediment transport in wave." *nstit te Hydrodyna ics and Hydra lic n r .*, Tech. University of Denmark series paper no. 36.

Ingle, J. C. Jr., (1966). "The movement of beach sand, in Developments in Sedimentology." *lse ier*, New York, 5, 221p

ICMAM. (2010). Report on Gulf of Mannar, 92p.

IHH Poondi, History of Tamil Nadu coastline, IHH Report No. 20, 2002.

Inman, D. L., Tait, R. J., Komar, P. D., and Nordstrom, C. E. (1969). "Dispersion of water and sediment in the surf zone." *Scripps nstit te of ceano raphy*, SIO Ref. 69-10, University of California, Sandiego, USA

Inman, D. L. and Dolan, R. (1989). "The outer banks of North Carolina: budget of sediment and inlet dynamics along a migrating barrier system." . *oastal Research*, 5 (2), 193-237.

Janardanan, K. and Sundar, V. (1994). "Development and Application of a Numerical Model for Shoreline Simulation." *H DR P RT nt. onf. on Hydro Technical n r for Port and Harbor onstr ction*, Japan, 1141-1155.

Jayakumar, S. and Arockiasamy, D. I. (2003). "Land Use/Land Cover mapping and Change Detection in part of Eastern Ghats of Tamil Nadu using Remote Sensing and GIS." *. of the ndian Society of Re ote Sensin* , 31(4), 251-260.

Jena, B.K., Chandramohan, P. and Kumar, V.S. (2001). "Longshore Transport based on directional waves along North Tamil Nadu coast. India." . *oastal Research*, 7(2), 322– 327.

Jena, B.K. and Chandramohan, P. (1997). "Sediment transport near the peninsular tip of India." *Proc. nd ndian at. onf. on Harbo r and cean n r .* 1027-1034.

Kaliasundaram, G., Govindasamy, S. and Ganesan, R.(1991) "Coastal erosions and accretions". *n oastal one ana e ent n Ta il ad State ndia eds atara an R. Dwi edi S. . and Ra achandran S.* Ocean Data Centre, Anna University, Chennai, 73–82.

Kamphuis, J.W.(2002). "Alongshore transport of sand." P*roc. of the th nternational onference on oastal n ineerin ardiff ales S*), 2478–2490.

Kamphuis, J. W., (1990). "Littoral transport rate." *Proc. nd nt. onf. on oastal n r .*, (182), 2402-2415.

Kamphuis, J.W. (2002). "Alongshore transport of sand". *Proc. th nt. onf. on oastal n r . S* 2478–2490.

Kirby, J.T. and Dalrymple, R.A.(1983)."A parabolic equation for the combined refraction -diffraction of Stokes waves by mildly-varying topography." *of l id echanics*,136,453-466.

Kirby, J. T. and Dalrymple, R. A. (1994). "User manual combined refraction/diffraction model, REF/DIF-1, Version 2.5." *enter for pplied oastal Research Depart ent of i il n ineerin ni ersity of Delaware.*

Krishnamurthy, K. (1967). "Seasonal variation in the plankton of Porto. Novo Waters (India)." *Hydrobiolo ia*, 29, 226-238.

Kulshrestha, S. M. and Gupta, M.G. (1966). "Satellite study of the Rameswaram Cyclonic storm of 20-23 December 1964." *. of pp. eteorolo y*, 5, 373-376.

Kraus, N. C. (1983). "Application of a shoreline prediction model." *Proc. oastal Str ct res* , 632-645.

Komar, P. D., and Inman, D. L., (1970). "Longshore sand transport on beaches." *eophysical Research* 75 (33), 5914-5927.

Komar, P. D. (1971). "The mechanics of sand transport on beaches." *eophysical Research*, 76 (3), 713-721.

Komar, P. D. (1973). "Computer models of delta growth due to sediment input from rivers and longshore transport." *B l. eolo ical Soc.of erica*, 84, 2217-2226.

Kraus, N. C. and Harikai, S.(1983)."Numerical model of the shoreline change at Oarai beach". *oastal n r .*, 7 (1), 1-28.

Kraus, N.C., Hanson, H. and Harikai, S. (1985). " Shoreline change at Oarai beach past, present , and future." *Proc. th oastal n r onf. , S* , 2107-2123.

Kuik, A. J. Vledder G. and Holthuijsen L. H. (1988). "A method for the routine analysis of pitch and roll buoy wave data." *. Phys. ceano r*, 1020–1034.

Kunte, P. D., and Wagle, B. G. (1991). "Spit Evaluation and shore drift direction along south Karnataka coast, India." *iornale di eolo ia*, 53, 71-80.

Kumar, A. and Jayappa, K.S. (2009)."Long and short term shoreline change along Mangalor coast, India." *ndian . n i Res*, 3(2), 177-188.

Kumar, J. and Mahadevan, R.(1993). "Numerical simulation of shoreline evolution using a one line model." *oastal Res.*, 9 (4), 915-923.

Kumar, V.S., Chandramohan, P. Kumar, K.A. Gowthaman, R. and Pednekar, P (2000). "Longshore currents and sediment transport along Kannirajapuram coast, Tamilnadu India", *. oastal Res.* 16(2), 247-254.

Kumar, V.S., Anand, N.M., Kumar, K.A. and Mandal, S. (2003). "Multi-peakedness and groupiness of shallow water waves along Indian coast." *. oastal Res.*, 19, 1052-1065.

Kumar, V.S., Anand, N.M., Chandramohan, P. and Naik, G.N.(2003). Longshore sediment transport rate measurement and estimation, central west coast of India". *oastal n ineerin* 48(2), 95-109.

Kumar, V.S., Kumar, K.A., and Raju, N.S.N. (2004). " Wave characteristics off Visakhapatnam coast during a cyclone." *rrent Science*, 86, 1524-1529.

Kumar, V.S., Pathak, K.C. Padnekar, P.. Raju, N.S.N and Gowthaman, R.(2006). "Coastal processes along the Indian coastline." *rrent Science* 91, 530-536.

Kumar,V.S., Sajiv Philip, C. and Nair, T.N.B.(2010). "Wave in shallow water off west coast of India during the onset of summer monsoon." *nnales eophysicae*, 28, 817-824.

Kumar, V.S., Singh, J.; Pednekar, P.S. and Gowthaman, R (2011). "Waves in the nearshore waters of northern Arabian Sea during the summer monsoon." *cean n r .*, 38(2-3), 382-388

Kuleli, T., (2010). "Quantitative analysis of shoreline changes at the Mediterranean Coast in Turkey. " *n iron. onit. ssess.*, 167, 387-397.

Kuleli, T., Guneroglu, A., Karsli, F., and Dihkan, M. (2011). "Automatic detection of shoreline change on coastal Ramsar Wetlands of Turkey." *cean n r .*, 38, 1141-1149.

Lafond, E.C. and Prasada Rao, R. (1954). "Beach erosion cycles near Waltair on the Bay of Bengal." *ndhra ni ersity e oirs in ceano raphy* 1, 63-77.

Le Mehaute, B. and Soldate, M. (1980). "A numerical model for predicting shoreline changes". *iscellaneo s Report S r y orps of n ineers*, CERC, 72p.

Larson, M., Kraus, N. C., and Hanson, H.(1990). " Decoupled numerical model of three-dimensional beach change. " *oastal n r* 164(3), 2173-2185.

Larson, M., Hanson, H., and Kraus, N. C., (1987). "Analytical solutions of the oneline model of shoreline change." *Technical Report R* , US Army Corps of Engineers, Washington, DC.

Longuet-Higgins, M.S. (1970). "Longshore currents generated by obliquely incident waves." *eophysical Res.* 75 (33), 6779-6681

Loveson, V. J. and Rajamanickam, G. V. (1988). "Evidence for the phenomena of emergence along southern Tamil Nadu coast through remote sensing method. " *n Ta il ci ili ation*, 5,80-88.

Loveson, V. J., Rajamanickam, G. V. and Chandrasekhar, N. (1990). "Environmental impact of micro details and swamps along the coast of Palk Bay Tamil Nadu, India." *Sea e el ariation and its i pact on oastal n iron ent.* 159-178.

Loveson, V. J., Rajamanickam, V. G. and Chandrasekar, N. (1990). "In Sea Level Variation and its Impact on Coastal Environment (ed. Rajamanickam, V. G.). ", 159–178.

Loveson V. J. (1993). "Geological and Geomorphological investigations related to sea level variations and heavy mineral accumulation along southern Tamil Nadu beaches, India." *np blished PhD thesis*, Madurai University. p 145.

Loveson, V. J and Rajamanickam, G. V. (1998). "Geomorphic evolution of Rameshwaram island south India." *n ndian o rnal of eo orpholo y*, 3, 59-74.

Mano, A., and Diposaptono, S. (1995). "Wave field in the Efflux of River Water." *oastal Dyna ics* , 185-196.

Mas, J. F. (1999). "Monitoring land-cover changes: a comparison of change detection techniques. " *nt. . Re ote Sens*., 20, 139-152.

Mimura, N., Shimizu, T., and Horikawa, K. (1983). "Laboratory study on the influence of detached breakwater on coastal change." *Proc. oastal Str ct res* , ASCE, 740-752.

Matsuoka, M., and Ozawa, Y. (1983). "Application of a numerical model to prediction of shoreline changes. *Proc oastal Str ct res* , A specialty Conference on the Design, Construction, Maintenance and Performance of Coastal Structures, 646-659.

Morton, R. A., Leach, M. P., Paine, J. G. and Cardoza, M. A. (1993). "Monitoring beach changes using GPS Surveying Techniques." *oastal Res.*, 9 (3), 702-720.

Mau, L.D., Nayak, G.N. and Sanil Kumar, V. (2007). "Shoreline changes in and around the Thubon River mouth, central Vietnam." *. ndian ssoc. Sedi entol*, 26(1-2), 45-51.

Murthy, M. V. R., Mani, J. S. and Subramanian, B. R. (2008). "Evolution and performance of beach fill at Ennore seaport, south east coast of India." *. oastal Res.*, 24, 232- 243.

Natesan, U. and Subramanian (1993). "Seasonal shoreline oscillation of Tamil Nadu Coast." *rrent Science*, 65(9), 667–668.

Natesan, U.(2008). "The shoreline dynamics of Dhanushkodi, Rameshwaram using GIS." *Proc. d ances in ater Reso rces and Hydra lic n ineerin* , Hogai University, Nanjing, China. 1-6.

Natesan, U., Vishnunath, R. and Kathiravan, K. (2015). "Shoreline oscillation of

Dhanushkodi, Rameswaram, India." *eocarto nt.*, 30(5), 520-531.

NEERI (2012). "Environmental Impact Assessment for Proposed Sethusamudram Ship Canal Project.", National Environmental Engineering Research Institute, Council of Scientific and Industrial Research, Nagpur, India.

Nobl, E.P., Shivaprasad, A., Karikalan, R., Dilipan, E., Thangaradjou, T. and Sivakumar, K. (2010). "Microlevel Mapping of Coastal Geomorphology and Coastal Resources of Rameswaram Island, India: A Remote Sensing and GIS Perspective.". . *oastal Res.* 26(3) 424–428.

NHO (2006), "NHO Chart No. 316." *ational Hydro raphic ffice*, Dehradun.

Nayak, B.U., Chandramohan, P. and Sakhardande, R.K. (1992). " Seasonal distribution of wave heights off Yanam on the East Coast of India. " *ndian . nstit tion of n ineers* 72,187-193.

Nguyen Ngoc Thach, Nguyen Ngoc Truc and Luong Phuong Hau. (2007)."Studying shoreline change by using LITPACK mathematical model (case study in Cat Hai Island, Hai Phong City, Vietnam)." *. Science arth Science*, 23,244-252.

O'Connor, B. A., Sayers, P. B., and MacDonald, N. J. (1995). "Combined refraction-diffraction - wave-current interaction over a complex nearshore bathymetry." *Proc. oastal Dyna ics , S* , 173-184.

Perlin, A., and Kit, E. (1999). "Longshore sediment transport on Mediterranean coast of Israel." *. aterway Port oastal and cean n r .*, 125 (2), 80-87

Perlin, M., and Dean, R. G. (1983). "A numerical model to simulate sediment transport in the vicinity of coastal structures." *iscellaneo s Report* No. 83-10, US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, 119p.

Prabakaran, K. and. Anbarasu, K. (2010). "Coastal Geomorphology and Evolution of Rameshwaram Island, Tamil Nadu, India." *. arth Sciences*. 2 (2), 30-35.

Pelnard-Considere, R. (1956). "Essai de theorie de l'Evolution des Forms de Rivage en Plage de Sable et de Galets." *th o ees de l Hydra li e es ner ies de la er estion* Report No. 1, 289-298.

Prasanna Kumar, S., Shenoi, S.S. and Kurup, P.G. (1983). "Littoral drift along shoreline between Munambum and Anthakaranazhi, Kerala coast". *ndian . ar.Sci*, 12 209-212.

Price, W.A., Tomlinson, D.W., and Willis, D.H. (1973). "Prediction changes in the plan shape of beach." *Proc. th oastal n ineerin onference, S* , 1321-1329.

Perlin, M. (1979). "Prediction beach planforms in the lee of a breakwater." *Proc. oastal Str ct res* ASCE, 792-808.

Perlin, M., and Dean, R. G.(1983). "A numerical model to simulate sediment transport in the vicinity of coastal structures". *iscellaneo s Report* No. 83- 10, US Army Engineer Waterways Experiment Station, Coastal Engineering Research Center, 119p.

PIANC (1997). " Approach Channels A Guide for Design, Final report of the joint Working Croup PIANC and IAPD in cooperation with IMPA and IALA." *S pple ent to B lletin no Report of workin ro p* , June.

Portilla, J., Ocampo-Torres, F.J. and Monbaliu, J. (2009)."Spectral Partitioning and identification of Wind sea and Swell." *. t os. ceanic Technol.*, 26, 117-122.

Ramanujam, N., Radhakrishnan, V., Sabeen, H.M. and Mukesh, M.V. (1996). "Morphodynamic State Beaches between Vaipar and Tiruchendur, Tamilnadu." *. of eolo ical Society of ndia*, 47(6), 741-746.

Rao, N. S. B. and Mazumdar, S. (1965). " A synoptic study of Rameswaram cyclone of December 1964 and the storm wave caused by it." *ndian . eteoral eophys*, 171-178.

Rao, N.S.B. and Mazumdar, S. (1996). "A technique for forecasting storm waves.", *ndian . eteoral eophys*, 17, 333-346.

Rao, B.P. (2003). "Sediment transport and exchange around Rameswaram Island between Gulf of Mannar and Palk Bay." *Ph.D. thesis*, University of Berahmpur, Orissa, India. 440p.

Rogers, W. E., Hwang, P. A. and Wang, D. W. (2003). “Investigation of wave growth and decay in the SWAN model: three regional-scale applications.” . *Physical ceano raphy*, 33 (1), 366-389.

Rea, C. C. and Komar, P.D. (1975). “Computer simulation models of a hooked beach shoreline configuration.” . *Sedi entary Petrolo y*, 45 (4), 886-872.

Ryu, J. H., Won, J. S., and Min, K. D. (2002). “Waterline extraction from Landsat TM data in a tidal flat: a case study in Gomso bay, Korea. ” *Re ote Sens.* Environ., 83, 442–456

Swain, J., Ananth, P.N. and Rao, C.V.K.P. (1993). “Shallow water wave characteristics off Cochin during monsoon.” *ndian . ari. Sci.*, 22. 256-262.

SPM, (1984). “Shore Protection Manual.” U.S. Army Coastal Engineering Research Center, Department of the Army, US Corps of engineers, Govt. Printing Office, Washington, DC, USA, Vols. 1 & 2.

Subba Rao, P.V. and Mantri, V.A. (2006). “Indian Seaweed resource and sustainable utilization: scenario at the dawn of a new century.” *rrent Science* 91 (2), 164 – 174.

Suresh, P.K. and Sundar, V (2011). “Comparison between measured and simulated shoreline changes near the tip of Indian peninsula.” . *Hydro en iron ent Res.* 5(3), 157-167.

Subbarao, D.V., Srinivasa Rao, K., Iyer, C. S. P. and Chittibalau, P. (2008). “Possible ecologicconsequences from Sethu Samudram Canal Project.” *ndia arine B lletin*, 56, 170-186.

Subramanian K. S. and Selvan, T. A. (2001). “Geology of Tamil Nadu and Pondicherry.” *P blished by eolo ical society of ndia*, Bangalore, p. 181.

Scripps Institution of Oceanography (1947). “A statistical study of wave conditions at five localities along the California coast.” *a eReport*, University of California 68, 34p.

Sajeev, R,. Chandramohan, P. and Sanil Kumar, V. (1997). “Studies on sediment transport along Kerala coast, south west coast of India.” *ndian . ar.Sci.*, 26(1), 11-15.

Sasaki, T. O. and Sakuramoto, H. (1978).“Field verification of a shoreline simulation model.”. *Proc. nt. onf. ater Reso rces n r .*, International Association for Hydraulic Research, 501-518.

Shimizu, T., Nodani, H., and Kondo, K.(1990). “Practical application of three dimensional beach evolution model.” *oastal n r Proc.*, 3 (188), 2481-2494.

Short A. D. (1999). “Handbook of beach and shoreface morphodynamics.” Chichester, UK 37.

Thanikachalam and Ramachandran, S. (2003). “Shoreline and Coral Reef Ecosystem changes in Gulf of Mannar, Southeast coast of India.” *o rnal of the ndian Society of Re ote Sensin* , 31(3), 157-172.

Van Rijn, L.C. (1993). “Principles of Sediment Transport in River Estuaries and Coastal Sea.” *a P blication*, The Netherlands, 592 p.

Van Rijn, L.C. (1986). “Sedimentation of dredged channels by currents and waves”. *aterway Port oastal and cean n r .*, 112(5), 541-559.

Walton, T.L. and Bruno, R.O. (1989). “Longshore transport at a detached breakwater, Phase II.” *. oastal Res.*, 5(4), 679–691.

Wang, D.W. and Hwang, P.A.(2011).“An Operation method for Separating Wind sea and Swell from the Ocean wave spectra.” *. t ospheric and ceanic Technolo y*,18,2052-2062.

Wang, P., Nicholas C. Kraus and Richard A. Davis, Jr. (1998). “Total Longshore Sediment Transport Rate in the Surf Zone: Field Measurements and Empirical Predictions.” *. of oastal Res.*, 14(1), 269-282.

Watts, G. M. (1953). “Study of sand movement at South Lake Worth Inlet, Florida.” *Beach rosion Board*, U.S. Army Corps Eng. *Tech. e o*. 42, 24p.

Walton, T. L., and Chiu, T. Y. (1979). "A review of analytical techniques to solve the sand transport equation and some simplified solutions." *Proc of oastal Str ct res , S* , 809-837.

Walton Jr., T. L. (1994). "Shoreline solution for tapered beach fill.". . *aterway Port oastal and cean n r* 120 (6), 651-655.

Willis, D. H. (1977). "Evaluation of alongshore transport models."*Proc. oastal Sedi ent , S* , 350-365.

Work, P. A., Fehrenbacher, F., and Voulgaris, G. (2004). "Nearshore impacts of dredging for beach nourishment." . *aterway Port oastal and cean n r* , 130 (1), 303-311.

Walton Jr., T. L., Cheng, J., Wang, R., and Manausa, M. (2005). "Modeling of three beach fill projects". . *cean n r* , 32, 557-569.

Zheng, G., Peng, L., Tao, G., and Wang, C. (2011). "Remote sensing analysis of Bohai Bay West Coast shoreline changes." *nt. onf. Spat. Data in. eo r. nowl. Ser . SD* , 549-552.

PUBLICATIONS

INTERNATIONAL OURNAL

1. Gowthaman, R., Sanil Kumar, V., Dwarakish G.S ., Shanas, P.R., Jena, B.K., and Jai Singh (2015). "Nearshore waves and longshore sediment transport along Rameshwaram Island off the east coast of India" *nternational o rnal of a al rchitect re and ocean en ineerin* . .

NATIONAL OURNAL

1. Gowthaman, R., Sanil Kumar, V., Dwarakish, G.S., Soumya S. Mohan, Jai Singh and Ashok Kumar, K. (2013) "Waves in Gulf of Mannar and Palk Bay around Dhanushkodi, Tamil Nadu, India", *rrent Science***,** Vol. 104. No. 10. pp. 1431-1435.

2. Gowthaman, R., Dwarakish, G.S. and Sanil kumar, V. (2014) "Landuse/Land cover around Ramsehwaram Island, East coast of India", *ndian o rnal of eo arine Science*, Vol. 43. No.7**.** pp**.** 1183-1186.

INTERNATIONAL CONFERENECE

1. Gowthaman, R., Dwarakish, G.S. , Sanil kumar, V. and Rajasekaran, C. (2013) "Shoreline changes off Rameshwaram Island" *Proc. nternational conference on Hydra lics water Reso rces oastal n iron ental n ineerin H DR*), IIT-Madras, Chennai, pp. 1008-1011.

NATIONAL CONFERENCE

1. Gowthaman, R., Dwarakish, G.S., Sanil Kumar, V. and Vinayaraj, P. (2011) "Changes detection studies of Rameshwaram Island, India using Remote sensing and GIS", *Proc. ational conference cean society of ndia S* NIOT, Chennai. pp. 47.

2. Gowthaman, R., Sanil Kumar, V., Dwarakish, G.S. and Vinayaraj, P. (2012) "Shoreline changes and littoral drift around Dhanushkodi", Proc. *ational conference on nte rated coastal one ana e ent* Bharampur University, Odisha. pp. 72.

3. Gowthaman, R., Sanil Kumar, V. and Dwarakish, G.S. (2013) "Shoreline changes of Dhanushkodi, Tamil Nadu India *Proc. ational conference on coastal en iron ents their ana e ent* , Mangalore University, Karnataka pp.120.

BRIEF BIO-DATA

Personal Information

Name : **R. Gowthaman**

Registration Number : **0 2026AM0 P01**

Date of Birth : **04-04-1 6**

Permanent Address : **No. F1, No le Shelter, Caran alam**

Dona paula P.O . Goa-403004

Education ualification

Post Graduation : **M.Sc., Geoinformatics**

Year : **200**

University : **Mangalore Uni ersity**

Graduation : **B.Sc., Computer Science**

Year : **1**

University : **Bharathidasan Uni ersity**

Present Occupation

Institute : **CSIR- National Institute of Oceanography**

Designation : **Senior Technical Officer II**

Address : **Dona Paula, Goa-40304.**