MANAGEMENT OF COASTAL EROSION ALONG PONDICHERRY COAST

SHORELINE MANAGEMENT PLAN

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EXECUTIVE SUMMARY

Many beaches along East coast of India are subjected to erosion, which threatens habitat, property, public infrastructure, and the tourist industry. Loss of sand can be attributed natural changes (sea level rise, storms, and more recently persistent low pressures due to climate change) and man-made activities (harbors, jetties, seawalls, groins, dredging of tidal inlets and damning of rivers). Pondicherry coast is not exceptional and after construction of Pondicherry harbour, coast north of harbour is subjected to sea erosion. Initially, sand bypassing was carried out by harbour authorities to prevent downdrift erosion and to maintain channel free from siltation. Later, discontinuing of sand bypassing due to various technical reasons, lead to erosion on Pondicherry city. UT Pondicherry and Tamil Nadu State Government resorted to short term measures to protect the coast from erosion. Seawall of length 6 km was constructed by UT Pondicherry, which covers city of Pondicherry and the coastal stretch (2 km) from Sodhanaikuppam to Thanthriyankuppam was protected groin field combined with seawall by Tamil Nadu government. The erosion problem shifted further north, Chinnamudalaiyar Chavadi is experiencing increased erosion and many buildings were lost to sea. Highly eroding fishing hamlet, north of Chinnamudalaiyar Chavadi, and Chinnakalapettai village in UT Pondicherry were also protected by seawall. As on date, 8 km length of the coast was protected by seawall and groin field along Pondicherry coast by UT Pondicherry and Tamil Nadu Government. The above solutions could protect the coast under threat but the authorities and stake holders need an integrated long-term solution for protection of coast and restoration of natural beach.

Since, the available information on Pondicherry coast is not sufficient for working out suitable strategies; NIOT was consulted by both UT Pondicherry and Tamil Nadu government to work out long term / short term strategies for management of coast from erosion and impact of cyclones. NIOT has initiated studies to evolve strategies for protection of Pondicherry coast under the project “Demonstration of Shore Protection Measures through Pilot project", with financial support from Ministry of Earth Sciences. NIOT has taken up task of developing strategies for protection of Pondicherry coast with objectives: 1) Assessment of status of existing

protection measures and its performance 2) To Understanding the processes responsible for shoreline changes through monitoring waves, tides, currents, sediment characteristics and coastal morphology 3) Analysis of long/short term trends of shoreline along Pondicherry coast and 4) Development of shore protection measures through numerical models. The first three activities were completed and documented in the present report. The final report with strategies for protection of coast will be arrived at based on the discussion with the governments of Tamil Nadu and UT Pondicherry and stake holders.

The study aims at understanding various dynamical aspects of coast (water level variations, currents & circulation, tides, waves, bathymetric variations, sediment transport, shoreline changes etc) to develop hindcast, nowcast and forecast models on shoreline changes in priority areas for identification of vulnerable areas of erosion/ accretion to arrive at remedial measures for protection of coastline from natural and human perturbations. The strategy proposed in the present study aims at obtaining a comprehensive picture on shoreline changes along Pondicherry coast and to take remedial measures for shoreline management along the stretch.

The study area with coastline length of 18 km was divided into four distinct zones, namely 1) Pondicherry harbour and adjoining areas, 2 km 2) Pondicherry city, protected by seawall, 6 km 3) Groin field, 2 km and 4) Open coast, 8 km. The shoreline changes in these four zones were analyzed using remote sensing data and field measurements. The result indicate that the average rate of erosion and accretion is 4m/yr and 5m/yr respectively and the coast needs immediate attention for its protection from natural causes or man-made activities. The estimated rate of net drift would be in the order of 0.28 – 0.30 million cum, which needs to be confirmed by detailed shoreline monitoring.

Coastal processes responsible for shoreline changes were monitored during 2012, where data on winds, waves, tides, currents, sediments, bathymetry etc were collected between Pondicherry Port and Kalapettai village, covering a coastline of 18 km. Seasonal variations on water levels, wave climate, currents and circulation, sediment transport, shoreline changes etc were studied. The measurements made indicated that the tide propagates from south to north. Currents measured upto a depth of 20 m were found to be seasonal, northerly during SW monsoon and southerly during NE monsoon. The average currents during SW and NE monsoon would be 0.3 m/s and 0.5 m/s. The nearshore currents generated by waves follow pattern of coastal currents in Tamil Nadu coast, which is added advantage in developing shore protection measures. Wave climate indicate that 70% of the waves approach the coast from SE direction and the remaining 30% from NE direction.

Pondicherry, known for tourism/recreation, has lost its natural beach due to construction of seawall. It is advisable to restore natural beach by implementing beach nourishment. Initial estimates indicate that sand to extent of 3.0 million cum need to be placed north of harbour for length of 600 m near the Gandhi statue. The above option not only helps in gaining natural beach but also helps in controlling the erosion of northern coast. The detailed design of beach nourishment scheme can be worked based on the discussions. Also, eco-friendly techniques and “soft engineering measures” could be implemented along with beach nourishment for retaining of sand and also to restore ecological functions of the coast.

Short-term solutions may need to be implemented, but these solutions have to take into account the long-term solutions and should be “no-regret” solutions.

A long-term and permanent solution can be found if both the Tamilnadu and Pondicherry governments jointly work towards a common, long-term and sustainable shore restoration strategy.

I hope that that the present report prepared by our team would help to assess the status of Pondicherry coast and to provide insight into possible coastal protection strategies based on scientific information collected and analysed along the coastal stretch of 18 km.

Dr.M.A.ATMANAND
DIRECTOR

ACKNOWLEDGEMENT

We wish to express our sincere thanks to Tamil Nadu public works department and Pondicherry public works department for their encouragement and cooperation throughout the progress of this work.

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1.0 INTRODUCTION

Environmentally friendly solutions that are compatible with ever-changing needs of society are major challenges in coastal zone management today. Political, social and technical issues must be considered, and possible solutions must balance the likely positive and negative impacts. For centuries, the coastline has been a focus for a variety of activities including industry, agriculture, recreation and fisheries. These national economic assets have been developed and flourished despite constant changes in the physical characteristics of the coast. The coastline is a national heritage and in order to sustain it for future generations, proper management and restoration of the coastal zone is essential. The coast performs various functions and also provides ecological services such as i) shoreline protection, ii) filter and barrier to salt-water intrusion, iii) natural habitat, iv) space for livelihood activities, v) space for recreational activities and well-being, etc., etc. 'Coastal restoration' is a process by which damaged natural sandy beaches are regenerated along with their inherent various functions and services they provide. It is only by having a healthy sandy beach that we can protect the coastline from the sea and defend the low lying areas from flooding and ensure the present and future livelihood of coastal communities.

Traditionally, the central focus has been on protection rather than on restoration. because of which coastal and flood protection works have been implemented in a piecemeal fashion, either in response to a recognized threat to an existing village or town, or as part of a new development scheme. The authorities responsible for coastal defence and flood protection tend to look at the issue within their own boundaries. The measures taken in response to a problem, sometimes lead, often unintentionally, to adverse effects on both adjoining and distant stretches of coastline.

Therefore, there is need for a well-defined plan that seek to treat the shoreline and and the issue of erosion in a more integrated, sustainable and strategic manner. This can be achieved by Shoreline Management Plan (SMP), which considers the issues at a reasonable scale. The policy adopted should ensure that the restoration of the eroded sandy beaches are taken up in a manner that is technically, environmentally and economically acceptable, both at the time any associated measures are implemented, and in the future.

For preparation of a SMP, the boundaries of the region have to be identified properly to avoid adverse impacts that may arise from the interventions planned as a part of the plan. The processes along the shoreline vary spatially and temporarily. The inputs and outputs of the region have to be assessed carefully depending on underlying processes. There are few questions which still need to be answered by scientific experiments. They are

i. The coastal stretch considered to be dominated by onshore- offshore transport or along shore transport
ii. The magnitude of the sediment transport in the onshore, offshore and along shore
iii. The modification of sediment pathways along the coastal stretch resulting from manmade interventions. These include construction of dams on upstream of the river, major harbour installation along the coast, coastal protection structures, and sand mining etc.

The Union Territory of Pondicherry comprises of four regions namely Pondicherry, Karaikal, Mahe and Yanam, which are not geographically contiguous. Pondicherry is located in the East Coast, about 162 kms. south of Chennai. This is the largest among the four regions and consists of 12 scattered areas interspersed with enclaves of Villupuram and Cuddalore Districts of Tamil Nadu. The Union Territory has a total area of 492 km^2: Pondicherry 293 km^2 , Karaikal 160 km^2 , Mahe 9 km^2, and Yanam 30 km^2 . Pondicherry, like all other coasts in this region is also undergoing continuous changes by natural geological agents like wind, wave, tide & currents. Along with these agents, increased urbanized coastal structures along the Pondicherry coast have amplified the complexity of the denudation process. Though the structures like groins, seawalls etc have been built to protect the Pondicherry coast from coastal erosion and to improve the social economy of the Union Territory, it has been observed that these structures act as an obstruction for the natural littoral drift which have made the sedimentation process more complex. [The impacts of these changes started at the time of construction phase of the coastal structures (seawall, jetty, breakwater and Groins) and further extending its effects till today as a continuous process to attain its stability by natural processes.]

The programme on "Demonstration of Shore Protection Measures" has been initiated by the National Institute of Ocean Technology with support from Ministry of Earth Sciences, Government of India which aims in developing environmentally friendly coastal protection and restoration measures. To prevent the Pondicherry coast from the continuous denudation and also to restore the available coastal belt, a detailed shoreline history and characteristics are analysed through Remote Sensing, Field measurements and numerical modelling. Significant coastal erosion and accretion zones are identified and the protection measures attempted along the coast are described in detail.

Like many ports on the East Coast, the Pondicherry Port breakwaters are trapping the littoral transport causing morphological changes to the coast of Pondicherry and neighbouring Tamil Nadu. The coastal stretch,6 km north of the northern break water, includes the Pondicherry city, which has been badly affected by coastal erosion resulting in damage of buildings along the shore. To combat erosion and to protect this coastal belt, a seawall was constructed during the year of 2000 leaving small pockets of beaches for fishing and other coastal activities. Though these seawalls could prevent the landward encroachment of the sea, reflection of waves caused scouring at the toe of the seawalls causing severe erosion of the northern coast.

After the 26 December, 2004 tsunami, Govt. of Pondicherry strengthened the seawall by increasing its width. Since the seawall actually defines where the shore-sea interface shall be in the shore section it protects, a discontinuity will form between the structure which does not move and the surrounding shore which continues to recede. Beach erosion is also being caused by the new diffraction and refraction pattern causing waves to arrive obliquely normal to the shoreline. The Pondicherry town stands more exposed to fury of waves than ever before to the cyclones and tsunamis. Restoration of the beaches is a top of the priority for the government and the pressure to develop alternative measures other than the conventional construction of groins and seawalls is intensifying.

Further, series of groins have been built during 2003 to stabilize the beach. Since, the construction of these groins, the average shoreline change within the groin field has been a seaward advancement of approximately 50 m; the greatest advancement of 75 m has occurred in the northern compartment, and the smallest advancement of approximately 35 m within the southernmost compartment. However the groin field shifted the erosion problem further northwards.

So far, the sea erosion has severely impacted 8 kilometres of the coastline destroying houses and villages and is proceeding northwards. This leads to the steepening of the foreshore area up to a distance of 15 km to the north of the Pondicherry town. The agencies responsible for coastal protection measures and the geographical boundaries of operation along a coastal stretch of 45km between two rivers (also termed as sediment cell) are given in Figure 1.

Many consultations were held with agencies like CES, IITM Chennai, DHI, IOM, CWPRS and NGO's to assess the reasons for coastal erosion and to arrive at remedial measures for the restoration of the Pondicherry coast. Their studies have acknowledged that the main reason for erosion of the Pondicherry coast and the adjoining areas is due to a deficit in sediment supply to northern coast caused by the construction of a harbour in Pondicherry. The ineffective use of the sand bypassing system at Pondicherry harbour and its later discontinuation aggravated the issues of coastal erosion in this region.

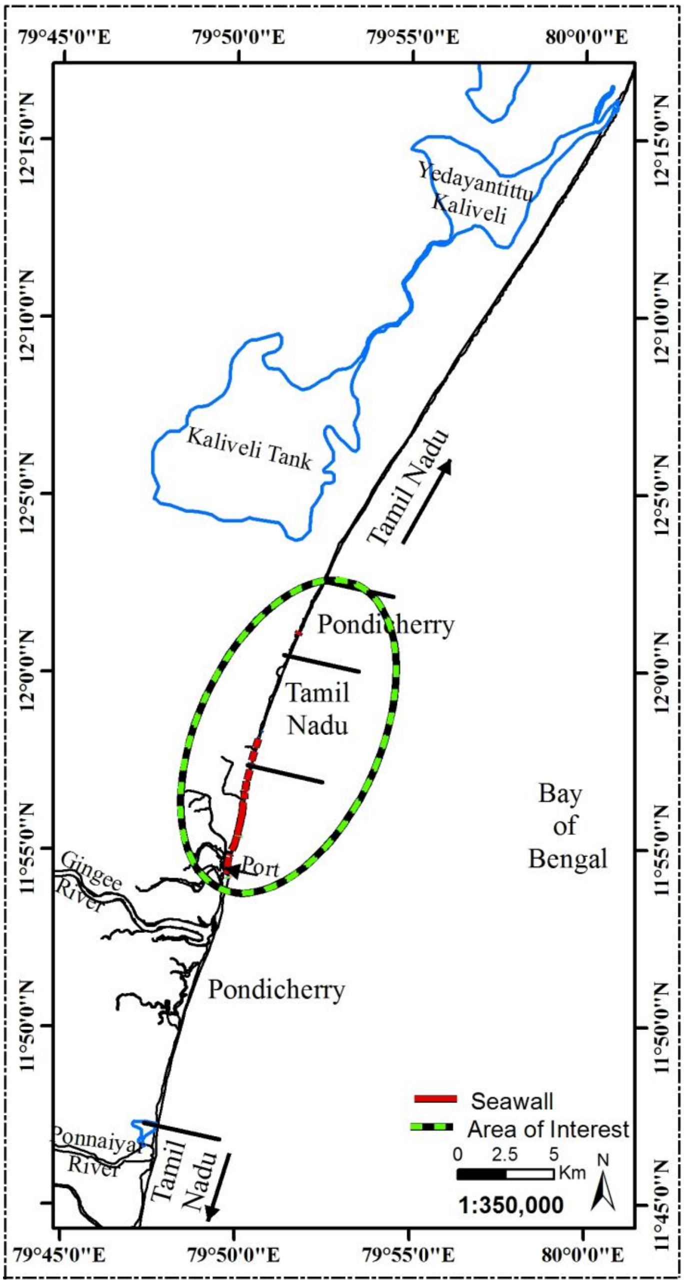


Figure 1. Pondicherry and Tamil Nadu coast

Since, the mitigation measures implemented along the coast till date could not yield fruitful results; the National Institute of Ocean Technology was consulted for assessing the status of existing protection measures and to develop strategies for long term management and restoration of the coastline of Pondicherry and Tamil Nadu.

NIOT has taken up task of developing strategies for the restoration of the Pondicherry and the Tamil Nadu coast following objectives:

1. Assessment of the status of existing protection measures and its performance
2. Understanding the processes responsible for shoreline changes through monitoring waves, tides, currents, sediment characteristics and coastal morphology
3. Analysis of long/short term trends of shoreline along the Pondicherry and the Tamil Nadu coast
4. Development of shore restoration measures through numerical models

The first three activities detailed above were completed and documented in the present report. The final report with strategies for the restoration of the coast will be arrived at based on the discussion with the state departments and stake holders meet.

Institute of Ocean management, Anna University is involved in the analysis of remote sensing data and support for field measurements.

2. PONDICHERRY COAST AND ITS ENVIRONS

2.1 Physical Status

Pondicherry city is the capital of the Union Territory of Pondicherry with main its economic activities being small scale industries and higher education. It was the capital of former French India and was also held at times by the Dutch and British. In 1962 it became part of the Union Territory of Pondicherry. Pondicherry region is situated on the Coromandel coast between 11°45' and 12°03' N latitudes and 79°37' and 79°53' E longitudes with an area of 293 km^2. The existing port of Pondicherry (11° 56' N latitude and 79° 50' E longitude) is situated between two major ports namely, Chennai and Tuticorin. The port is suitable for lightrage operations during fair weather months (February to September). The coast is of open type with estuaries. Though the regional coastline appears to be almost straight, it is a part of a larger concave coast.

2.2 Environmental Conditions

The terrain is gently undulating with prominent high grounds varying from 30 to 45 m above Mean Sea Level (MSL) towards interior northwest and northestern parts of region. There are two major rivers draining this region 1) the Gingee River, which traverses the region diagonally from north-west to south-east and 2) the Ponnaiyar (Penniyar) river, which forms the southern border of the region. The river Gingee also known as the Varahanadi or Sankaraparani which has its source in the hills of Malayanur of Villupuram district, Tamil Nadu has a course of 34km in this region before it confluences with the Bay of Bengal. The river Ponnaiyar originates from the hills of Karnataka and enters the Pondicherry region after flowing through the districts of Dharmapuri, Salem, Vellore and Cuddalore of Tamil Nadu. All the rivers are ephemeral in nature.

2.2.1 Climate

Climate at the Pondicherry is hot and humid. The maximum and minimum temperature recorded at the Pondicherry is 35.7^0 C in the month of June and 20.9^0 C in January respectively. The average maximum temperature is 31.5^0 C and average minimum temperature is 23.9^0 C.

2.2.2 Meteorological Conditions

Pondicherry has hot and humid summer, cool winter and two distinct monsoon seasons (south-westerly and north-easterly).

Hot: Summer (February)

Rainy season: South-West Monsoon (March-September)

Rainy Season: North-East Monsoon (October to December)

Cold: Winter (January)

2.2.3 Rainfall

The rainfall in the Pondicherry is influenced by the Southwest and Northeast monsoon. Wet season persists mainly during the north east monsoon period between October and December. The average rainfall received in northeast monsoon is about 1300 mm. Southwest monsoon starts in the month of March and rains still September.

2.2.4 Wind

The average wind speed during the southwest monsoon period is about 35 km/h (9/7 m/s), frequently rising up to 45-55 km/h (12.5-15.3 m/s). The average wind speed during northeast monsoon prevails around 20 km/h (5.6 km/s). During the cyclone period the winds are around 100 km/hr (Nisha 2008) and 140 km/hr (Thane 2011).

2.2.5. Wave

As a part of Coromandel Coast, the Pondicherry region is experiencing two different monsoon seasons, North-East and South-West, annually. During South-West monsoon the waves are approaching the coast from S-E direction while during the following North-East monsoon the wave direction is from N-E and E. The normal wave climate in the Bay of Bengal is mild with significant wave height varies from 1 m to 1.5 m and peak period varies from 7 sec to 9 sec, but the wave climate is very severe during cyclone with significant wave heights ranging from 4 to 6 m and peak periods from 10 sec to 18 sec. The severe climate exists only for less than 1% a year, but from erosion point of view, its impacts need to be considered.

2.2.6 Cyclones

Pondicherry, being a part of the Indian subcontinent, experiences tropical cyclones which originate from the depression generated in the Bay of Bengal during the northeast monsoon season (October to December). It experiences an average of 2 -3 cyclones annually. Highest wind speed of 189 km/hr and the lowest wind speed of 83 km/hr have crossed the Pondicherry coast in the past. Pondicherry is also affected by cyclone generated waves during this period. Cyclone data over the Bay of Bengal since 1891 indicates that on average, a moderate to severe cyclone hits Tamil Nadu and Pondicherry coasts every two years.

2.3 Pondicherry Port and its Development

History reveals that there have been at least four ports in Pondicherry; the locations of these ports are shown in Figure 2.

2.3.1 The Ancient Port (Roman Port)

There is evidence of an ancient port town situated on the bank of Ariyankuppam river about 8km south of Pondicherry township. This port town has a history that dates back to the second century BC. An excavated ancient port town, Arikamedu had strong trade links with Rome and Greece between 100 BC and 100 AD.

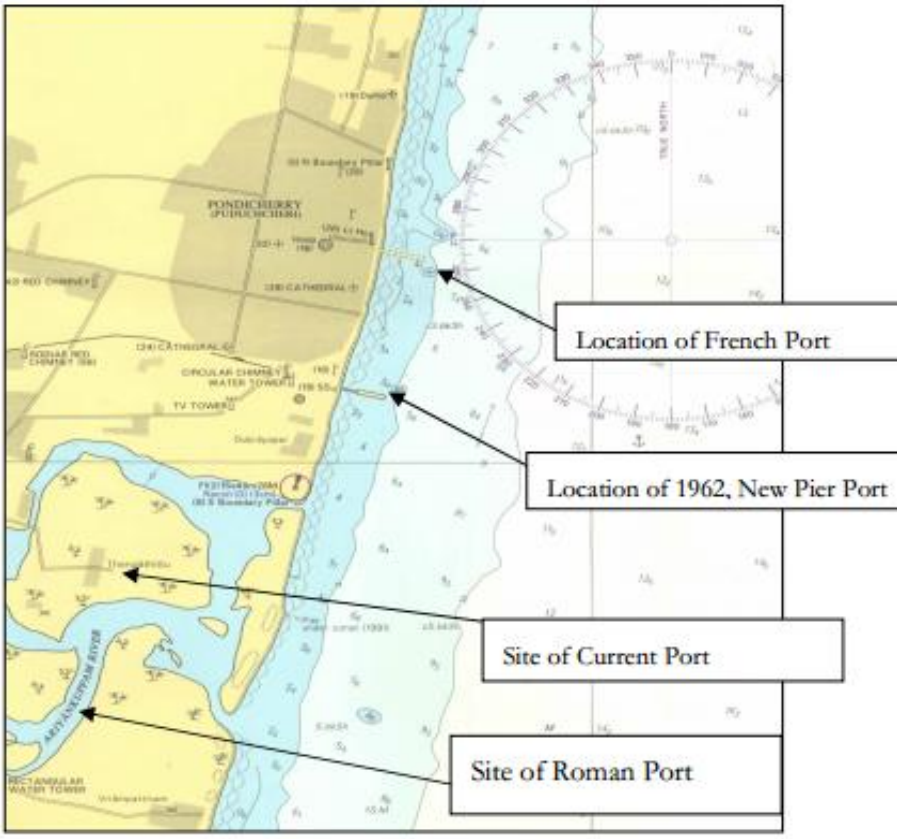


Figure 2. Locations of the past and present port

2.3.2 The French Port (Roman Port)

In 1674 Francois Martin, the first Governor, started to build Pondicherry and transformed it from a small fishing village into a flourishing port-town and centre of international trade. By the 20th Century the French port comprised a pier in the Centre of Pondicherry Town. During the Second World War the trade came almost to a standstill and even after the war the trade remained much diminished. The French pier was damaged in a cyclone in 1952 and was not usable thereafter.

2.3.3 The 1962 New Pier Port

In 1962 a New Pier and port was built south of the town. The New Pier and its associated 11 acre walled port land was used to berth small lighters that transhipped goods from ships that lay at anchor off the coast. The associated port has a number of warehouses and two rail sidings that have recently been converted to broad gauge. The New Pier was in use until quite recently. However, the support works to the pier are now severely corroded making the pier unsafe for heavy loadings. The port area is now also therefore largely unused.

2.3.4 The Current Port

The current port was built south of the New Pier in the late 1980's. The shoreline is tilted approximately 20^0 from the North. The breakwaters of north and south are 150 m and 280 m respectively and the tip of south breakwater was originally located at a water depth of 4 m (Figure 3) but because of siltation it is presently at a depth of about 1 m. These breakwaters were constructed with the provision of a sand bypassing system with a capacity of about 400,000 m^3/year. However, the sand bypassing system has not been sufficiently or appropriately utilized. Because of this, deposition occurred on the south side of the breakwater and erosion on the north side of the northern breakwater. For protecting the shoreline against erosion, the Pondicherry/Tamil Nadu government has built riprap using boulders weighing 0.5 to 1.5 tonnes for a total length of about 8.55 km. In many places in this region, the seabed below the riprap was eroded due to severe wave action around ground subsidence.

Figure 3. The Location of existing Pondicherry Port.

3.0 COASTAL PROTECTION WORKS ALONG PONDICHERRY / TAMIL NADU COAST

After the construction of the Pondicherry harbour, dredging was carried out to maintain the navigational channel and also to protect the northern coast from downdrift erosion being caused by the harbour. However, the dredged spoils were frequently deposited on the southern side of the harbour mouth. After discontinuing the sand bypassing, the northern coast started eroding and Tamil Nadu / Pondicherry governments have attempted several protection measures in association with IIT Madras, Chennai from 1990 and continued till 2006. These protection measures include sand bypassing/beach nourishment, seawalls and groins, details of which are given below.

3.1 Sand bypassing

The erosion and accretion estimated by Sundar et al., from 1986 to 2002 using satellite data revealed that the rate of erosion is about 4 m/yr on the northern side of port and the accretion at south of the port is 6 m/yr. The extent of erosion in the North of Northern breakwater is 31 hectares and 33 hectares of beach sand accreted with in 1.5 km on the South of the Southern breakwaters. Artificial beach nourishment which was carried out during 2002 – 2003 with the sand dredged from the Pondicherry harbour, helped in building of a beach (Figure 4).

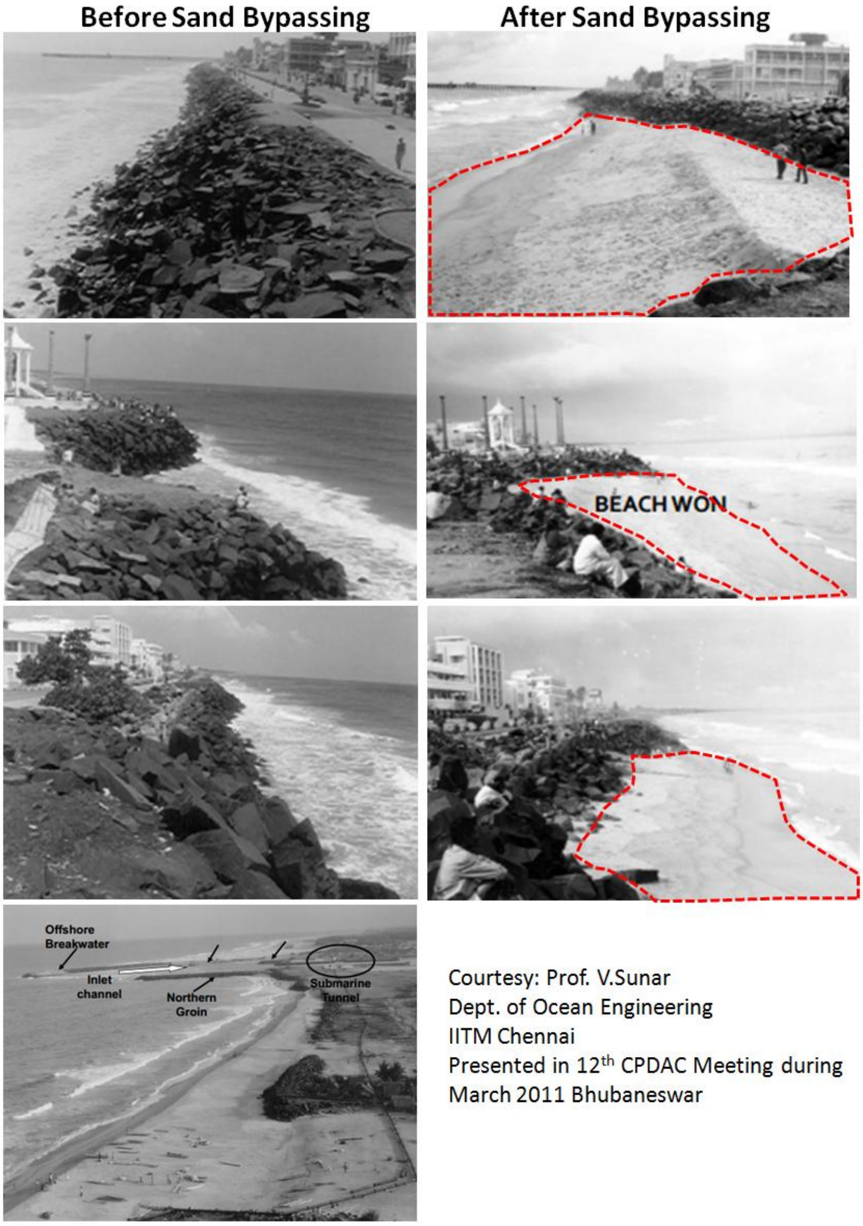


Figure 4. Sand bypassing during 2002-2003

3.2 Seawalls

After the discontinuation of sand bypassing, the Pondicherry coast was subjected to erosion. A seawall of 6km long was built along the Pondicherry town by the Pondicherry Government during 2002 – 2003, with a estimated cost of 40 Cr resulting in the erosion of the northern coast. To protect the coast from erosion, Tamil Nadu PWD initiated protection measures by constructing a seawall of 500m length in Nadukuppam during 2003 - 2004 and 920 m in Sothanaikuppam during 2005 - 2006. These efforts continued up to Kottakuppam 820 m in 2006 - 2007 and also at Chinnamudalaiyar Chavadi. The seawall protected the coast under threat, but the foreshore became steep and the natural beaches eroded (Figure 5).

Figure 5. Constructed seawall along the Pondicherry coast

Table 1. Details of coastal structures along Tamil Nadu coast

Village Name	Structures	Length	Year of
Sothanaikuppam	Seawall	64	1998-1999
Sothanaikuppam	Seawall	62	1999-2000
Nadukuppam	Seawall	500	2003-2004
Sothanaikuppam	Seawall	400	2005-2006
Sothanaikuppam	Seawall	420	2005-2006
Sothanaikuppam	Seawall	100	2005-2006
Kottakuppam	Seawall	820	2006-2007
Nadukuppam	Seawall	31	2006-2007
South Thanthiriyankuppam	Groin	95	2006-2007
North Thanthiriyankuppam	Groin	170	2006-2007
Chinnamudalaiyar Chavadi	Seawall	120	2008-2009
		200	2009-2010

(Source: PWD, Tamil Nadu)

3.2 Groin

Groin construction was attempted by both the governments when the demand for a sandy beach by the fishermen intensified. This was initiated in Sothanaikuppam village with two groins (south 50m and north 55m during 2005) and which showed a moderate beach build up. Later, two more groins were constructed at Kottakuppam village with 40m length on south (during 2005) and 70m length on north. These groins trapped the sand and beach width of about 30m was formed. In 2007, two groins were built on either side of the Thanthiriyankuppam village with the length of 95m and 170m, the tip of the northern groin (170m) extended upto a depth of about 4m at time of construction. After the groin construction, the wide beach which existed on the northern side before groin construction was lost, and buildings were under threat. Further 320m of length of seawall was built by PWD, Tamil Nadu during the year 2008 - 2010 and there is a proposal to build a series of seven more groins from Chinnamudalaiyar Chavadi to Bommiyarpalayam (Figure 6).

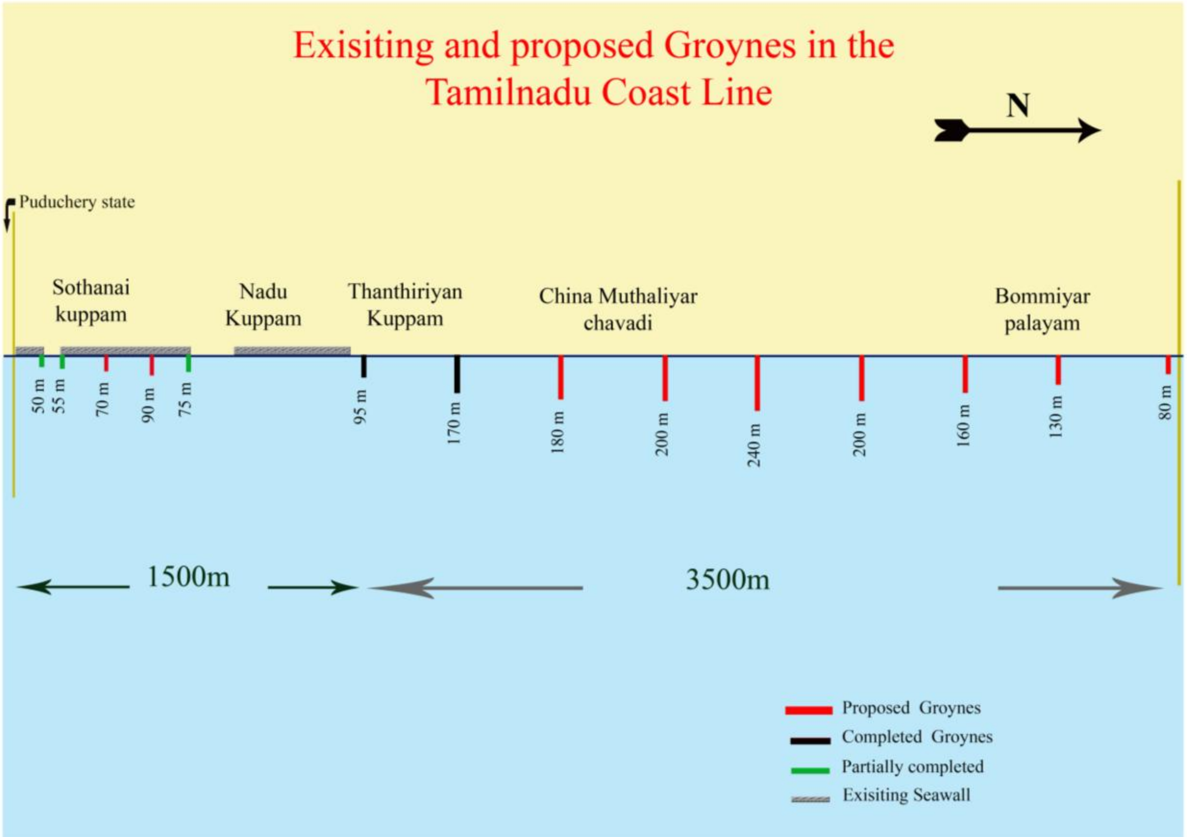


Figure 6. Existing and proposed coastal structures along the Tamil Nadu coast (Source: PWD, Tamil Nadu)

Figure 7. Construction of groins along the Pondicherry coast

In spite of considerable efforts made by the Government of Pondicherry/Tamil Nadu states to protect the eroding coast from natural and manmade activities the issue is not resolved because the measures are localized in nature and the problem has invariably shifted to the coastal villages in the north. Therefore, a scientific understanding of the local coastal processes was undertaken by NIOT to investigate the cause of the problems and to provide a technical solution for restoring the affected coastline.

4.0 PRESENT STATUS OF THE COAST

The developmental activities like the construction of ports and harbours, shore protection measures, expansion of beaches for tourism activities etc., causes changes in the geomorphology of the coastal areas, resulting in periodical erosion of the beaches and loss of human habitats like fishermen villages. Before planning any coastal protection measures, the present status of the coast needs to be assessed. Considering the northern breakwater as the starting point, various coastal protections structures implemented by Pondicherry / Tamil Nadu governments are enumerated and detailed in Table 2.

Table 2. Status of Pondicherry coast from northern breakwater to Kanakachettikulam

Sno	Coastal Morphology	Length (m)	Chainage (km)	Villages	Zone
1	North	0	0.00	Port Area	Zone A (1.8 km)
2	Seawall	575	0.58		
3	Sandy Beach	130	0.71		
4	Seawall	105	0.81		
5	Sandy Beach	70	0.88		
6	Seawall	70	0.95		
7	Sandy Beach	65	1.01		
8	Seawall	800	1.81	Dubrayapet	
9	Jetty	5	1.82		
10	Sandy Beach	30	1.85		
11	Groin	25	1.87		
12	Seawall	1835	3.71	Township	Zone B (4 km)
13	Groin	15	3.72		
14	Sandy Beach	50	3.77		
15	River Mouth	20	3.79		
16	Sandy Beach	5	3.80		
17	Groin	15	3.82	Kuruchikuppam	
18	Seawall	370	4.18		
19	River Mouth	10	4.19		
20	Seawall	95	4.29		
21	Sandy Beach	20	4.31		
22	Seawall	465	4.77	Vaithikuppam	
23	Sandy Beach	85	4.86		
24	Seawall	555	5.41	Sollitandavankuppam	
25	Sandy Beach	95	5.51		
26	Seawall	285	5.79		
27	Groin	15	5.81	Sothanaikuppam	Zone C (2.5 km)
28	Sandy Beach	80	5.89		
29	Groin	15	5.91		
30	Seawall	500	6.41	Kottakuppam	
31	Groin	10	6.42		
32	Sandy Beach	185	6.60		
33	Groin	15	6.61	Nadukuppam	
34	Seawall	475	7.09		
35	Sandy Beach	65	7.15		
36	Groin	20	7.17	Thanthriyankuppam	
37	Seawall	345	7.52		
38	Groin	10	7.53		
39	Sandy Beach	715	8.24	Chinnamudalaiyar chavadi	
40	Seawall	65	8.31		
41	Sandy Beach	4640	12.95	Periyamudalaiyarchavadi, Bommiyarpalayam & Pillaichavadi	Zone D (8.2 km)
42	Seawall	165	13.11	Chinna Kalapet	
43	Sandy Beach	3450	16.56	Kalapet & Kanakachettikulam	

The coastal stretch of 18.5 km length from Pondicherry port on south to Kanakachettikulam on north was divided into four zones based on protection schemes already implemented (Figure 8).

- Zone A - The coastal stretch on either side of the Pondicherry port,
- Zone B - The coastal stretch which mostly protected by seawall
- Zone C - The stretch covered by Groins fields
- Zone D - The open coast with almost sandy beaches, subjected to localised erosion at some places.

The shoreline change analysis along coastal stretch of 18 km was carried out using Remote sensing data and GIS. The images of 1991, 2000, 2006 and 2010 were used to delineate spatial/temporal changes of shoreline.

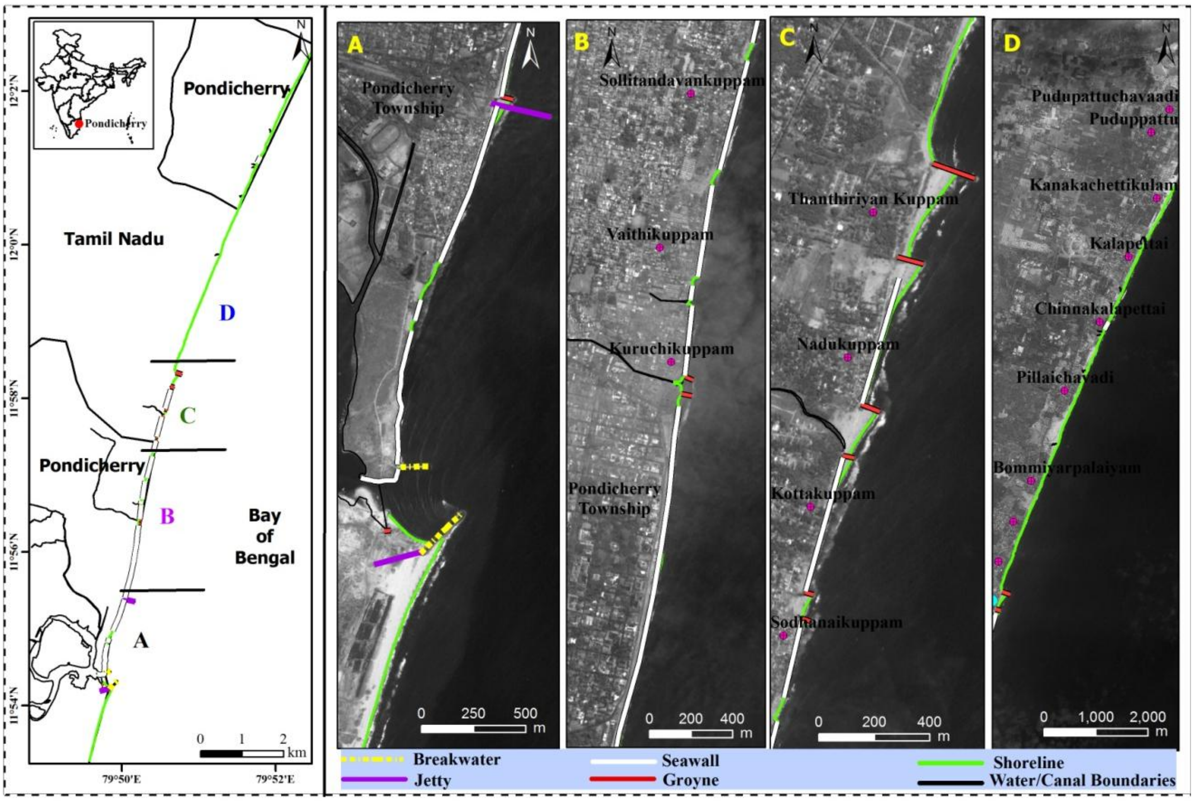
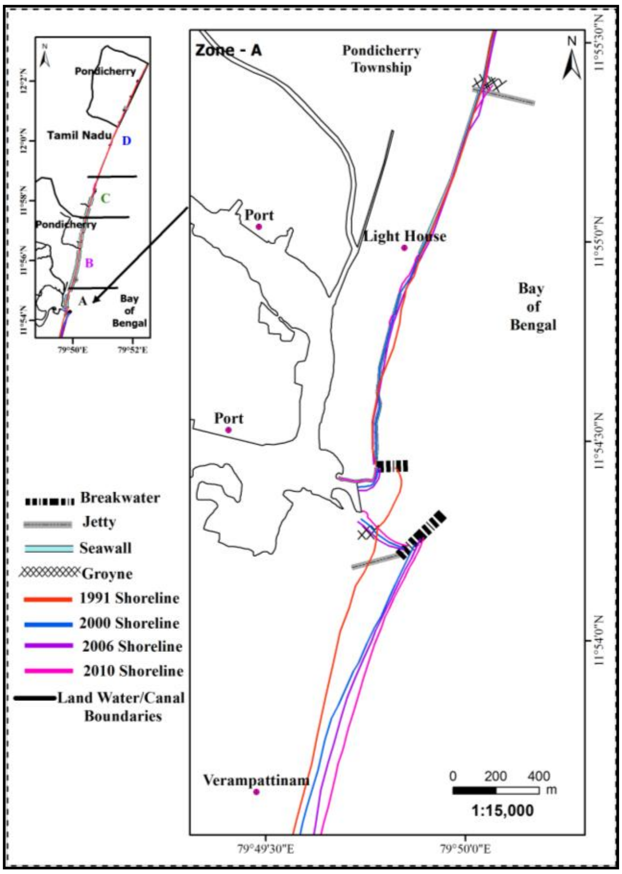


Figure 8. Classification of Pondicherry coast into zones based on structures built along the coast (A: Port Region B: Seawall region C:Groin region D: Open Coast. (Satellite Image Source: Cartosat 2010)

4.1 Zone A (Pondicherry Port)

A coastal stretch of 3.5km at Pondicherry harbour was analysed for its temporal changes using satellite data and field data collected during February 2012 by RTK GPS. The southern coast is accreting with maximum accretion to an extent of 180m during 1991 - 2010, while northern coast is eroding with a maximum erosion of 40m. Northern coast is protected with seawall, leaving gap of 270m for operation of fishing activities. It is observed that sediments started bypassing the southern breakwaters. (Figure 9 & 10). The decadal changes in this zone between 1991-2000 and 2000-2010 are given in Table 3, which shows maximum accretion of about 180 m at south of the breakwater.



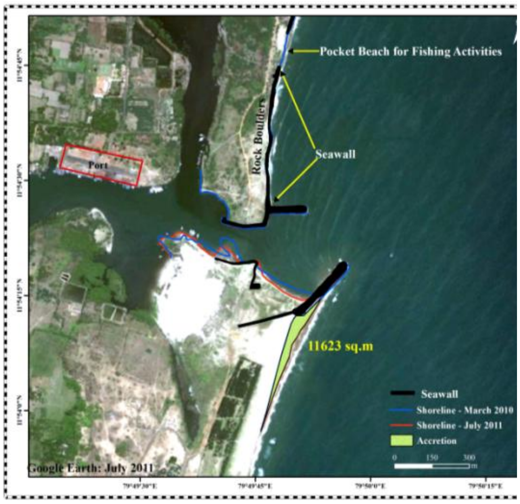


Figure 9. (b) Accreted Coastal area in Zone A. (Google Earth 2011)

Figure 9. (a) Shoreline change analysis at Zone A

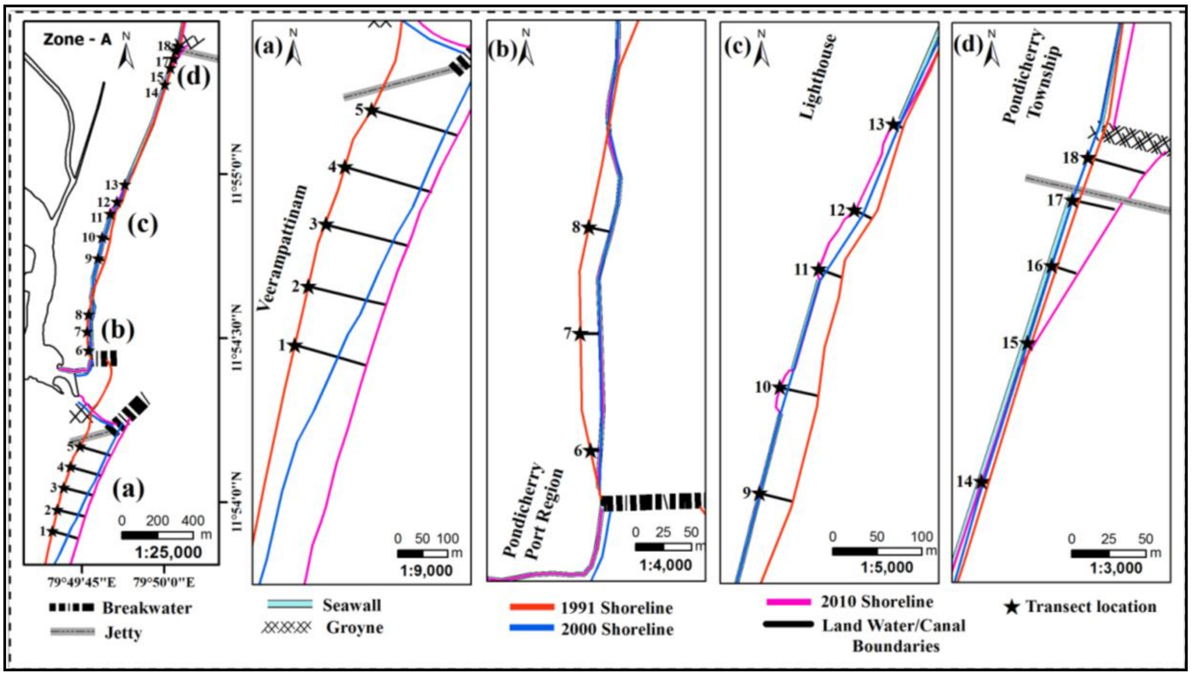


Figure 10. Temporal changes of shoreline (1991 - 2010) in Zone A

Table 3. Decadal shoreline change analysis from 1991 - 2000 and 2000 - 2010 at Zone A

ID	Length of the Coastline (m)	Shoreline Change (1991 - 2000) in m	Shoreline Change (2000 - 2010) in m	Total Shoreline Change (1991 - 2010) in m	Remarks
1	(a) 500	90	60	150	Accretion
2		120	40	160	
3		140	30	170	
4		155	20	175	
5		155	25	180	
6	(b) 200	10	4	14	Accretion
7		17	5	22	
8		20	6	26	
9	(c) 440	-40	0	-40	Erosion
10		-35	-5	-40	
11		-20	-5	-25	
12		-10	-10	-20	
13		-5	-5	-10	
14	(d) 230	-3	-2	-5	Erosion
15		-3	5	2	Accretion
16		-2	15	13	
17		-4	28	24	
18		-5	40	35	

4.2 Zone B (Seawall)

There is no significant change in position of shoreline due to the presence of seawalls in this region. Though, the seawall protected the coast under threat, it restricted beach access to tourist and fishermen. The shoreline analysis from 1991 - 2010 (Figure 11) no significant variation in the coastline except near Kuruchikuppam channel mouth separated by 70 m apart. Two groins (50 m length) separated by 70m built at Kuruchikuppam resulted in the formation of a beach, which is used by fishermen for operation of boats. The decadal changes in this zone between 1991-2000 and 2000-2010 are given in Table 4, which shows maximum erosion of about 13 m at south of Sollitandavankuppam village.

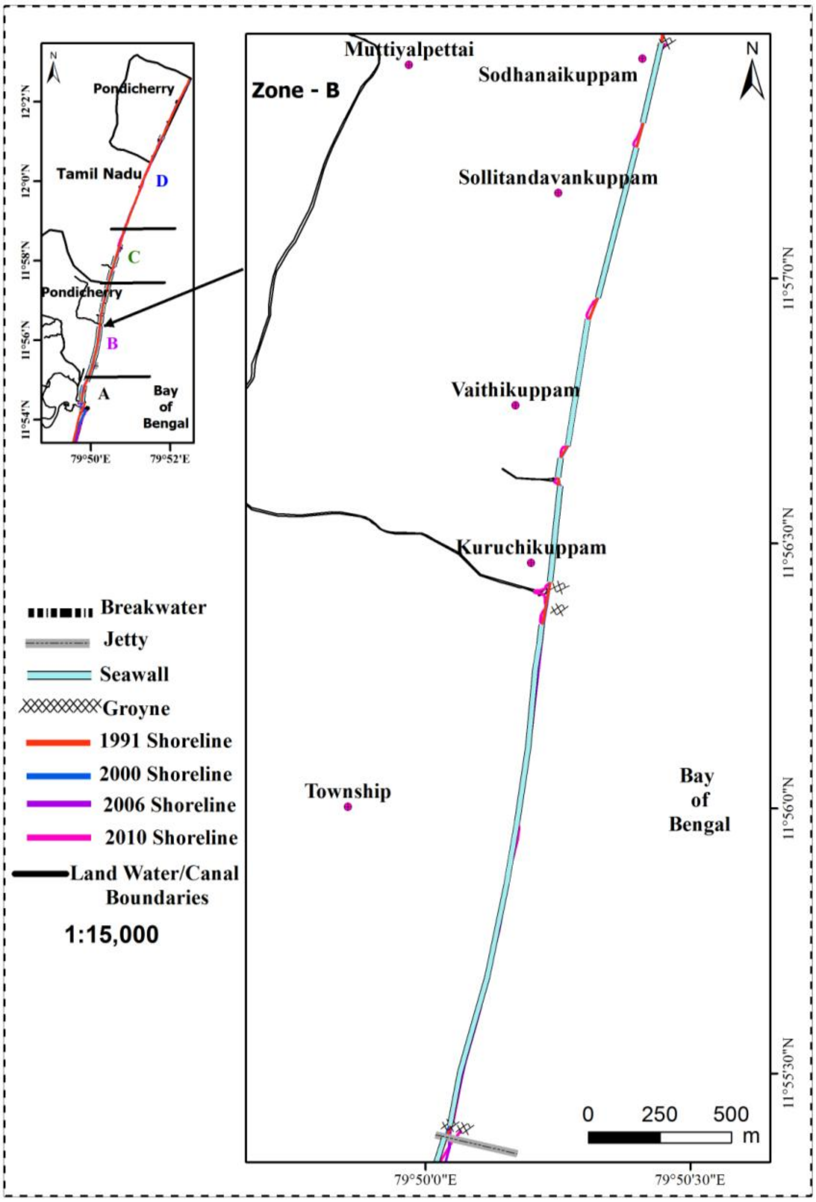


Figure 11. Shoreline changes analysis at Zone B (1991-2010)

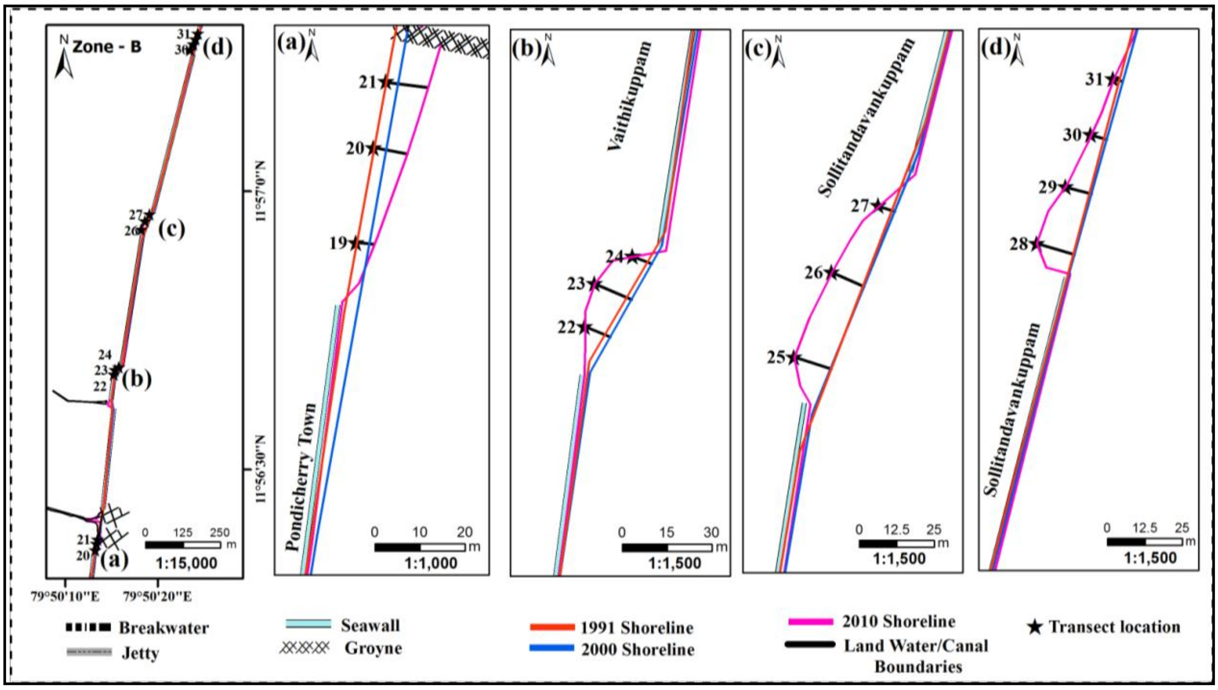


Figure 12. Temporal changes of shoreline (1991 - 2010) in Zone B

Table.4 Decadal shoreline change analysis from 1991 - 2000 and 2000 - 2010 at Zone B

ID	Length of the Coastline in m	Shoreline Change (1991 - 2000) in m	Shoreline Change (2000 - 2010) in m	Total Shoreline Change (1991 - 2010) in m	Remarks
19	(a) 35	3	2	5	Accretion
20		3	5	8	Accretion
21		3	10	13	Accretion
22	(b) 30	2	-9	-7	Erosion
23		2	-13	-11	Erosion
24		2	-6	-4	Erosion
25	(c) 55	-2	-11	-13	Erosion
26		2	-11	-9	Erosion
27		2	-5	-3	Erosion
28	(d) 60	2	-13	-11	Erosion
29		2	-9	-7	Erosion
30		2	-5	-3	Erosion
31		2	-4	-2	Erosion

4.3 Zone C (Groins)

Groin field was built to stabilize the beach in this part of coastal stretch for a length of 1.2 km (Figure 13) with six groins of varied length and spacing. It was reported that the northerly and southerly drift along Pondicherry coast is 1.0 x 10^6 m^3 and 0.4 x 10^6 m^3 respectively, resulting net northerly drift of 0.6 x 10^6 m^3 (S. Neelamani and R.Sundaravadivelu 2006). The recent analysis of shoreline change indicate these numbers are on higher side and the estimated net northerly drift would be around 0.2 to 0.28 x 10^6 m^3 per year. In the absence of beach nourishment, the performance of groin field and its down drift impacts depends on gross/net littoral drift rates. The decadal changes in this zone between 1991-2000 and 2000-2010 are given in Table 5, which shows maximum accretion of about 86 m at south of the longest groin at Thandirayankuppam.

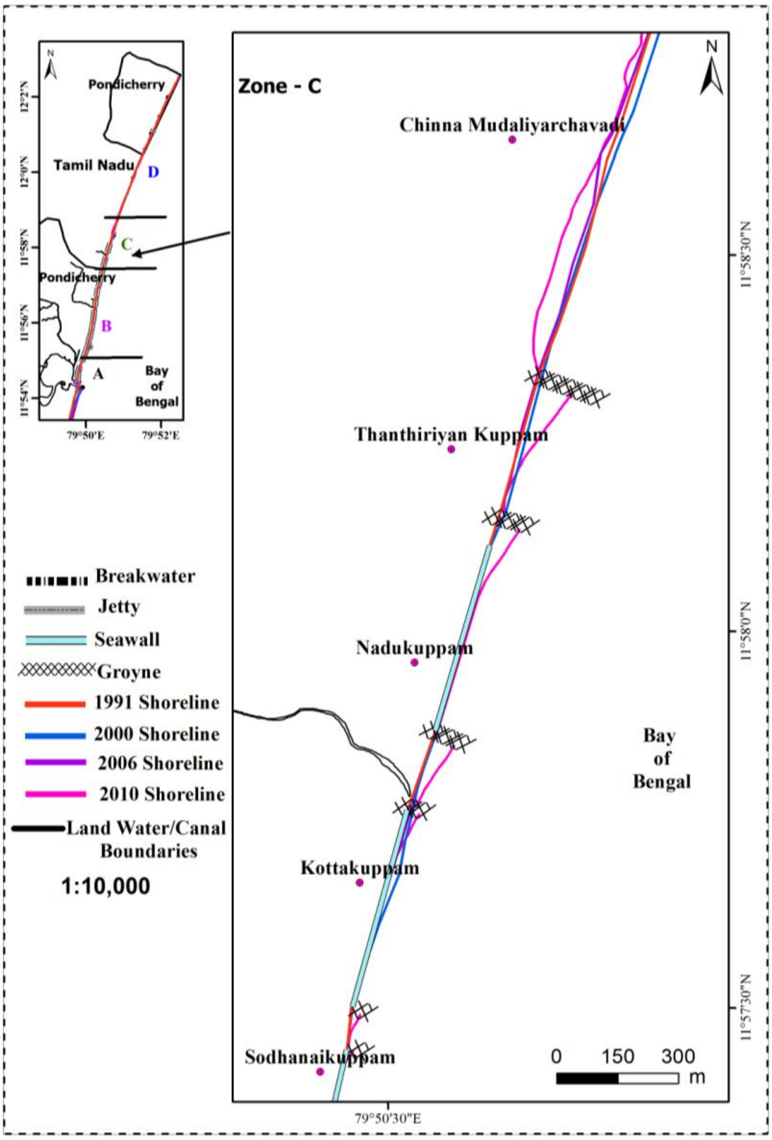


Figure 13. Shoreline change analysis at Zone C

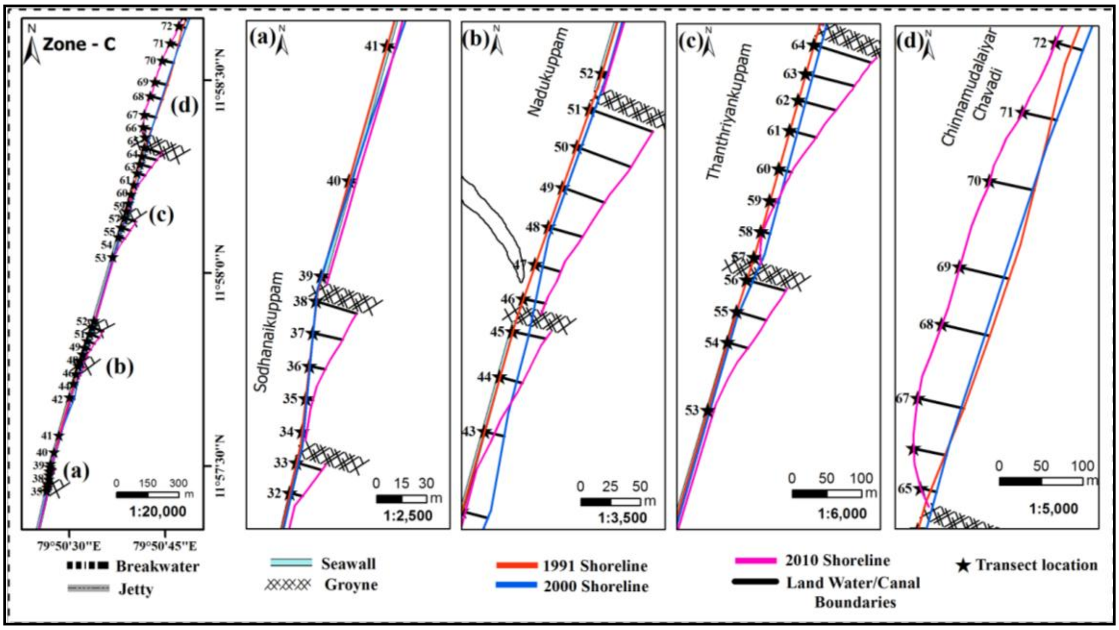


Figure 14. Temporal changes of Shoreline (1991 - 2010) in Zone C

Table 5. Decadal Shoreline Change analysis from 1991 - 2000 and 2000 - 2010 at Zone C

ID	Length of the Coastline in m	Shoreline Change (1991 - 2000) in m	Shoreline Change (2000 - 2010) in m	Total Shoreline Change (1991 - 2010) in m	Remarks
32	(a) 265	2	6	8	Accretion
33		2	15	17	
34		1	1	2	
35		1	3	4	
36		1	9	10	
37		0	18	18	
38		-1	25	24	
39		-1	5	4	
40		2	2	4	
41		5	-1	4	
42	(b) 385	22	-20	2	Accretion
43		17	-8	9	
44		15	5	20	
45		13	14	27	
46		10	8	18	
47		6	16	22	
48		3	26	29	
49		3	34	37	
50		4	45	49	
51		4	52	56	
52		4	1	5	

53	(c)545	3	5	8	Accretion
54		4	26	30	
55		4	40	44	
56		9	49	58	
57		12	-3	9	
58		13	-10	3	
59		13	-3	10	
60		12	7	19	
61		11	28	39	
62		10	45	55	
63		10	61	71	
64		10	76	86	

65	(d) 555	7	-19	-12	Erosion
66		2	-40	-38	
67		-4	-52	-56	
68		-6	-52	-58	
69		-7	-53	-60	
70		-2	-52	-54	
71		5	-41	-36	
72		14	-33	-19	

Although as many as 27 fundamental parameters govern the beach processes at a groin field, four non-dimensional quantities are prominent in controlling groin field performance as: (1) bypassing, parameterized by the ratio of depth at groin tip to incident wave height; (2) ratio of net to gross longshore transport rates, (3) ratio of groin separation distance to groin length, and (4) structure permeability. The amount of material interrupted by a groin is dependent on groin length and spacing of groins. The effectiveness of groin structures relies on the availability of littoral material to fill the groin compartments, and/or a amount of material to be placed for nourishment in these compartments as part of beach nourishment.

Groin structures can be expected to cause adverse impact on the downdrift property if the supply of sediment is low. It is recognised that groins should be used only to maintain existing conditions, rather than enhancing beach volume or eliminating erosion. Poor designs and lack of understanding of their functional design, or failure to implement the correct construction sequence, or failure to fill up the groin compartments with sand during construction, or improper cross-sectional shape are responsible for adverse affects. However, when properly designed, constructed and combined with beach nourishment, groins can function effectively under certain conditions, particularly increasing the fill life of renourished beaches. But this should be used only after exhausting all other available options for restoration. The groin field as shown in Figure 15 (6 groins) built along the coast of Tamil Nadu neighbouring Pondicherry was analyzed for its performance.

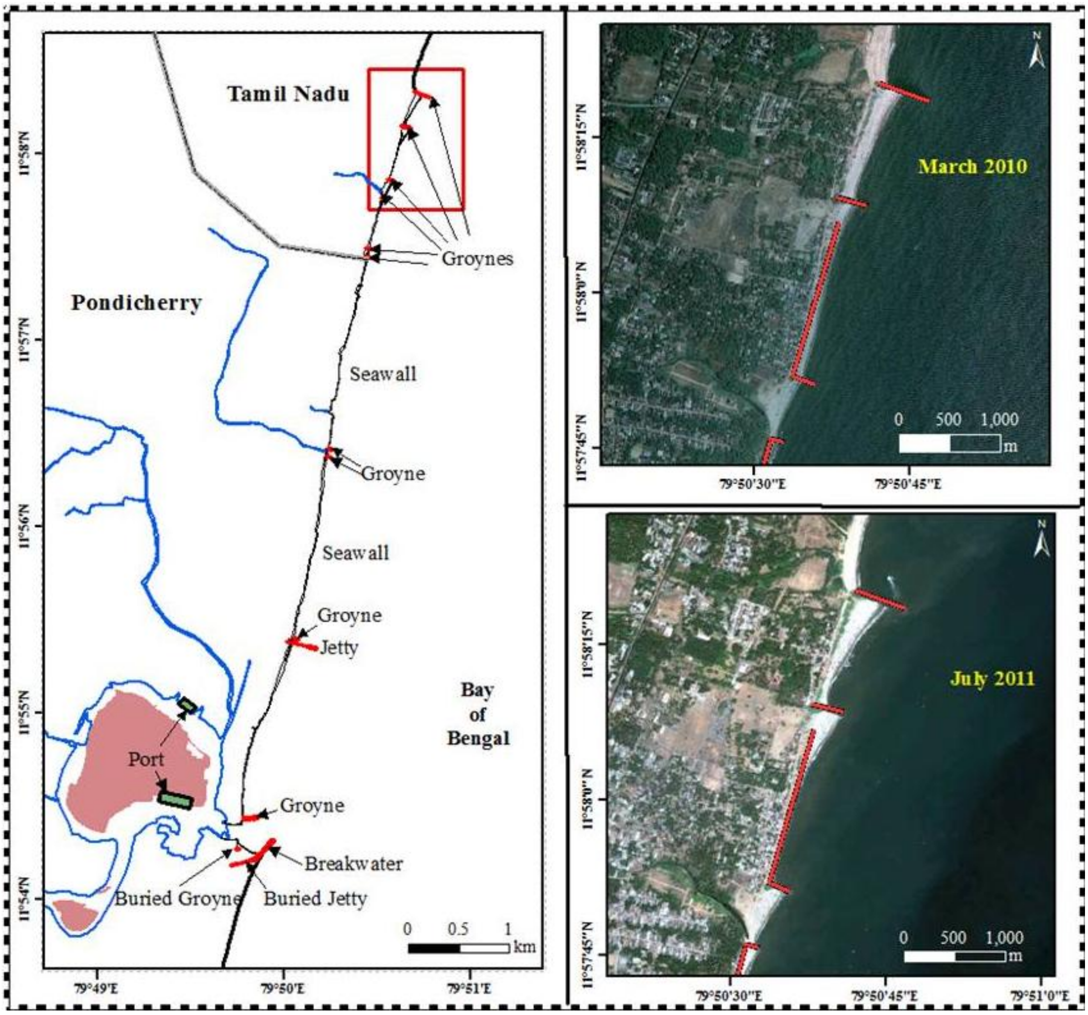
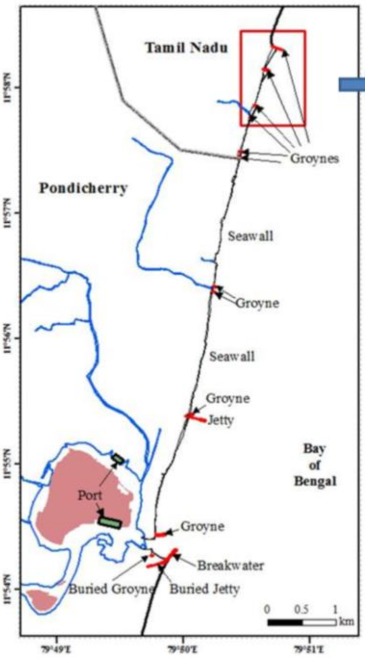


Figure 15. Short term shoreline change analysis (2010 - 2011) of groin region

In order to assess the functional performance of groins, 3 groin compartments (G1-G2, G2-G3 and G3-G4) of varying size were analysed as shown in Figure 16. The groin compartment G1- G2 performed well in relation to spacing and length of groin. The sand accumulation in G1-G2 compartment shows its performance, where as the increased spacing between G2 - G3 resulted in decrease in sand accumulation.



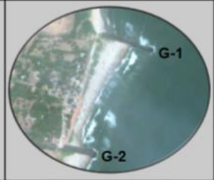
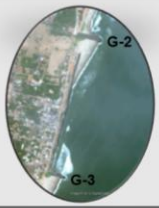
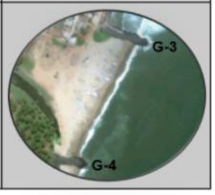
Sno	Spacing between groins (m)	Length of groins (m)	Status as on July 2011
Groin 1-Groin 2	340	160 (G-1) 100 (G-2)	
Groin 2- Groin 3	530	100 (G-2) 75 (G-3)	
Groin 3- Groin 4	170	75 (G-3) 45 (G-4)	

Figure 16. Performance of groin field at Thandirayankuppam village

A beach area formed between G1 - G2, G2 - G3 and G3 - G4 is 1496 sq.m, 4617 sq.m and 4155 sq.m respectively. Some variation in beach formation is noticed during SW and NE monsoon, which indicates that drift during the NE monsoon is also significant. Maximum erosion is noticed north of the northern groin (G1) at Chinnamudalaiyar Chavadi to an extent of 7678 sq.m (Figure 17).

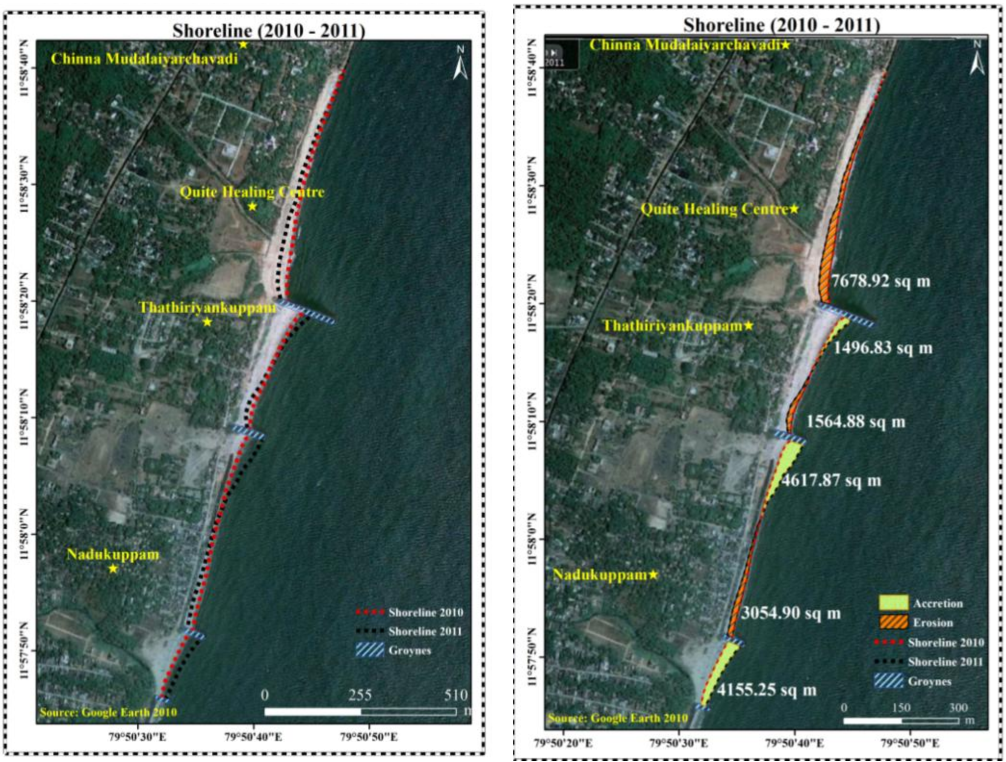
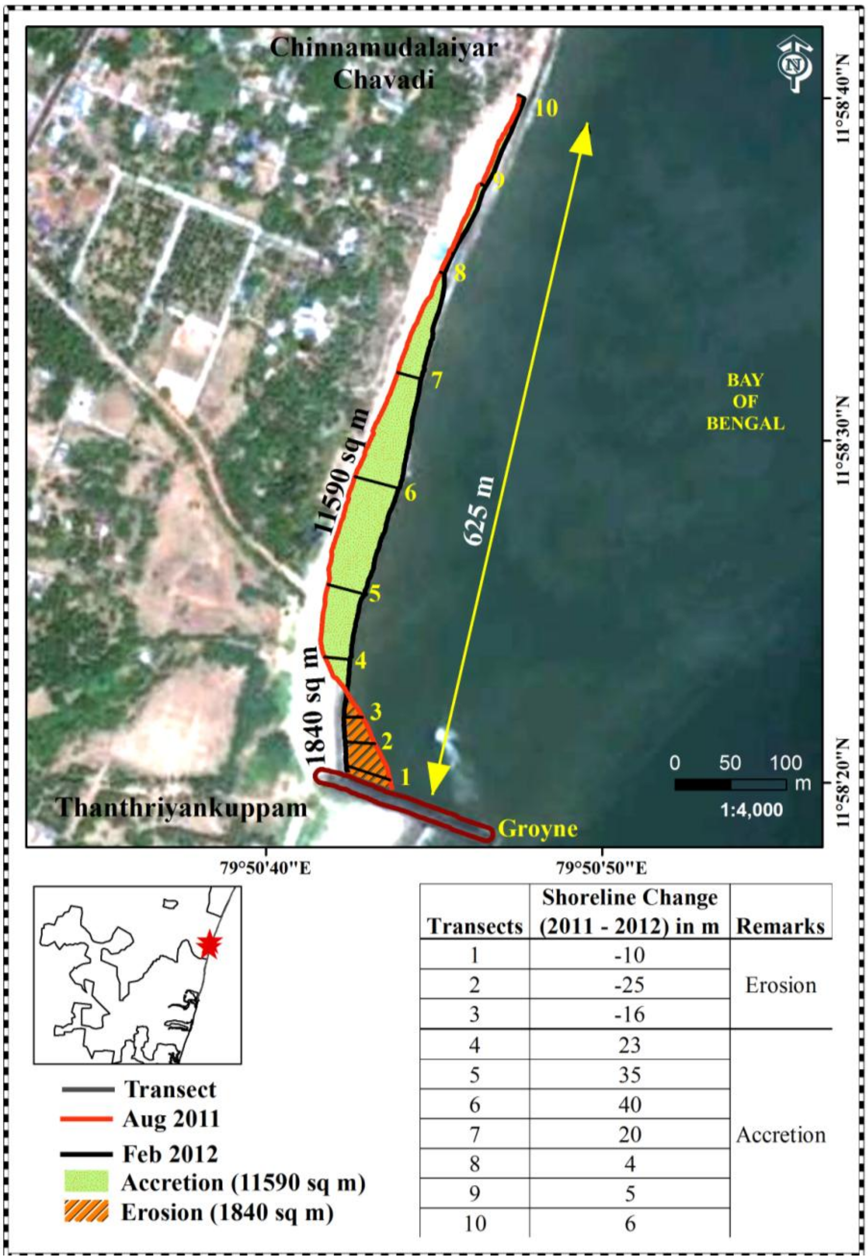


Figure 17. Eroding and accreting coast of Zone C from 2010 to 2011

The shoreline north of longest groin (170 m) at Thandirayankuppam indicates an erosion of 60 m in 3 months immediately after construction of groin. The erosion on north extends up to a distance of 3 km, while accretion up to 2 km during period of 2006-2011, the details are shown in Figure 18. The long groin resulted in gain of beach to an extent of 4800 m^2 in south and loss of beach to an order of 17,000 m^2 in north during period of one year. Before construction of groin, the seasonal variation of shoreline is about 11 m and it was increased to 30 m after construction of groin. In addition to seasonal and manmade shoreline changes, the episodic events like low pressure system formed during Aug/Sep, of 2007 has resulted in further increased erosion to an extent of 15 m.

Figure 18. Shoreline changes at northernmost long groin (2007-2011)

Further the coastline length of 625 m north of the northern most groin at Chinnamudaliar Chavadi region was monitored using Trimble GeoXT during August 2011 and February 2012. The coastline experienced 17 m erosion immediately north of the groin during 2011 to 2012. An area of 11590 sq m beach was lost up to distance of 560 m north (towards Chinnamudalaiyar Chavadi Figure 19). The long term (1991 – 2010) shoreline analysis results shows that this region undergoes erosion only after construction of the longest groin in the north of Thadirayankuppam. During NE monsoon of 2011, portion of beach lost was regained due to southerly drift, which is supplemented by sand bypassing from the groin. The above analysis clearly shown that implementation of groin without nourishment can cause adverse impact on adjacent coast.



Transects	Shoreline Change (2011 - 2012) in m	Remarks
1	-10	Erosion
2	-25	
3	-16	
4	23	Accretion
5	35	
6	40	
7	20	
8	4	
9	5	
10	6	

Figure 19. Chinnamudalaiyar Chavadi erosion and accretion results (2011 - 2012)

Also in the absence of seawall, possible erosion immediate north of G3 could not be ruled out to readjustment of coastline due to construction of groins as shown in Figure 20. The performance of groins to protect the coast also depends on availability of sand in littoral zone. A comparative analysis of groin field at Royapuram and Pondicherry is shown in Figure 21, which indicates Pondicherry coast is relatively better compared to Royapuram coast due to availability of sand in the littoral zone.

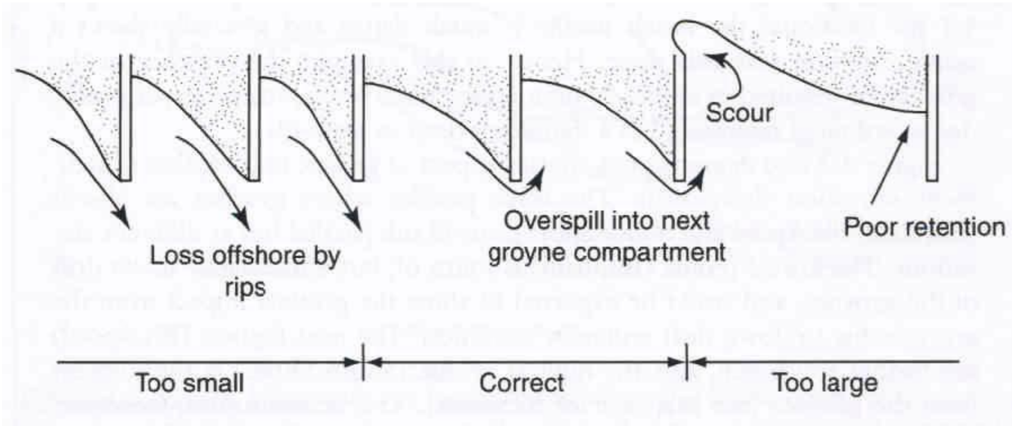


Figure 20. Functional performance of groins in relation to length and spacing

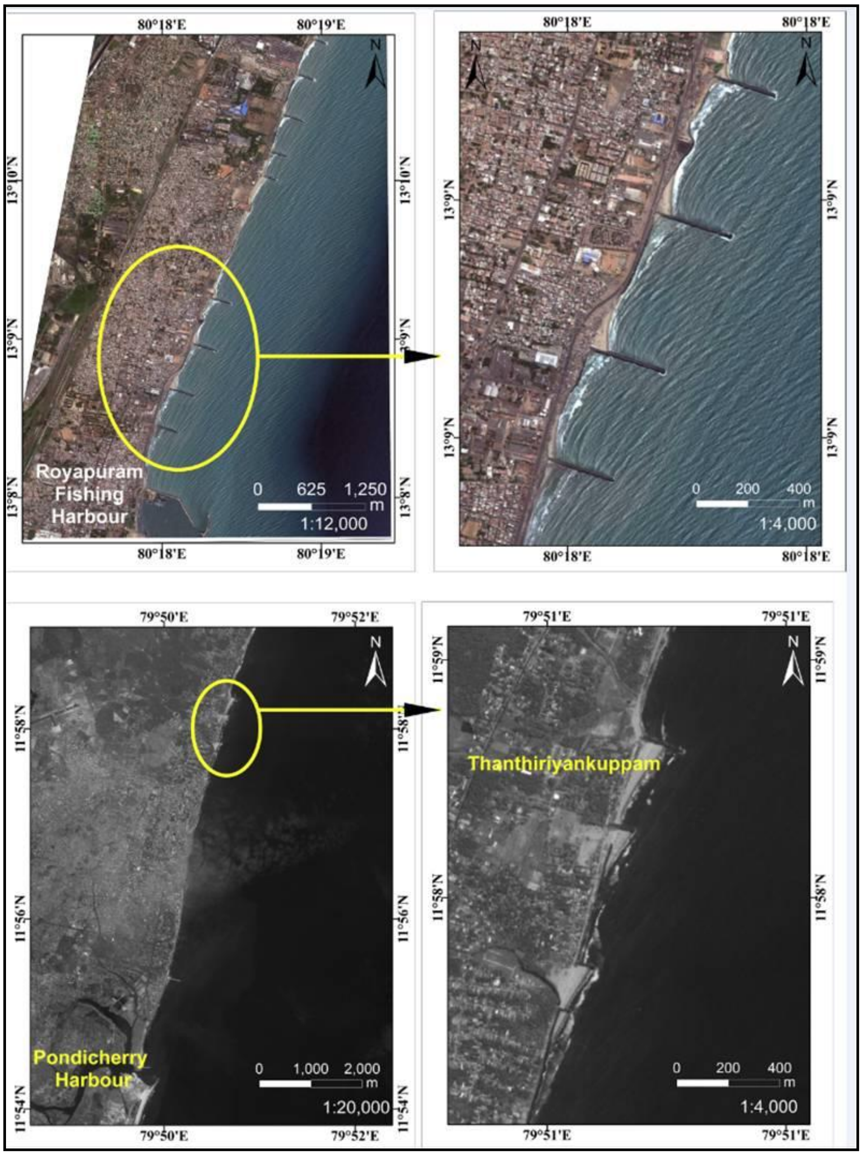


Figure 21. Performance of groin field at two independent sites - Royapuram and Pondicherry

4.4 Zone D (Open Coast)

This coastal stretch extends from Periyamudalaiyar Chavadi to Kanakachettikulam which is about a 8.2 km open coast with full of sandy beaches. A 165 m Rubble Mound seawall was constructed at Chinnakalapettai village during 2008. The long term shoreline analysis (1991 - 2010) shows that the maximum erosion (26 m) is observed from Periyamudalaiyar Chavadi to Bommiyarpalayam (Figure 22) , where PWD, Tamil Nadu has proposed as a protective measure a series of groins. The coast north of seawall at Chinnakalapettai village shows 16 m erosion (Figure 23). There is no significant erosion / accretion in Kalapettai and Kanakachettikulam villages (Table 6).

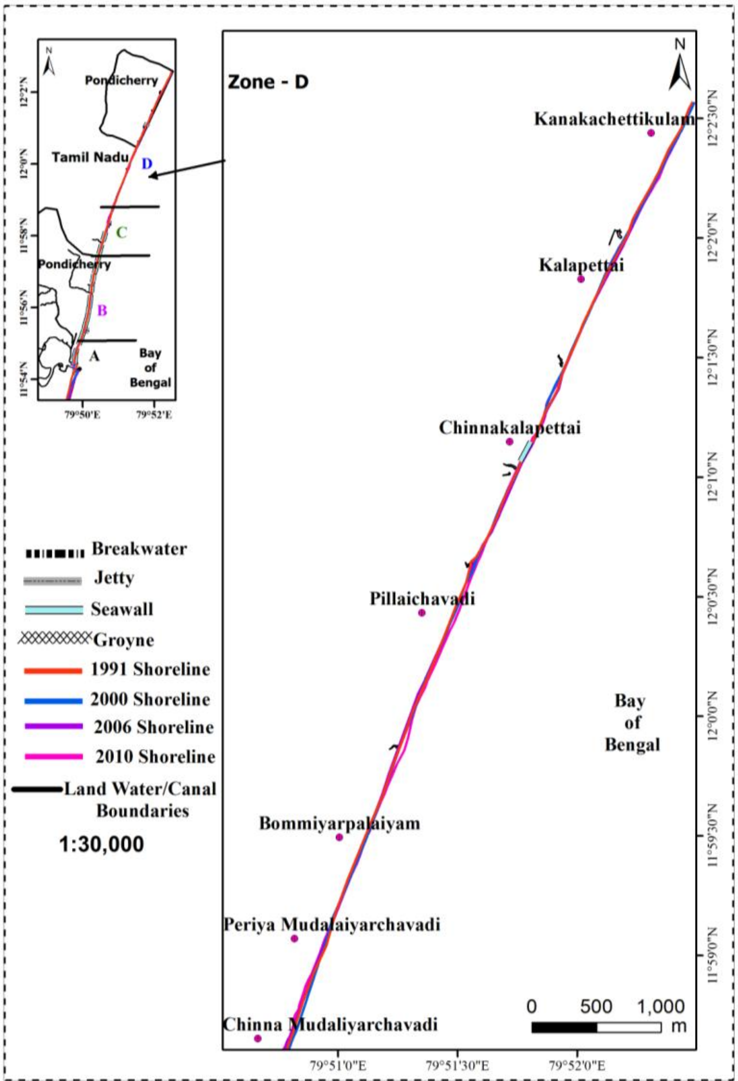


Figure 22. Shoreline change analysis at open coast (Zone: D)

It is important to note that the area just north of the Thandirayankuppam groins has shown that localised shoreline change taking place in the same year is of a much larger magnitude. Localised shoreline change in this case recession and erosion of the shoreline of up to 50 m was recorded during the same year. While the long term shoreline change may be or a lower value (26 m as observed above) the localised, seasonal change, is of great importance as it results in maximum damage to the coastal environment, property and livelihoods. The groins have therefore resulted in greater variation and change of the shoreline demonstrating the shoreline is now more unstable than before. In the long term, groins therefore make the overall shoreline more unstable.

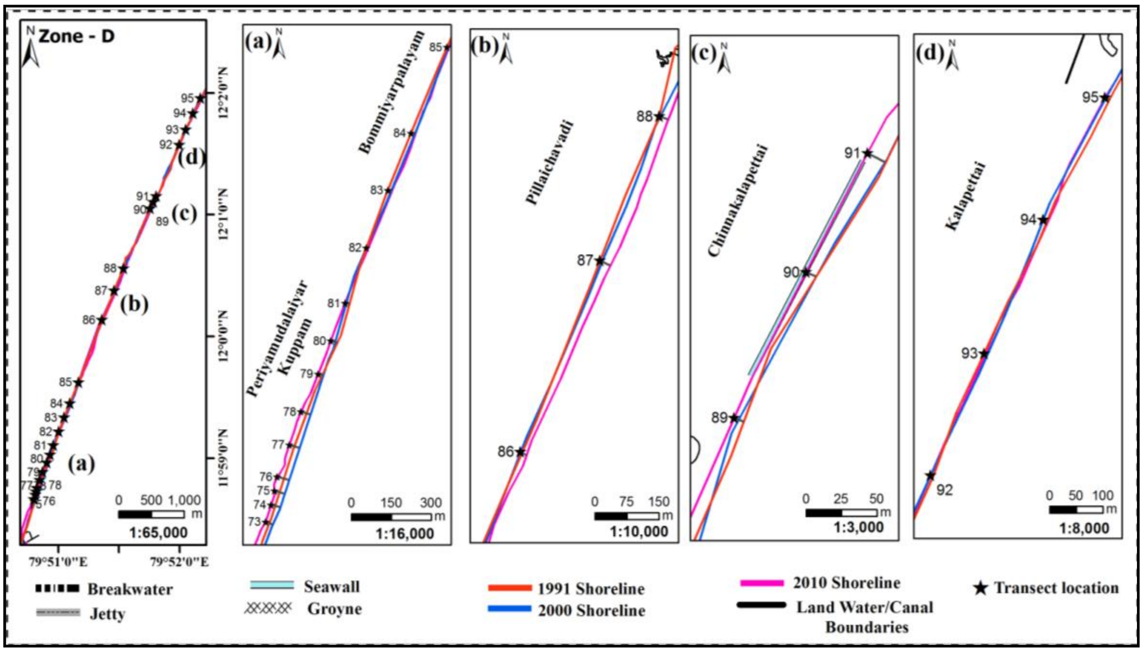


Figure 23. Temporal changes of shoreline (1991 - 2010) in Zone D

Table 6 . Decadal shoreline change analysis from 1991 - 2000 and 2000 - 2010 at Zone D

ID	Length of the Coastline in m	Shoreline Change (1991 - 2000) in m	Shoreline Change (2000 - 2010) in m	Total Shoreline Change (1991 - 2010) in m	Remarks
73	(a) 1800	15	-30	-15	Erosion
74		20	-35	-15	
75		20	-40	-20	
76		20	-45	-25	
77		20	-40	-20	
78		15	-35	-20	
79		5	-20	-15	
80		-8	-18	-26	
81		-12	-4	-16	
82		2	5	7	Accretion
83		10	5	15	
84		13	2	15	
85		3	3	6	

86	(b) 850	4	-16	-12	Erosion
87		5	21	26	Accretion
88		2	22	24	
89	(c) 250	3	4	7	Accretion
90		-2	-6	-8	Erosion
91		-2	-14	-16	
92	(d) 775	-4	-1	-5	Erosion
93		6	-3	3	Accretion
94		-7	9	2	
95		-7	-2	-9	Erosion

5.0 LONG-TERM SHORELINE CHANGES

The long-term shoreline changes were analysed using data from toposheets and satellite imageries for the period of 1972-1991, 1991-2000 and 2000-2010 to assess the decadal changes. The shoreline changes during the period 1972-1991 indicates erosion at Pondicherry port, Pondicherry township and few villages of Villupuram district (Figure 24a). During 1991-2000, medium erosion/accretion was noticed at many places along the coast (Figure 24b). But, during 2000-2010, significant erosion was noticed at many places along Pondicherry and Tamil Nadu coast and the erosion areas are extended to north of Pondicherry (Figure 24c).

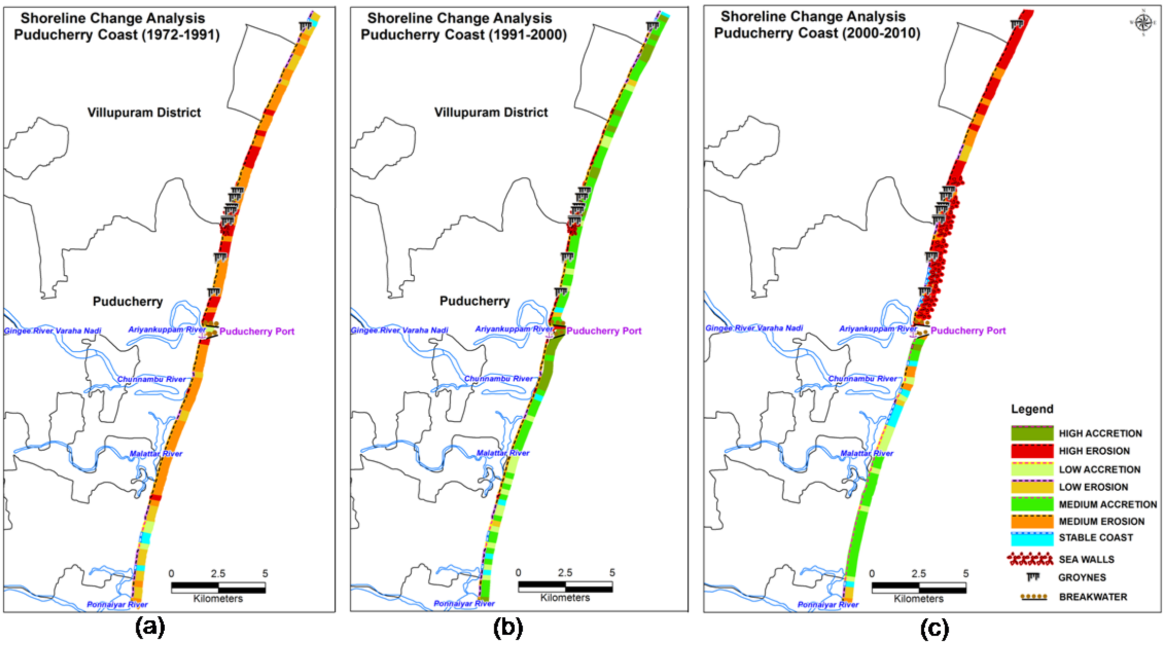


Figure 24. Long-term shoreline changes along Pondicherry and Villupuram Districts: (a) during 1972-1991, (b) during 1991-2000 and (c) during 2000-2010

Prediction of shoreline change in the vicinity of coastal structures differs from reality due to lack of long-term data on beach profiles (Plan & Cross section) and forcing functions such as waves and currents. Tamil Nadu State Public Works Department monitors the monthly shoreline oscillations since 1978 under the project 'crest of berm' where a simple distance measurement technique was used to measure the distance of berm crest from a reference point. This method forms an essential input for studying long-term behaviour of the coast at a particular location and if it is linked with remote sensing data, spatial linkage can be established among observation points monitored by PWD.

The field data available at two locations, viz., Devanampattinam in south (18 km from Pondicherry port) and Oyyalikuppam in north (80 km from Pondicherry port) was used to relate remote sensing data. Though, these locations do not represent the shoreline behaviour of Pondicherry coast, it can be used as indicator for long-term shoreline change analysis. The shoreline changes at Oyyalikuppam and Devanampattinam is shown in Figures 25 & 26 respectively. The natural shoreline oscillation is about 10 m at both the stations between 2002-2007. After 2007, significant erosion noticed at Oyyalikuppam which is also observed from short-term analysis along Pondicherry coast. The data clearly suggests that Pondicherry coast experiences natural oscillation of 10 m, which can increase up to 20 m when episodic events occur due to low pressure or cyclonic storm.

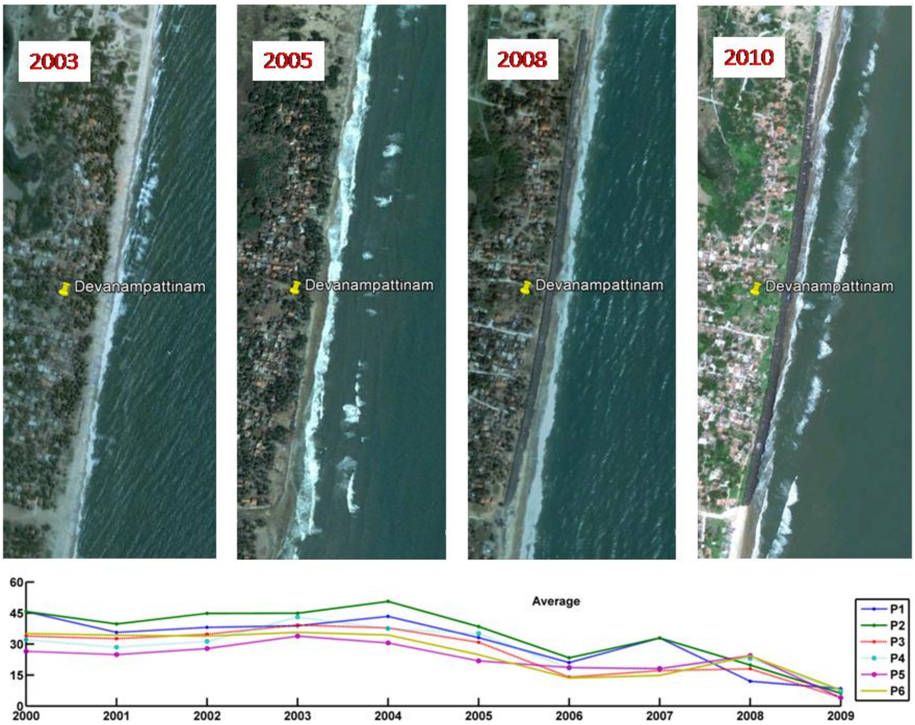


Figure 25. Shoreline oscillations at Devanampattinam based on crest of berm data (2000-2009)

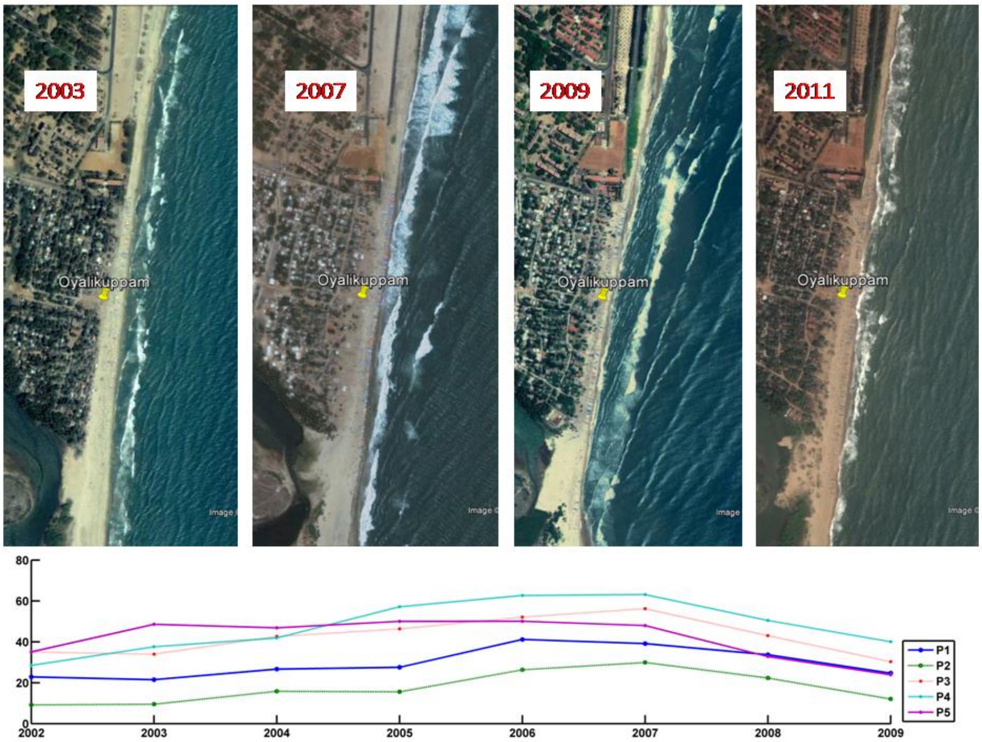


Figure 26. Shoreline oscillations at Oyyalikuppam based on crest of berm data (2002-2009)

6.0 MONITORING OF COASTAL PROCESSES

Coastal processes along the Pondicherry coast were monitored to understand the dynamics of the coast, covering both the Pondicherry and Tamil Nadu regions. The measurement scheme covers a coastal stretch of length 18 km (from Pondicherry Port to Kalapettai village), where water levels, waves, coastal and nearshore currents were monitored over a period of 15 days for constructing numerical models. The location of observations is shown in Figure 27 and parameters monitored were indicated in Table 7.

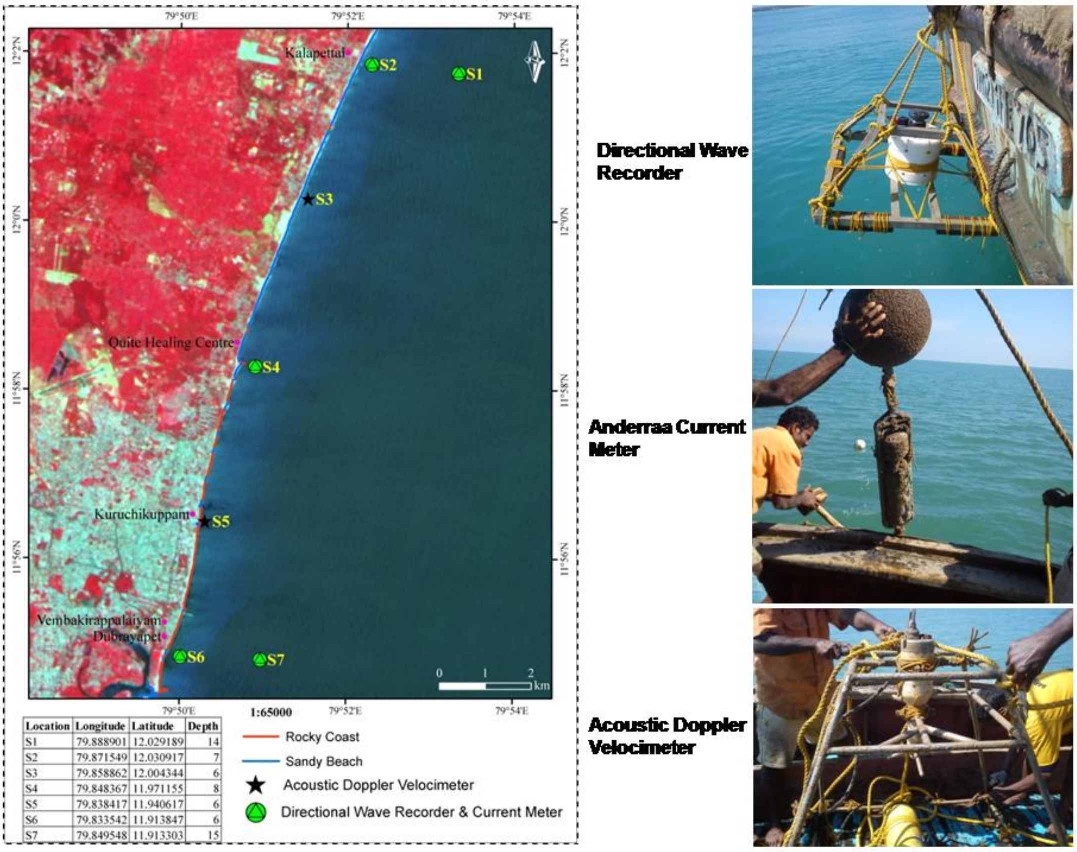


Figure 27. Locations and instruments used for observations along Pondicherry coast

Table 7. Details of parameters and instruments used for monitoring coastal processes

S No.	Parameter	Instrument	No. of locations
1.	Tide and wave	Directional Wave Recorder (Valeport)	5
2.	Coastal currents	Recording Current Meter (Aanderaa)	5
3.	Wave orbital velocities	Acoustic Doppler Velocimeter (Sontek)	2
4.	Bathymetry survey	Echosounder (ODOM)	17km X 5 km
6.	Bed sediments	Grab Sampler	49
7.	Suspended sediments	Water Samplers, Niskin	40

The northern and southern boundaries of the study area were monitored by two cross-shore transects (S1-S2 & S6-S7) perpendicular to coast and nearshore processes were monitored with two ADV (S-3 & S-5) as shown in Figure 27. The wave and tide gauges were deployed along with current meters at boundaries (S1-S2, S6-S7) and location of instruments against total depth at each station is given in Table 8.

Table 8. Deployment details of instruments at various stations

Station ID	**Total water depth (m)**	**Tide Gauge depth (m) from surface**	**Current Meter depth (m) from surface**	**ADV depth (m) from surface**
S-1	13	13	6.5	-
S-2	7	7	3.0	-
S-3	4	-	-	3.5
S-4	9.5	9.5	5.0	
S-5	4	-	-	3.5
S-6	7	7	3.5	-
S-7	13	13	6.5	-

6.1 Bathymetry Data

Seabed morphology was mapped from near shore to 20m water depth using a single beam echo sounder during November 2010 and March 2011. The bathymetry survey was collected covering 17 km along shore (north to south) and 5 km cross-shore (east to west). The transducer was fixed at the boat along the portside with a 2m pipe and the DGPS antenna was mounted perpendicularly on top of it. The heave motion of the boat was measured using the sensor and corrections were made at real time for the entire survey period. DGPS Potential errors, such as vessel roll, pitch, and yaw, and time lag between the positioning sensor (GPS) and the sonar measurement, were recorded with on board instrumentation and incorporated into the post-processing procedure (USACE 2001). Care was taken to prevent/minimize other errors such as inaccurate alignment of sensors, transducer draft depth, and sound velocity measurements (USACE 2001). The area to be surveyed was marked with a grid spacing of 100 m on a satellite map and the line position was maintained by interfacing DGPS to PC based software (HYPACK). Since the coastal environment displays more variation in the cross-shore direction than the alongshore direction the transect survey was performed perpendicular to the shoreline. Tidal corrections were applied during post processing using measured tide data from DWR. The depth values were post processed, analyzed and interpolated using HYPACK MAX software.

6.2 Topographic Data

Topographic survey was carried out for the entire Pondicherry coast with 75 transects of 250 m horizontal spacing. Real Time Kinematic Global Positioning System (RTK-GPS) was used for near shore elevation data collection. RTKGPS survey is based on the use of carrier phase measurements which provides improved location accuracy, from the 15-meter nominal GPS accuracy to about 1 cm in case of the best implementations. The entire Pondicherry coast was surveyed using Trimble RTK GPS system. TRIMBLE R8 GNSS receiver used as a single reference station which provides the real-time corrections to the mobile unit TRIMBLE TSC 2. The reference base station was established at a known benchmark where the latitude, longitude and elevation were marked on the ground. The mobile unit was carried along the coast and the elevation data was recorded in the control unit. The land topography and sea bathymetry data were merged in GIS and resultant map is shown in Figure 28.

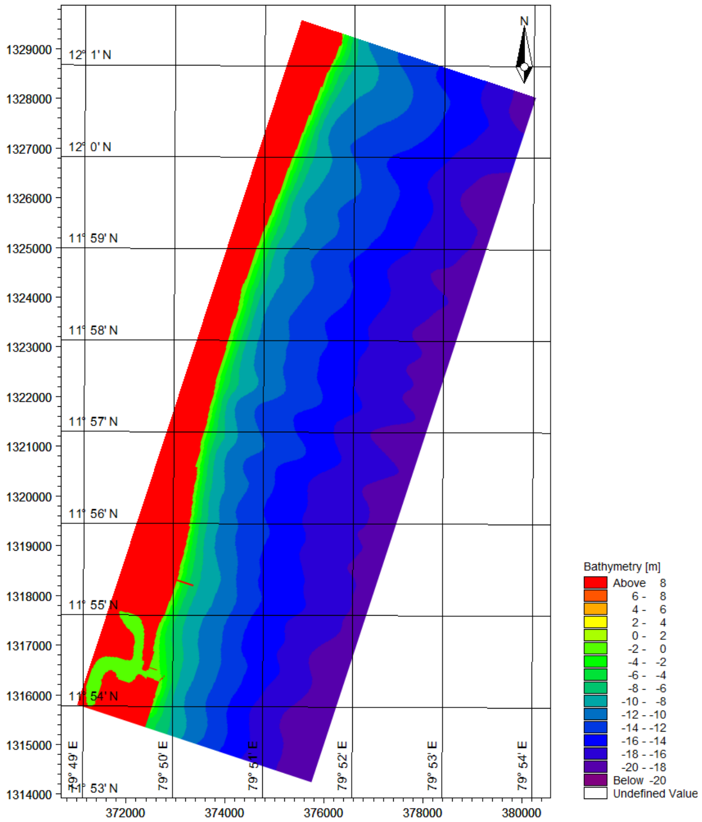


Figure 28. Surveyed bathymetry/topography along Pondicherry coast during 2011-2012

6.3 Tides and Tidal Analysis

Tides in Bay of Bengal are semidiurnal in nature as the sea level reaches its highest level in November and lowest in March along the south east coast of India, the tidal range in March varied between 0.5 m (neap tides) and 0.7 m (spring tides) whereas in November the range varied between 1.3 -1.0 m.

The observed tide at any given port is the result of many factors, including the response of the ocean basin to the tide producing forces, to the modifications of the tide due to shallow water effects of local embayments and rivers, to the regional and local effects of weather on water levels. The design water levels for Pondicherry are given below**:**

Mean High Water Spring	:	1.3 m
Mean High Water Neap	:	1.0 m
Mean Sea Level	:	0.6 m
Mean Low Water Neap	:	0.7 m
Mean Low Water Spring	:	0.5 m

Water levels were monitored at 4 locations (S-1, S-2, S-6 & S-7) with 15 min interval for a period of 15 days (Figure 29) to represent tide curve.

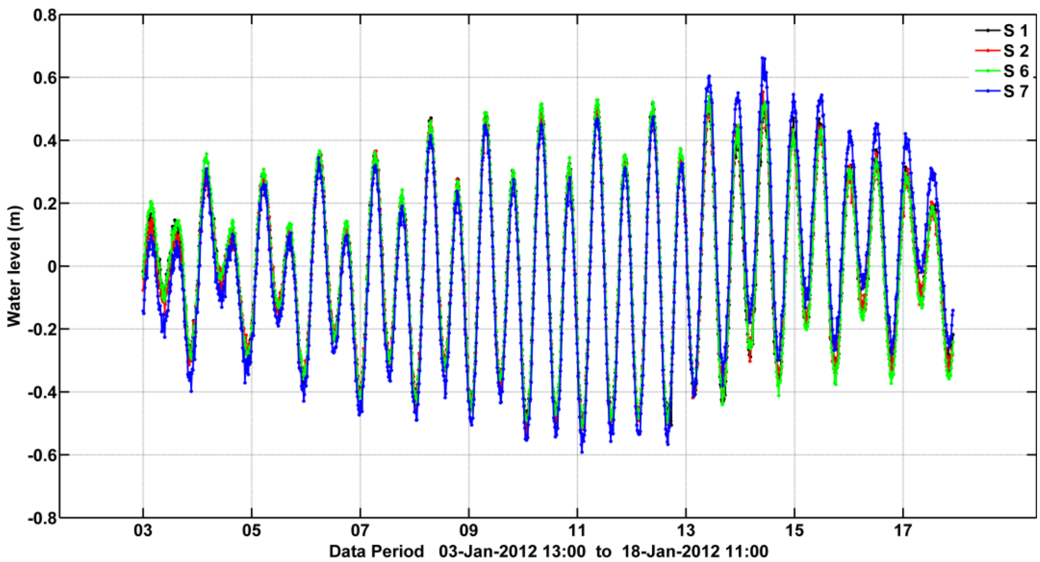


Figure 29. Observed water levels during NE monsoon at four stations of Pondicherry coast

However, water level oscillation at Pondicherry could be influenced by a myriad of surface meteorological and hydrological factors in addition to the well known astronomical forcing and, therefore, considerable amount of non-tidal contributors were present in the measurements. In shallow waters water levels can be affected by storms at higher frequencies due local wind and barometric pressure, which result water level above tide. Following conventional practice, the data was smoothed and the non-tidal contribution was removed from the measured data using known techniques of tidal analysis (Figures 30 & 31).

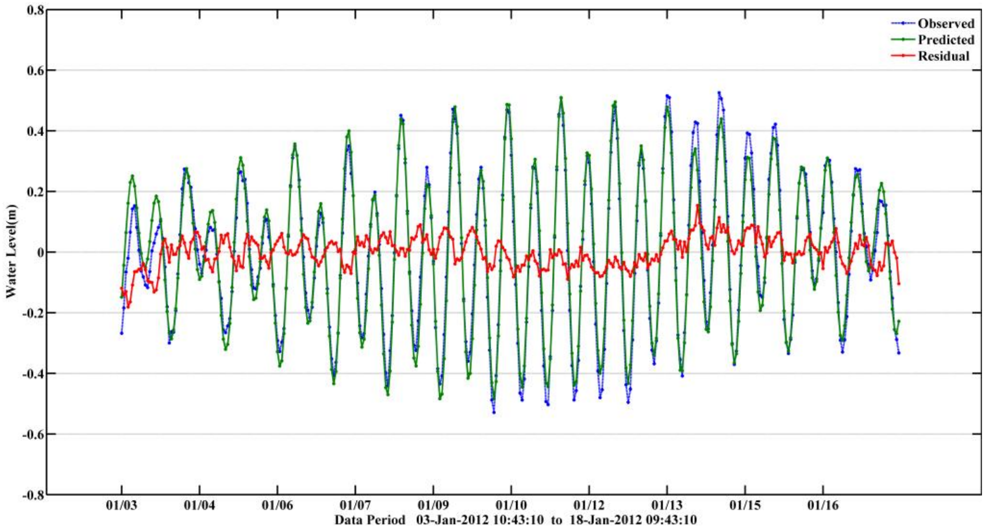


Figure 30. Observed/predicted tide along with residual at Station S-2 (Kalapettai)

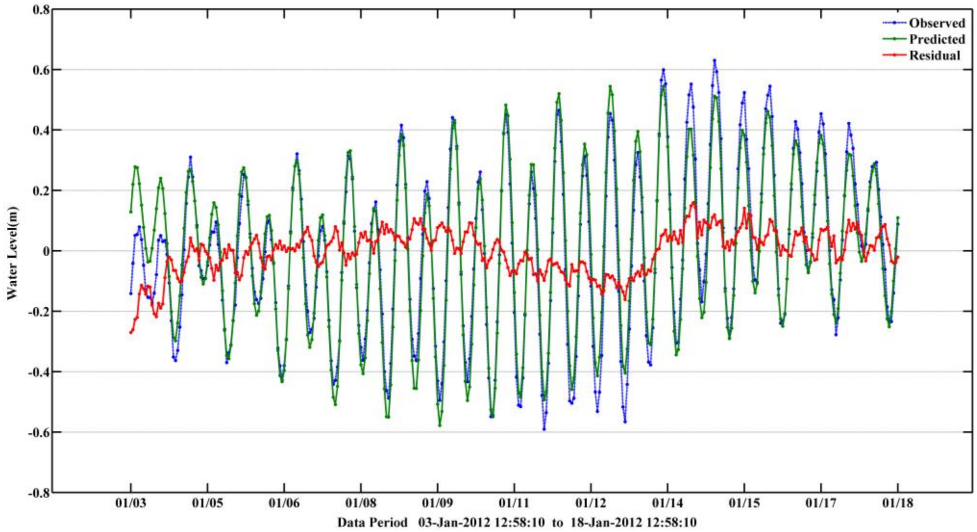


Figure 31. Observed/predicted tide along with residual at Station S-6 (Lighthouse)

The mathematical process of looking at one constituent at a time from an observed time series is called harmonic analysis. By knowing the periods of the constituents, it is possible to remove them, providing there is a series which is long enough. From harmonic analysis of the observed water level series, two values are obtained for each tidal constituent. Amplitude, the vertical distance between mean tide level of the crest is one of the values. The other values phase lag is the amount of time elapsed from the maximum astronomic event to the first maximum of its corresponding constituent tide. It is usually expressed in degrees of one complete cosine curve (360^0) of that constituent. Harmonic constants are unique to the particular station and computed constituents for Pondicherry coast is given in Table 6. The amplitude of various constituents, frequency and residuals (non-tidal component) at boundaries of study area (S2 and S6) were shown in Figures 32 & 33.

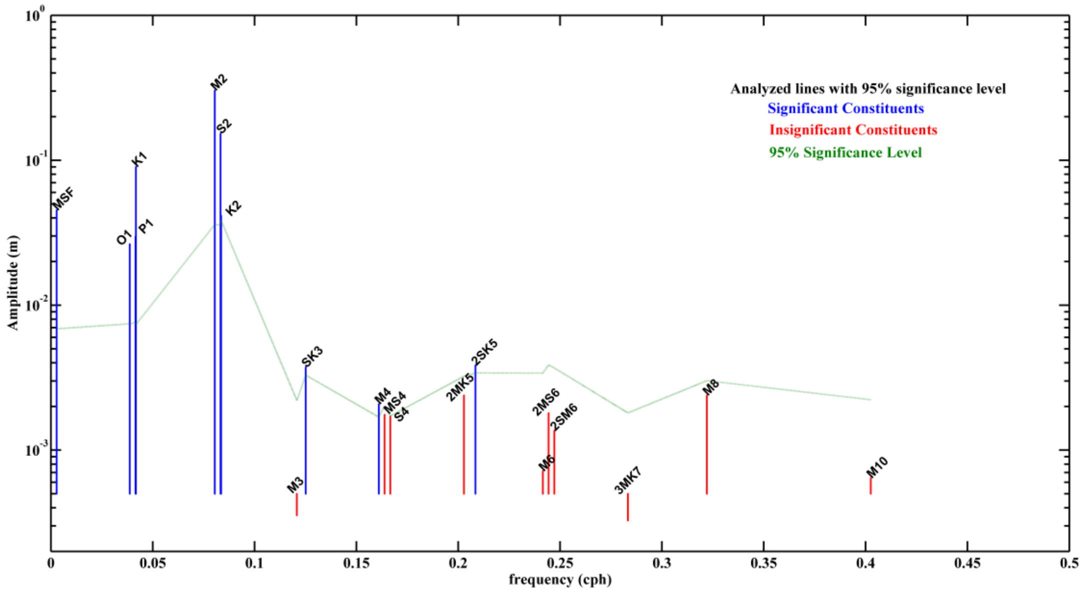


Figure 32. Amplitude and frequency spectrum of tide at station S-2 during NE monsoon

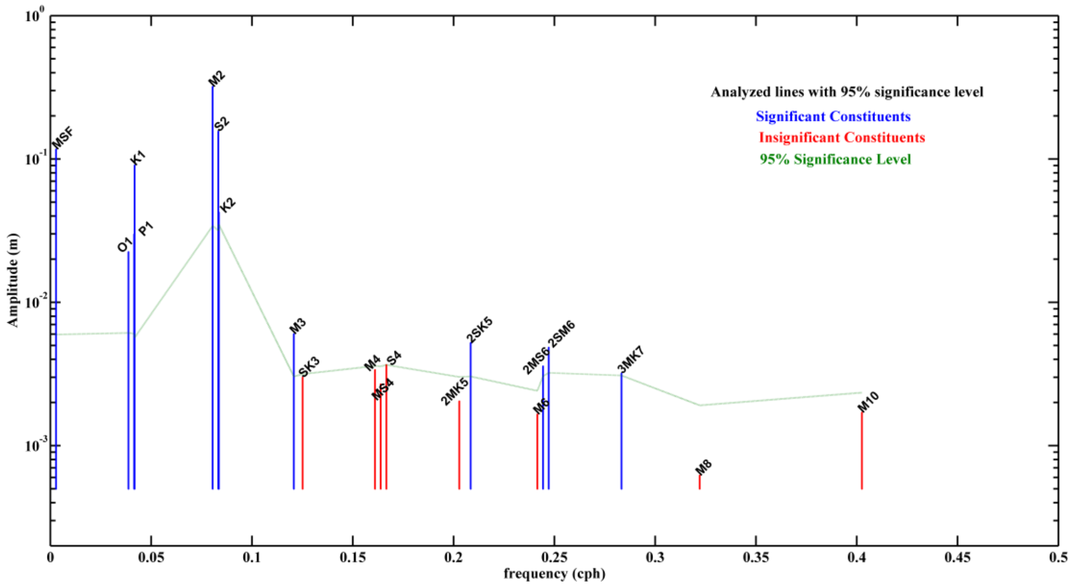


Figure 33. Amplitude and frequency spectrum of tide at station S-6 during NE monsoon

The type of tides at a given location can be represented by the Form Number, which is the ratio of the sums of the amplitudes of the constituents of (K_1 and O_1) to that of the constituents (M_2 and S_2). The tides at Pondicherry are thus classified as semidiurnal in nature, having a Form Number of 0.22 (Table 9).

Table 9. Frequencies and amplitudes of tidal constituents during NE monsoon

Type	Tide Constituent	Freq (cycles/hr)	S-1		S-2		S-7		S-6	
			amplitude (m)	phase (deg)	amplitude (m)	phase (deg)	amplitude (m)	phase (deg)	amplitude (m)	phase (deg)
Diurnal	O1	0.03873	0.0267	336.92	0.0264	331.29	0.0256	334.60	0.0225	325.01
	P1	0.04155	0.0302	336.73	0.0298	337.35	0.0298	338.40	0.0299	340.23
	K1	0.04178	0.0913	330.28	0.0900	330.28	0.0901	331.33	0.0903	333.16
Semidiurnal	M2	0.08051	0.3098	223.84	0.3032	223.84	0.3178	224.20	0.3194	223.84
	S2	0.08333	0.1558	278.62	0.1523	277.64	0.1486	276.00	0.1556	276.58
	K2	0.08356	0.0424	301.02	0.0414	300.04	0.0404	298.40	0.0423	298.98
Quarter diurnal	M4	0.16102	0.0027	122.97	0.0021	146.18	0.0012	81.15	0.0034	146.76
	MS4	0.16384	0.0043	280.90	0.0018	356.27	0.0023	32.04	0.0027	113.66
	S4	0.16667	0.0035	82.25	0.0017	245.08	0.0019	0.36	0.0037	34.86

The water level gauge deployed during the period 29 December, 2011 to 17 January 2012 measured surge level during the landfall of Thane cyclone. The detided water level indicates a surge level of 0.7m at the time of cyclone crossing the coast (Figure 34). The cyclone crossing the coast during high phase of tide and hence the total measured water level is 1.3 m.

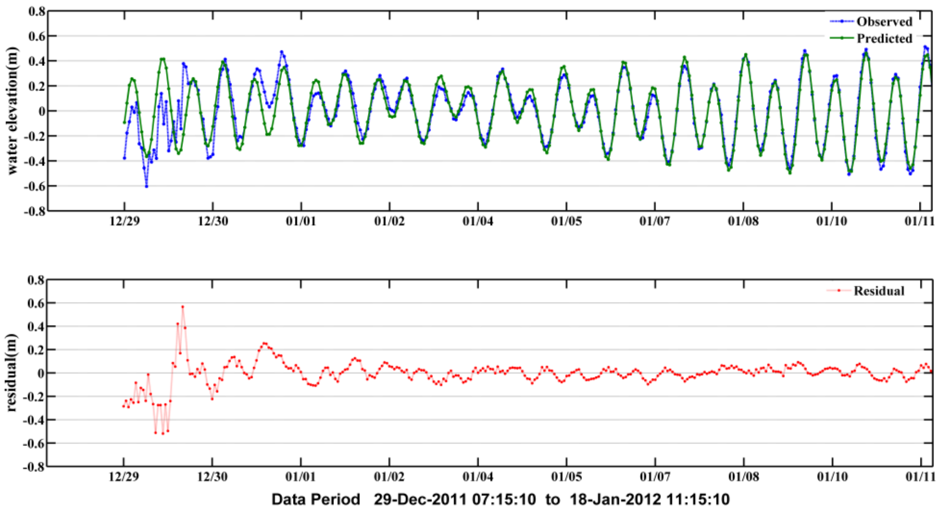


Figure 34. Measured water level at Thanthriyankuppam village (station S2) during Dec 2011 Thane cyclone

When any natural event or engineering project, such as, dredging or breakwater construction, which has the potential to cause major alterations in the adjacent topography. Hence, the Tide measurements made along the Pondicherry coast represent the base line information, which is very useful planning coastal protection scheme and for monitoring its performance in future.

6.4 Waves

The Bay of Bengal experiences three different weather conditions normally fair, southwest monsoon and northeast monsoon. During fair weather season, the sea surface is usually calm and the coastal region is dominated by swells and to a smaller extent by locally generated waves, during this period beach building takes place. Extreme weather events are common during southwest monsoon (June-September) as well as northeast monsoon (November-January) seasons. SW monsoon is dominated by northerly drift and NE monsoon by southerly drift.

Wave measurements were carried out off Pondicherry coast by INCOIS, MoES during July 2009 to June 2010 using a Datawell directional waverider buoy in 30 m water depth. The data were recorded for 20 min at every 3 h interval. Frequency distribution of wave heights show that the waves are approaching from southeast by direction for about 9 months in a year and approaches from east direction for the rest of the year (Figure 35). The wave heights ranges from 0.4 m to 1.2 m during southwest monsoon with SE direction.

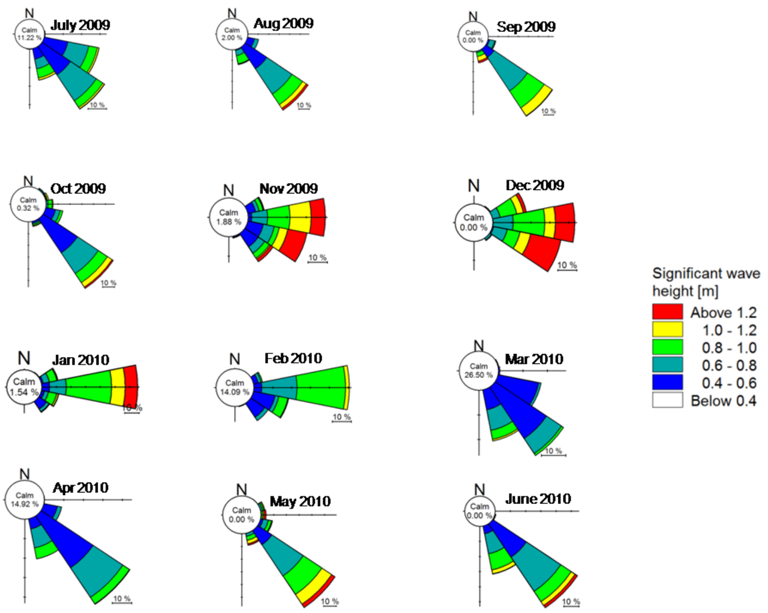


Figure 35. Monthly wave climate measured using waverider buoy at south of Pondicherry port at 30 m water depth

The characteristics of waves during northeast monsoon (January 2012) off Pondicherry coast are measured and analysed. The significant wave height during the NE monsoon period ranges from 0.25 m to 1.50 m with an average value of 0.60 m. Frequency distributions of wave heights show that almost 50% of the significant wave heights are in the range 0.5 - 0.7 m indicating low wave activity during the observation period. The depression during 13-15 January, 2012 caused the waves to grow and the significant wave height reached up to 1.5 m on 14 January (Figure 36).

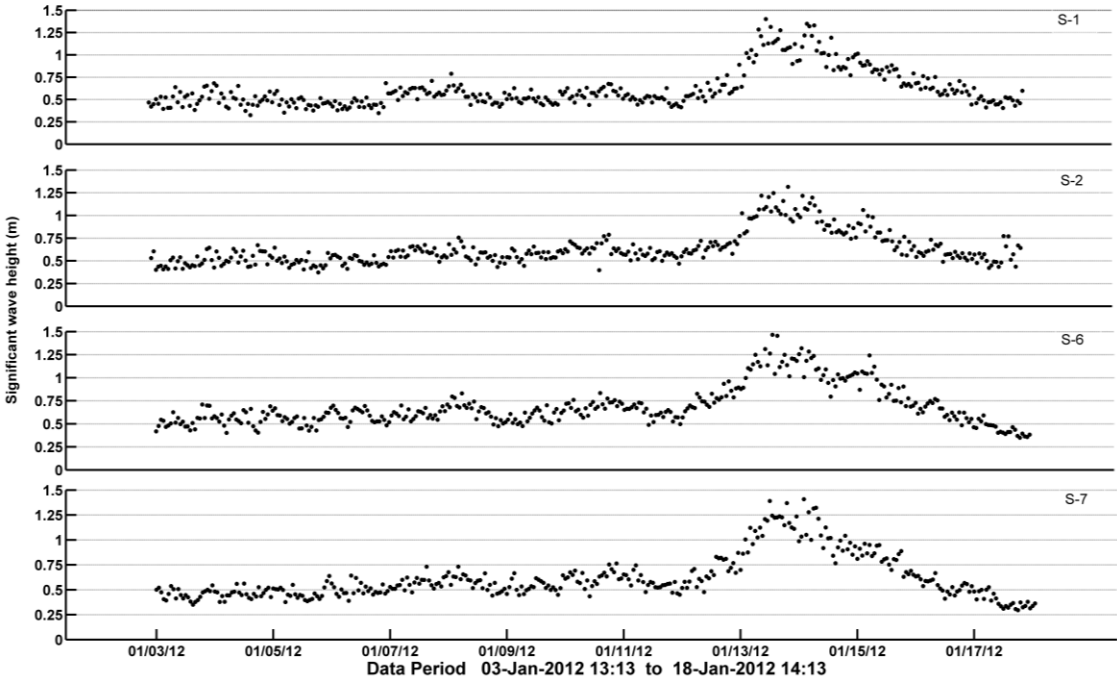


Figure 36. Significant wave height at four stations during NE monsoon

The wave rose diagram shows that the wave approach as the Pondicherry from southeast with maximum significant wave height of 1.2 m at all the locations (Figure 37). The wave periods ranges between 3 - 18 sec at all the locations during northeast monsoon. The frequency distribution shows that more than 50% of the waves have T_z in the range of 8-10 sec and 15% of the waves are above 10 s during the deployment period. The wave statistics along Pondicherry coast during the observation period were shown in Table 10.

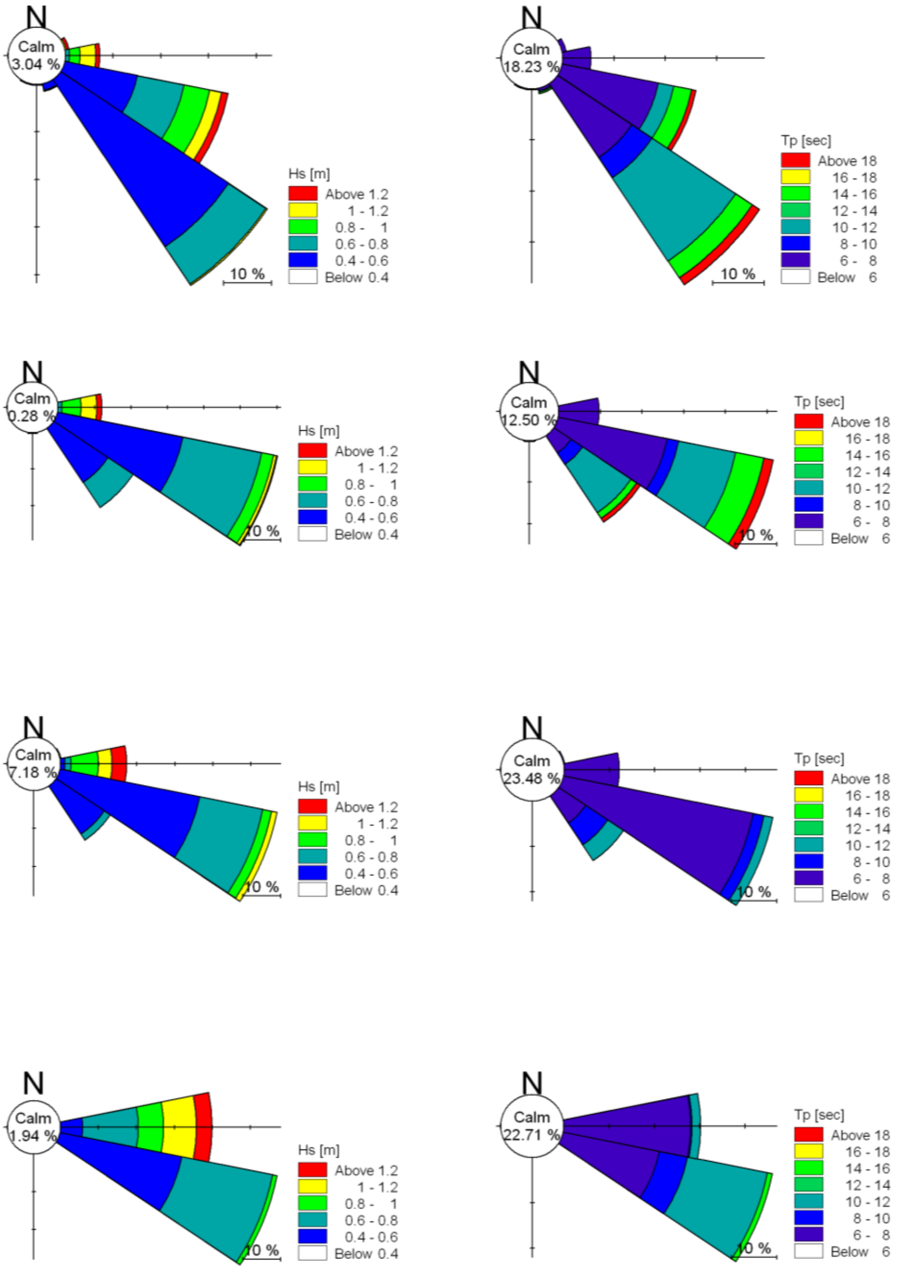


Figure 37. Wave rose diagram of the significant wave height and peak period based on measurement at four stations during the period 03-17 January 2012

Table 10. Wave statistics during the measurement period 03-17 January 2012

Location	**Significant wave height (m)**				**Average period (s)**				**Mean wave direction (deg)**			
	Min	*Max*	*Mean*	*Std*	*Min*	*Max*	*Mean*	*Std*	*Min*	*Max*	*Mean*	*Std*
S-1	0.32	1.40	0.62	0.21	4.64	9.12	5.24	1.19	80.00	150.00	115.00	14.54
S-2	0.37	1.31	0.63	0.17	4.18	11.67	6.08	1.67	84.57	135.00	106.00	10.00
S-6	0.34	1.51	0.68	0.21	3.94	9.65	5.32	1.11	82.51	117.00	101.00	7.48
S-7	0.29	1.40	0.62	0.22	4.88	7.73	5.83	0.47	80.00	136.00	112.00	11.00

A depression formed over southeast Bay of Bengal in the evening of 25th December, 2011 and lay centred about 1000 km southeast of Chennai. It gradually moved north-north-westwards and intensified into a deep depression in the early morning of 26th December, 2011 and into a cyclonic storm 'THANE' in the same midnight. It then moved west-northwestwards and intensified into a severe cyclonic storm in the afternoon and into a very severe cyclonic storm in the evening of 28th December, 2011. It then moved west-southwestwards and crossed north Tamil Nadu & Pondicherry coast between Cuddalore and Pondicherry within 06:30 and 07:30 hrs IST of 30th December, 2011 with a wind speed of 120-140 kmph.

After landfall, the system rapidly weakened into a severe cyclonic storm over north coastal Tamil Nadu at 08:30 hrs IST of 30th and into a deep depression around noon and into a depression in the same evening over the north Interior Tamil Nadu. The track and associated parameters are shown in Figure 38.

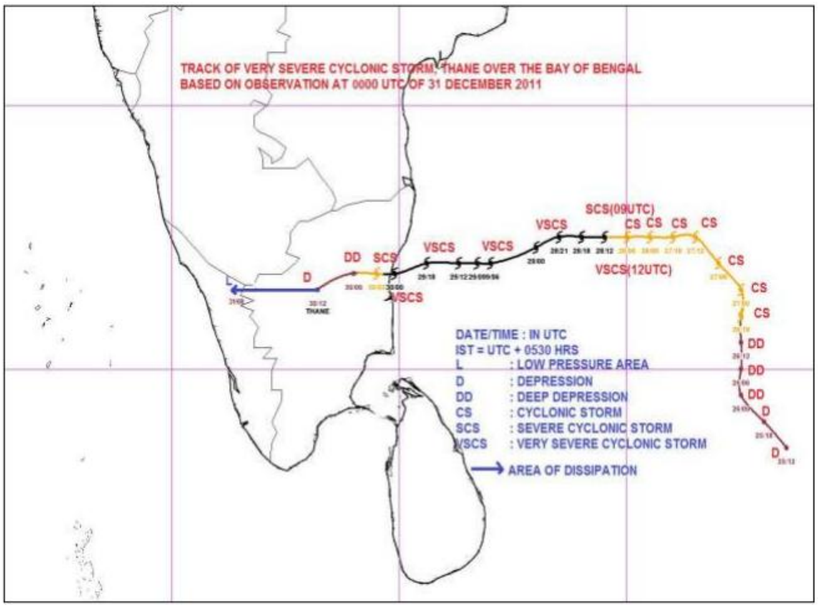


Figure 38. Track of THANE cyclone over the Bay of Bengal during December 2011

Waves were measured at a water depth of 9.5m using water level recorder off Pondicherry coast during the passage of Thane cyclone. The maximum wave height recorded during the passage of cyclone at Pondicherry coast was 7.2m, where as this height before and after the passage were 3.0m and 2.0m (Figure 39). The wave rose plot indicates the wave direction approximately 100º to 170º with a wave period varying between 10 s to 12 s (Figure 40).

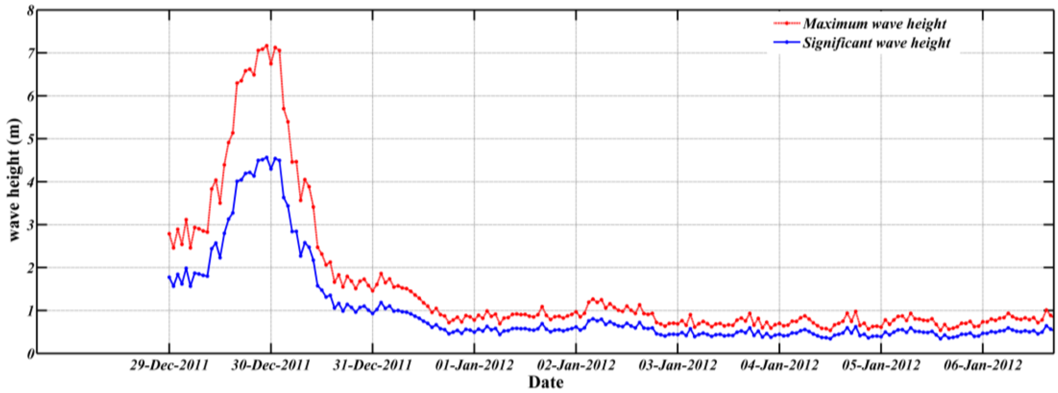
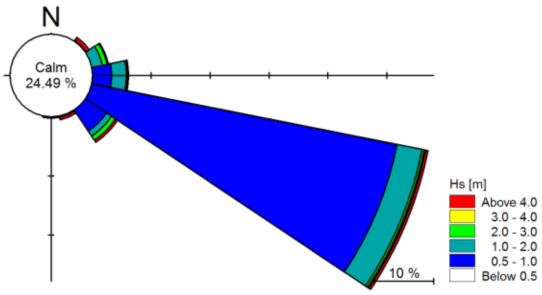


Figure 39. Maximum and significant wave height during Thane cyclone (Dec 2011)



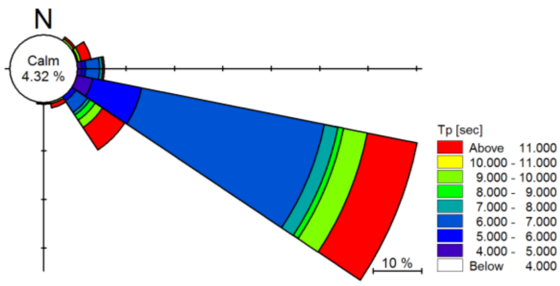


Figure 40. Wave rose plots of H_s and T_P during Thane cyclone (Dec 2011)

6.5 Coastal Currents

Coastal currents are responsible for large scale sediment transport along the open coast. Coastal currents are driven mainly by tide, wind and also by open ocean circulations. Because of tides or local topography, coastal currents are generally irregular. Shankar et al (1996) have studied East Indian Coastal Currents (EICC) and reported that EICC reverses direction twice a year, flowing north-eastward from February till September with a strong peak in March-April and south-westward from October to January with strongest in November. Major diving mechanisms of its variability was attributed to wind in the Bay of Bengal, which reverses with monsoon. It has also been reported that periods of peak monsoon do not coincide with times of maximum current speed.

In order to study the variation of coastal currents along Pondicherry coast, current measurements were carried out Off Pondicherry using the RCM 9 self-recording current meters (Anderaa Data Instruments) at 5 locations (S1,S2,S4,S6 and S7). Current data was collected at every 10 minutes interval for a period of 15 days during 3-17 January 2012. Currents at each station were resolved into zonal (u-component) and meridional (v-component) directions (Figure 41), with the flow to the east and the north being defined as positive. The measured current was up to 0.5 m/s with a mean value of 0.12 m/s (Table 11). The v-component of current dominated the u-component at all the stations which results in large alongshore flow than the cross shore flow with a magnitude of 0.2 m/s.

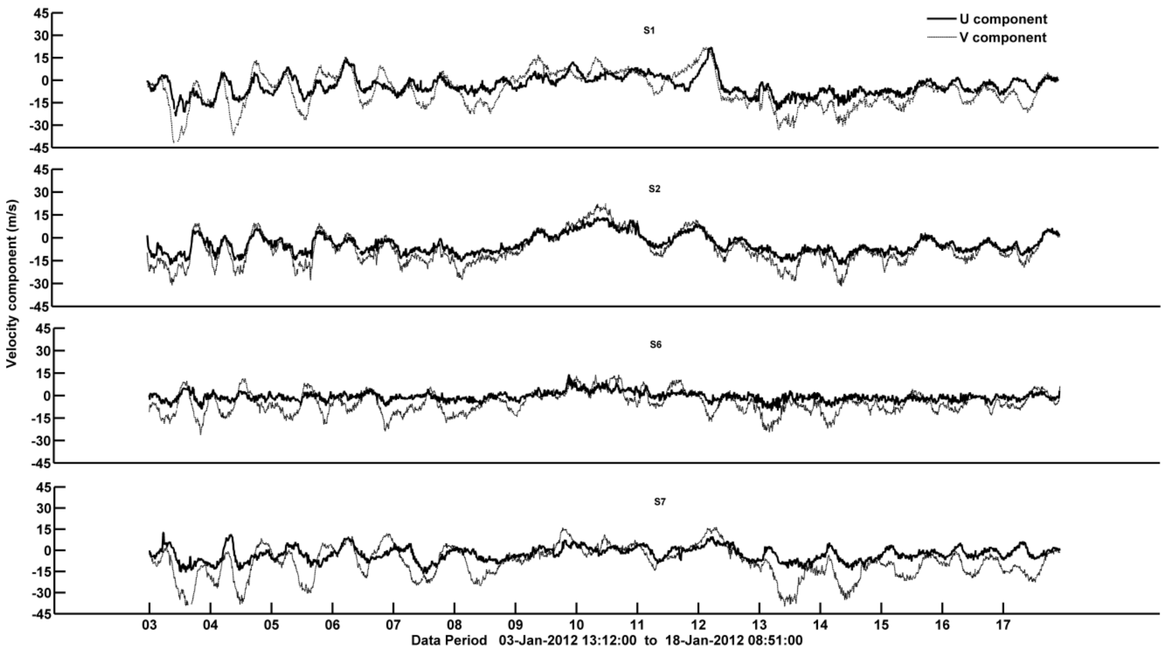


Figure 41. Measured zonal (u) and meridional (v) component of coastal currents during the period 03-17 January 2012

Table 11. Spatial distribution of current magnitude and direction at four stations

Station No.	***Total water depth (m)***	***Level of current meter (m)***	***Observed current speed (cm/s)***			***U-component of current (cm/s)***			***V-component of current (cm/s)***			***Direction (^{o})***		
			Mean	Max	SD	Mean	Max	SD	Mean	Max	SD	Mean	Max	SD
S1	14	4	12.84	52.28	8.34	-3.68	22	6.5	-6.69	22.05	11.57	180	359	87.92
S2	7	3	12.59	36.36	7.38	-4.35	13.69	6.2	-7.35	22.79	10.07	174	357	77.33
S6	6	3	7.87	26.69	4.9	-0.75	14.05	2.9	-4.93	13.87	7.25	164	359	77.39
S7	15	4	12.47	48.1	9.08	-2.63	12.77	4.9	-8.71	16.49	11.43	180	359	76.62

The rose plots of current magnitude and direction for the period of observations are shown in Figure 42. Currents are southerly during observation period, the period of observation belongs NE monsoon.

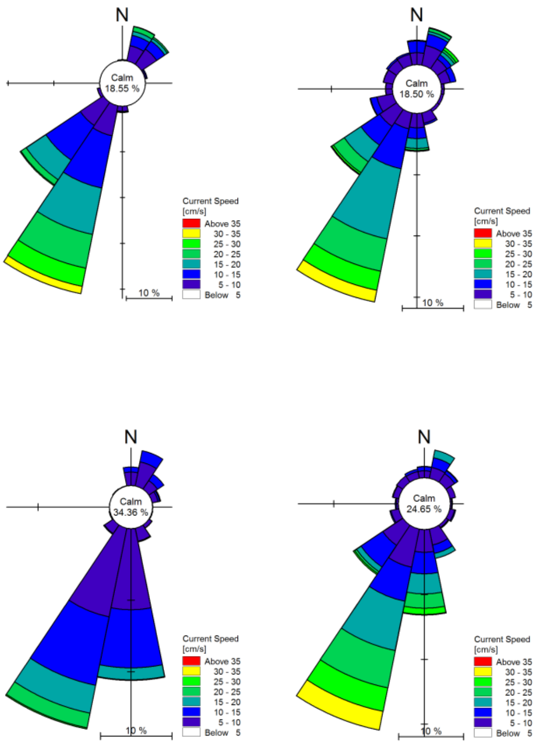


Figure 42. Rose plots of the observed currents along Pondicherry coast, NE monsoon

The progressive vector diagrams of the currents are shown in Figure 43. PVD at station S1, S2 and S7 show a strong southerly movement during the observation period, compared to station S6 location. The resultant movement at S1,S2 and S7 in the X-direction was 8, 10 and 6 km respectively, whereas that in the Y-direction was 15, 15 and 20 km for the same stations. In general, the PVDs indicate flows parallel to coast with variation across the stations.

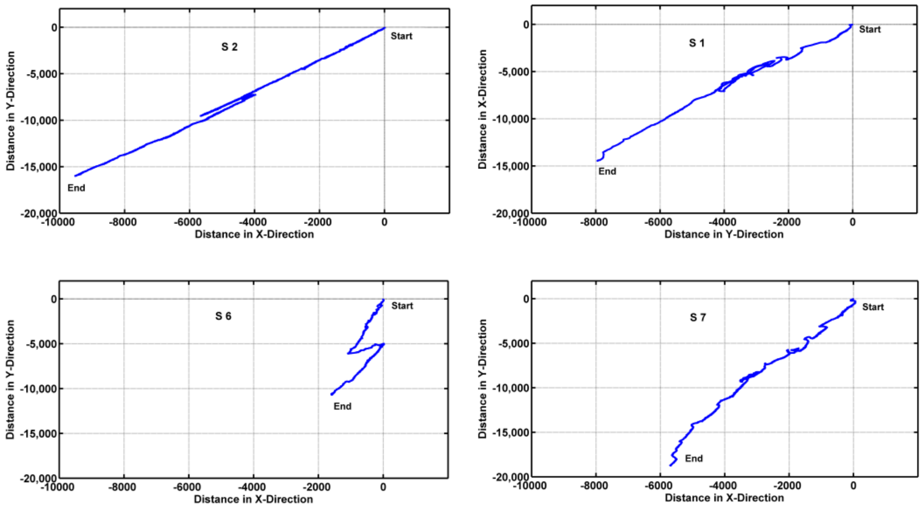


Figure 43. Progressive vector of observed currents during NE monsoon at four stations

Maximum currents (1.4 m/s) were noticed when the Thane cyclone crossing the coast on 30th December 2011 (Figure 44).

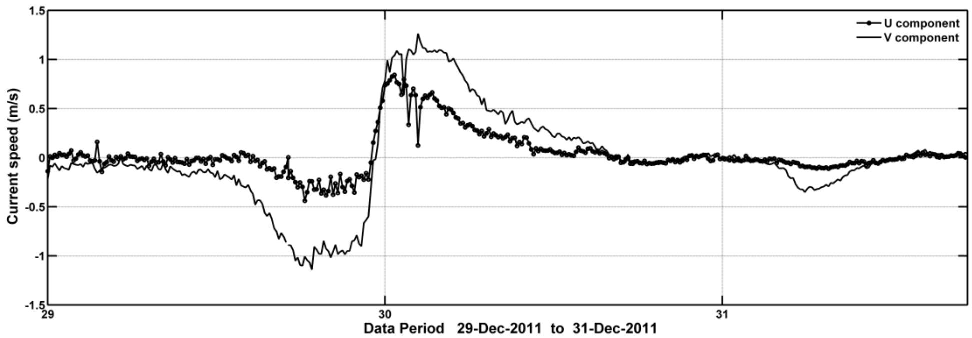


Figure 44.Maximum observed currents during December 2011Thane cyclone

6.6 Nearshore Currents

Beach changes result from sediment transport which is controlled by several factors; near shore currents play major role in driving sediment transport. Nearshore currents are driven by waves, they are modified at near coast. In order to analyse the along shore variability, nearshore currents (wave induced), were measured by Acoustic Doppler Velocimeter (ADV) with a sampling frequency of 2 Hz at a measuring interval of 20 minutes. The pressure and velocity sensors were located at a distance of 1.1 m from sea bed to measure pressure and wave orbital velocities. They are measured at two stations, namely station S3 and S5 (station locations are as shown in Figure 27). The direction of nearshore currents at station 3 and 5 follow coastal currents which is southerly during northeast monsoon (Figure 45 & 46).

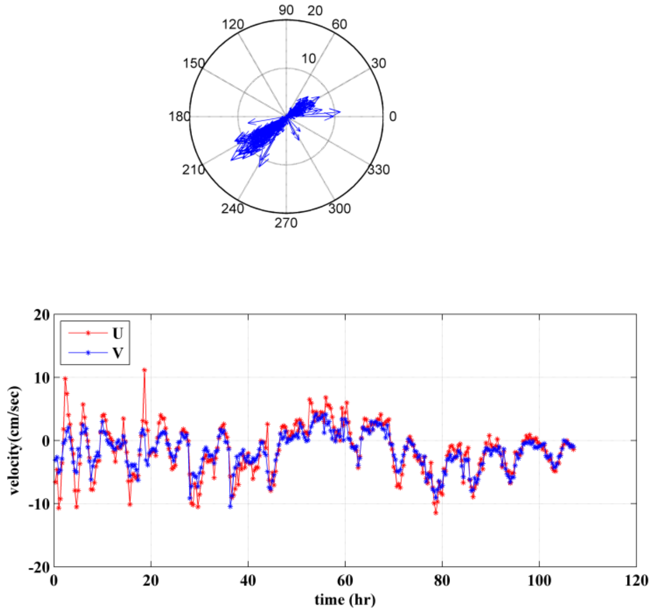


Figure 45. Observed nearshore currents at station S3 (Pillaichavadi)

The magnitude of nearshore current at S3 is 11cm/s and 13 cm/s at S5. The coastal configuration play dominant role in direction, which is evident from figure, the station S3 is oriented at 10^0 with respect to north and station S5 parallel to the coast (Figure 46). The intensity of longshore currents is much more than that of on-offshore component except the phase of the sudden bursts of offshore-going currents.

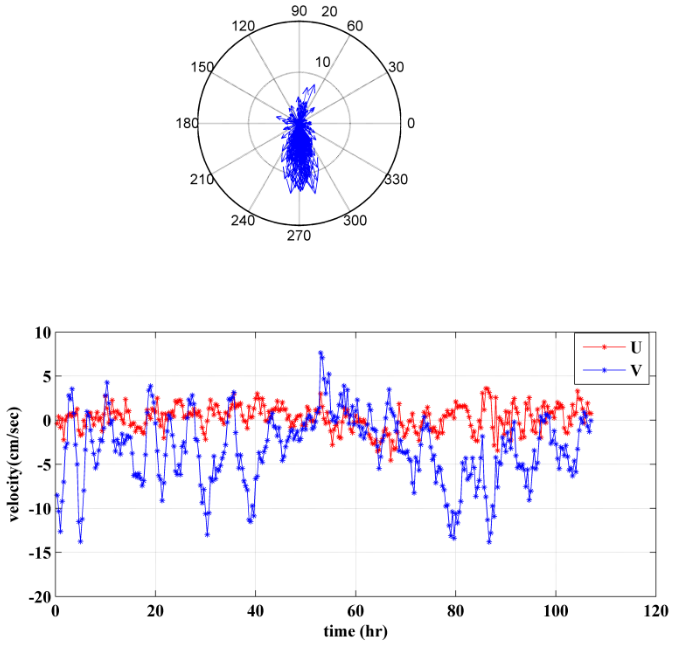


Figure 46. Observed nearshore currents at station S5 (Kuruchikuppam)

6.7 Suspended Sediment Characteristics

Knowledge of dynamics of suspended sediments in coastal areas is of great importance in determining the fate and transport of suspended sediment and sediment adherent concentration. SSC in coastal waters is influenced by coastal currents in intermediate water (8m - 20m) and nearshore circulation in littoral zones 0m to 6m.

Suspended sediment concentration was monitored from 40 stations along the Pondicherry coast during the period 03-17 January 2012 (Figure 47). During the survey, samples were collected from Pondicherry port to north of Kalapettai village using water sampler from 4 discrete depths (4 to 15 m depth). Relatively high concentration of suspended sediment (40 - 56 mg/l) was observed along the beach stations and reduced concentrations (24 mg/l) were observed in the region beyond 13 m water depth (Figure 47).

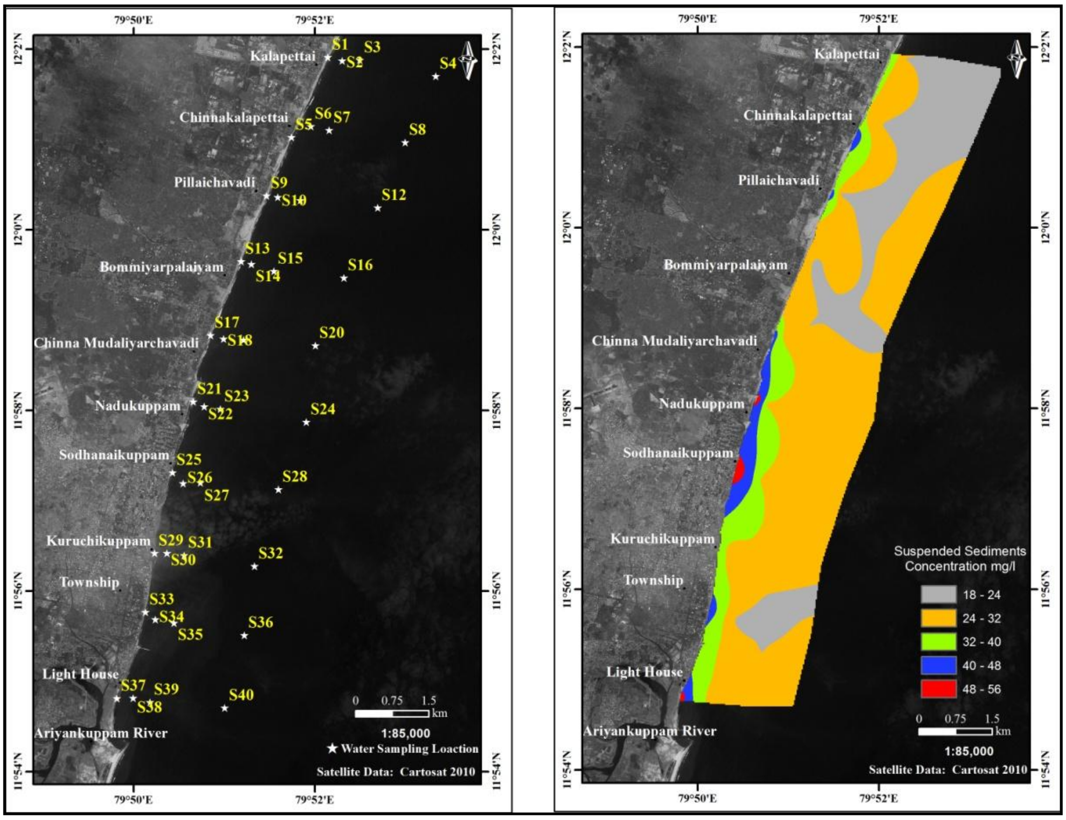


Figure 47. (a):Water Sample location and (b): Distribution of Suspended Sediments during NE monsoon period

7.0 SUMMARY AND RECOMMENDATIONS

The coast along Pondicherry and the adjacent areas of the Villupuram district has been experiencing severe erosion for the past 20 years. Natural causes interception of littoral drift by the harbour at Ariyankuppam village, Pondicherry constructed in 1990 and the subsequent construction of coastal defence structures such as seawalls and groins caused erosion in this regions. Pondicherry and Tamil Nadu governments made several attempts to protect the coast under threat using options like seawalls and groins. Though these protection measures have offered some relief to the coast under threat, adjacent parts of coast areas are eroding, more unstable and are constantly under threat.

There is a need for a well-defined plan that seeks to treat the shoreline and the issue of erosion in a more integrated, sustainable and strategic manner. This can be achieved by a Shoreline Management Plan (SMP), which considers the issues at a reasonable scale and focuses on restoring the natural sandy beaches. Policy makers, engineers and stakeholders seek a long term solution to restore the sandy beaches of this entire affected region. The basic questions which need to be answered and understood before attempting any such coastal restoration scheme are following:

1) Present status of coast (geomorphic setting and functional performance of already implemented protection measures)

2) Coastal processes along this coast in relation to proposed coastal restoration schemes

3) Priorities of policy makers and stakeholders

4) Requirements of stakeholders

5) Economical, environmental and social sustainability of proposed restoration measures

Considering the above, the overall objective of the coastal restoration project should be to address the coastal restoration needs through the implementation of economically viable restoration works using environmental and socially appropriate solutions. This report describes the present status of the coast and the performance of existing coastal protection schemes. The data on sea bathymetry, land topography, hydrodynamics (tides, waves, currents and sediment characteristics) and shoreline changes was collected for analysing the coastal processes. A joint meeting with Tamil Nadu and Pondicherry governments is required to draw strategies for coastal restoration measures where various technical alternatives can be analysed in relation to the priorities of the government keeping in view that the solution adopted should be sustainable, long term and permanent without affecting the coastline located further north.

The analysis of long-term shoreline change data indicate that the average rate of shoreline recession and progression over a period of 30 years is in order of 4 m/yr and 5 m/yr respectively. However, localized shoreline change rates, recession specifically, of 50 m in a season were observed. However, the rate of shoreline change and/or erosion is dependent on gradient of sediment transport along the coast, which is dependent on configuration of the coast, near shore current and availability of the sediments.

The 18 km length of coastline of Pondicherry was divided into four zones for analysis. The first zone (Zone A) covering a length of 3.5 km represents the zone of direct influence of the Pondicherry harbour. The sand has accumulated up to the tip of the south breakwater with maximum accretion of 180 m and the sediment started bypassing to the north. The northern side of the harbour is protected by a seawall and sediment deposition is noticed during the NE monsoon due to the southerly drift. The maximum erosion is about 40 m at distance of 600 m from north breakwater from 1991 to 2000. The second zone (Zone B- 4 km), which is part of Pondicherry township is protected by a seawall. Scouring at the foot of the seawall is noticed during active monsoon. The third zone (Zone C- 2.5 km) is protected by a series of disjointed groins. These groins were constructed during 2005-2007 and accretion to an extent of 90 m is noticed at northern longest groin located at Thathiriyankuppam. The accretion at all groin compartments indicate availability of sediments along the Pondicherry coast during both monsoons.

The CWPRS (1978) has reported that the net drift was estimated to be about 500,000 cu.m. at the time of design of Pondicherry Harbour but the present estimated rate of net drift by us would be in the order of 2,00,000 – 2,80,000 cu m, which needs to be confirmed by detailed shoreline monitoring. The coast north of longest groin at Chinnamudalaiyar Chavadi village has experienced increased erosion and shoreline recession during 2008 to an extent of 70 m. South of this coast regained some lost material during 2012 due to southerly drift and bypassing of sediments from the groin with a net accretion of 20 m. The Zone D with a length of 8 km is not protected by major scheme and maximum erosion observed 1991-2010 is around 25m. A sea wall of length 165 m was constructed at village Chinnakalapettai to protect the coast from erosion.

The following are major observations for arriving at coastal restoration strategies for both the Pondicherry and adjacent Tamil Nadu coast.

- Pondicherry has been known as a beautiful beach town. The beaches here, particularly along the famous beach road were used for all kinds of activities by a large cross-section of people. Children chased crabs and looked for interesting shells. The famous Masi Magam festival of Pondciherry relied on the big beach where the chariots of all the gods from all the temples near and far would come. With the beach almost gone and the rocky sea wall, all these little everyday pleasures of each and every resident of Pondicherry and all those who throng to its shores, have been snatched away.
- The basic objective of shore restoration projects moderate the long-term average erosion rate and shoreline change from man-made causes, which can be achieved only if the natural dynamics of the coast is well understood.
- The medium term analysis of shoreline change data from 1991 - 2012, indicate that this region needs immediate attention.
- Protection schemes till date have been implemented in isolation both in Pondicherry and Tamil Nadu, a common phenomenon even in developed countries. This has happened because of various constraints like scientific/engineering understanding of nature, economics of the scheme to be implemented, institutional issues, lack of inter-state coordination and acceptance by stakeholders. It is recommended that short-term and long-term strategies can be drawn considering the coast in total by Pondicherry and Tamil Nadu Government. The short-term strategies required at specific sites can be designed and integrated in long-term strategies, if a shoreline management plan is prepared.
- Pondicherry harbour is causing a deficit in sediment supply to the northern coast. Sand bypassing carried out by harbour authorities for certain period could maintain the beach north of the harbour. Later, discontinuing the sand bypassing resulted in loss of beaches in the northern coast. The recent analysis of satellite data suggests that parts of the littoral sediments are bypassed naturally to northern coast. While designing the shore restoration scheme for Pondicherry coast, the configuration of harbour and its relation to natural bypassing of sand at harbour should be studied.

- Pondicherry wave climate is influenced by both the SE and NE waves with occasional cyclonic storms crossing the coast. The maximum surge level observed above tide is 0.7m with a tidal range of 1.2 m. The waves approaches from SE direction from April – September with mean direction 135 deg, while during NE monsoon, the direction is 90 deg. The coastal currents are seasonal, directed to north during SW monsoon and south during NE monsoon. The average currents during SW and NE monsoon would be 0.3m/s and 0.5 m/s. The near shore currents generated by waves follow similar pattern like coastal currents in Tamil Nadu coast, which is an added advantage in developing common shore restoration measures. A detailed study conducted at Vellar estuary and Ennore shows shoreline change governed by wave climate and tidal influence is insignificant. Low pressure systems like events of 2007 can cause significant damage to coast and some of its changes could be permanent. The coastal protection scheme-seawall built along the Pondicherry town for length of 6 km need to be assed carefully to avoid further damage during cyclone or low pressure periods.

- As Pondicherry is known for its tourism/recreation, it is advisable to restore the natural beach by implementing beach nourishment. At Ennore, sand dredged from harbour to an extent of 3.5 million cum was placed on north of harbour to prevent downdrift erosion. The performance of beach nourishment was assessed based on long-term data at Ennore which shows nourishment has supplied sand to northern coast for period of 5 years and coastline was stable even after the construction of harbour. Initial estimates indicate that sand to the extent of 3.0 million cum needs to be placed north of the harbour for length of 600 m near the Gandhi statue. The above option will not only help in gaining a natural beach but also help in controlling the erosion of the northern coast. The detailed design of beach nourishment scheme can be worked out based on discussions. Also, eco-friendly techniques and "soft engineering measures" to stabilize the coast could be implemented along with beach nourishment for retaining the sand and to restore the ecological functions and services that are provided by sandy beach ecosystems as well as enhance livelihood opportunities for the fishing communities and increase value to the coast.

- A long term and permanent solution can be found if both the Tamil Nadu and Pondicherry Governments jointly work towards a common, long-term and sustainable shore restoration strategy.

- Short-term solutions may need to be implemented, but these have to take into account the long-term solutions and should be “no-regret” solutions.
- Worldwide there is now increasing examples of replacement of hard structures like seawalls with softer options such as beach nourishment, sand bypassing, dune planting and offshore submerged reefs. Thus, the general principle of “working with nature” would be a better approach for cost-effective and sustainable coastal protection measures. Pondicherry needs to consider modern protection practices which achieve a more effective and sustainable means of coastal protection while also addressing local amenity and economic development aspects. It is most important to ensure that the natural movement and flow of sediment along the shoreline is maintained.
- All Shore protection schemes should be monitored scientifically under technical guidance of expert institutes by Tamil Nadu and Pondicherry governments for improvement in its performance. The crest of berm data collected by Tamil Nadu PWD do not cover any location along Pondicherry coast. The closest locations considered for analyzing the data along this coast are Devanampattinam and Oyyalikuppam at south and north of Pondicherry respectively.
- Given the social and economical importance of the Pondicherry beaches, the coastal restoration option should consider the protection of land, buildings, groundwater, ecology, livelihoods and public and private infrastructure against future loss and damage caused by erosion and storms.
- The beach restoration will primarily benefit the coastal dwellers living along the Pondicherry and nearby Tamil Nadu coast including fishing households, the owners, operators and employees of fishing boats, hotels and other tourism related businesses and their employees. But mostly it will benefit all the residents of this peaceful coastline whose young children have never even seen its beautiful beaches. No one expected that waves due to monsoon or cyclone take away the natural beach.

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