Sethusamudram Shipping Canal Project and the unconsidered high risk factors: Can it withstand them?

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" I was about six years old when my father embarked on the project of building a wooden sailboat to take pilgrims from Rameshwaram to Dhanushkodi, (also called Sethukkarai), and back.
He worked at building the boat on the seashore, with the help of a relative, Ahmed Jallaluddin, who later married my sister, Zohara.
I watched the boat take shape. The wooden hull and the bulkheads were seasoned with the heat from wood fires.
My father was doing good business with the boat when, one day, a cyclone bringing winds of over 100 miles per hour carried away our boat, along with some of the landmass of Sethukkarai.
The Pamban Bridge collapsed with the train full of passengers on it.
Until then, I had only seen the beauty of the sea, now its uncontrollable energy came as a revelation to me."

A.P.J.Abdul Kalam, *in* "Wings of Fire – An Autobiography"

To
the wellbeing of our friend
Ananda Ram Kumar

Preface:

Sethusamudram Shipping Canal Project, when completed, will transform parts of the southern coromandal coast qualitatively. Since historical times, this portion of the coast (Palk Bay, Adam's Bridge) is used only to fleets of small crafts involved in coastal trading and fishing. Sethu Canal will transform this into a coast that shall start witnessing fleets of large vessels involved in overseas trading pass by.

Is the idea that a navigational channel in the Adam's Bridge-Palk Bay area can be dredged without any major hazard, based on a correct knowledge base? What are the environmental factors that might have the capacity to make this idea a failure? What are the actions that would be required to increase the chances of physical stability of the proposed channel?

These are the questions this monograph seeks to address.

Southern coromandal coast (South East Indian Coast or the south east Bay of Bengal coast – stretching from Pulicat to Kanyakumari) has a long history of shipping. Epics like Silappathiharam and Manimehalai (dated 600-900 A.D) have recorded the shipping activity of this coast. Written memoirs of the seafarers who had frequented this coast are available at least for the past 400 years. Pulicat, Sao Tome (now Chennai), Puducherry (Pondicherry), Cuddalore, Karaikal, Porto Novo, Nagore, Nagapattinam, Muthuppet, Adhirampattinam, Thondi, Alankulam, Rameshwaram, Periyapattinam, Kilakkarai, Kayalpattinam, Kulasekaranpattinam, Tuticorin were the important ports at some time in the past till three centuries back. Many of them have lost this status and have become mere fishing villages today. Chennai, Tuticorin, Cuddalore are the three ports that have continued with their status till the present time.

Overseas and coastal trading had flourished in this coast in the past. However, coastal trade was more prominent than the overseas ones. Out of the above mentioned ports, Pulicat, Sao Tome and Nagapattinam were the only ones that were involved in both the above said trades during the pre-modern times (prior to 1800 A.D.). Rice, textiles, areca, tobacco, saltpeter and horses were the main goods that these ports had handled.

Pulicat was the prominent port in the late 16th century. Sao Tome gained prominence in the first two decades of 17th century as Pulicat lost its glory. Sao Tome lost its prominence to Nagapattinam in 1630 and Nagappattinam retained this glory till the end of that century.

'The coastal trade was carried on in a relatively large number of small craft, in marked contrast to overseas trade which was carried on in a relatively limited number of sizable vessels. These coastal vessels ranged from mere dugouts to larger single-masted boats and were termed

catamarans, phares, machuas, champans, tonis, and pagels… It is important to note that the relatively small individual sizes of these craft are more than compensated for by the size of the coastal trading fleets.' (Sanjay Subrahmanyam, 'The political economy of commerce : southern India, 1500-1650' Cambridge University Press, 1990, p-49)

The conclusions that we may arrive from the foregoing paragraphs are two: 1) The ports of the coromandal coast seem to have had a very short lived existence, 2) The sea trade in this area was dominated by coastal trade and hence by fleets of small vessels.

These two conclusions are important for us in this book.

Why did these ports have an ephemeral existence? What was the usual navigation route that the fleets of small costal trading vessels took and what were their navigational experiences?

Rise and fall of kingdoms and empires (fall of the chola, pandya kingdoms and the Vijayanagara Empire; rise and fall of the Portuguese and Dutch rule; rise of the English rule) was one of the most important factors for the short existence of many of these ports. Changing overseas market scenario was also a major factor. Apart from these political and economic factors, environmental, geological and oceanographic factors have played a very definitive role in determining the life period of each of these ports. We are interested in exploring these three factors in this book.

Coastal Navigation between Pulicat and Nagapattinam faces the open sea; between Nagapttinam and Kayalpattinam it is protected by the Sri Lankan land mass in the east and the Indian land mass in the west. We are interested (in this book) in the navigational experiences of the fleets of small crafts in this second area (named as the Palk Bay, Adam's Bridge and the Gulf of Mannar in the modern times).

The Sethusamudram Shipping Canal Project (SSCP) was first proposed in the year 1860. The idea was to cut-short the distance traveled (by avoiding circumnavigation of Ceylon) by ships originating from the west coast and bound for ports like Madras and Calcutta. These ships would travel through the Gulf of Mannar and Palk Bay and enter the Bay of Bengal.

Thus, for the first time an idea has been proposed to throw open the Palk Bay (where fleets small vessels have only operated from the time immemorial) to large vessels participating in overseas trade. However, this idea has remained in hibernation for the last 144 years.

1860 to 1922 saw nine different proposals presented to the British Raj. Govt., of India appointed the Sir.A.Ramasamy Mudaliyar Committee to study and give its opinion on the project in 1955. In 1968, it appointed

Venkateswaram committee to evaluate the project once again. In 1981, the Ministry of Shipping and Surface Transport appointed Lakshminarayanan Committee to evaluate the project and present its comments. In 1996, the Tamil Nadu Government asked the Pallavan Transport Consultancy (PTCS) Ltd., to review the project and present its suggestions. After all these efforts, the Tuticorin Port Trust (TPT) commissioned the National Engineering Environmental Research Institute (NEERI), in 1998, to prepare a report on the status of the environment through which the channel will pass through. Once this Initial Environmental Evaluation (IEE) was ready, TPT commissioned NEERI to do an Environmental Impact Assessment (EIA) for the proposed project in May, 2002. The EIA was completed and was presented to the Tamil Nadu Pollution Control Board (TNPCB) and the Ministry of Environment & Forests (MoE&F) for obtaining a clearance for the project in June 2004. Following this, the TNPCB had arranged a series of Public Hearings (PH) at various district headquarters to gather the opinions of those people who might be affected by the project and from the people who are concerned, in mid September, 2004. All these PHs were subsequently cancelled and were postponed to 20th to 25th November, 2004 as the TNPCB wished to gather furthermore opinion on the proposed project.

The NEERI EIA and the Technical Feasibility Report (TFR) state that the project is feasible technically and has the potential to operate without any environmental hazard. These two reports are the ones from which the current SSCP proposal draws its legitimacy. The present book analyses those portions of the EIA and TFR that are directly linked to the physical stability of the channel and offers a critique and suggestions.

The author of this monograph is a medical doctor and not a marine geologist or a meteorologist or a (macro) structural engineer. Hence, the inferences are made only after the original works are quoted extensively; This may, at times, seem to be a cumbersome process, but it will certainly help the readers of this book to refute the arguments of the author as the original works are in front of them to make their own conclusions.

R.Ramesh

16 November 2004

1. The Project:

This is an offshore project*.

It envisages dredging of the shallow sea bed of the Palk Bay (PB) and Adam's Bridge (AB) to a depth of 12 meters in order to make navigation possible for ships drawing a draught of 9.15 or 10.7.

The total length of the channel will be 152.2 km (excluding the navigation route in the GOM). The canal will have two legs of dredging totaling 74.2 km: one, the Adam's Bridge leg (length 20 km) part; second, the Bay of Bengal (BOB) leg (length 54.2 km). Apart from these two legs it also will have one more leg in the PB (of length 78 km) where dredging is not required (as this area has a depth of 12 m). ('Executive Summary, Technical Feasibility and Economic Analysis of Proposed Sethusamudram Channel', NEERI, July, 2004, p-X). The navigable route from Tutucorin to Adam's Bridge is more than 12 meters deep and hence it does not require dredging.

The canal will have 1:3 side slopes.

The calculated quantity of (capital) dredged material for the total length is 81.5 to 88.5 million m^3. Adam's Bridge leg is supposed to generate 31.5 - 33.5 million m^3. The Bay of Bengal leg is supposed to generate around 50-55 million m^3.

The annual volume of dredged material for the maintenance of the canal is calculated to be 0.1 million m^3 for the Adam's Bridge leg (20 km) of the channel (NEERI EIA, p-6.4). The same has not been calculated for the Bay of Bengal leg (54.2 km length) of the channel yet.

The nature of dredged material is presumed to be clayey and sandy for both the legs. Borehole soil investigations have been done for the Adam's Bridge part but the data for the Bay of Bengal leg is from subsoil analysis only. However, **presence of hard strata below the soft sediment is envisaged** in data collected by National Hydrographic Office (NHO), Dehradun.

The top clayey layer that will be dredged from the Adam's Bridge leg of the canal is supposed to be 7-8 million m^3 in volume. The lower dredged stratum is supposed to be sandy and it will be 24.5 to 25.5 million m^3 in volume.

The top clayey layer is expected to be dumped in an area identified (using satellite imageries) as a wasteland in the Rameshwaram (Pamban) island. This covers an area of 753 hectares and is located between Rameshwaram in the west and Dhanushkodi in the east (NEERI EIA, p6.6). The lower sandy layer from the Adam's Bridge leg is supposed to be dumped in an area in the Gulf of Mannar (GOM) 25-30 km away from the Adam's Bridge where a depth of 30-50 meters is available. (NEERI EIA, p-6.6)

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* Project coming up in an area located beyond the low tide line

If the dredged material from the Bay of Bengal leg of the canal (50-55 million m^3) turns out to have a high silt content, then land disposal in proximity to dredging area (which shall avoid the ecologically sensitive locations like Point Calimere Bird Sanctuary) is being thought of. Also, as this area is close to Bay of Bengal where depth more than 40 meters is available, disposal in sea would be a preferred option. (NEERI EIA, p-6.9)

2. The Design:

2.1 Design Procedure

The Channel has three basic components:

1) The structure of the channel proper,

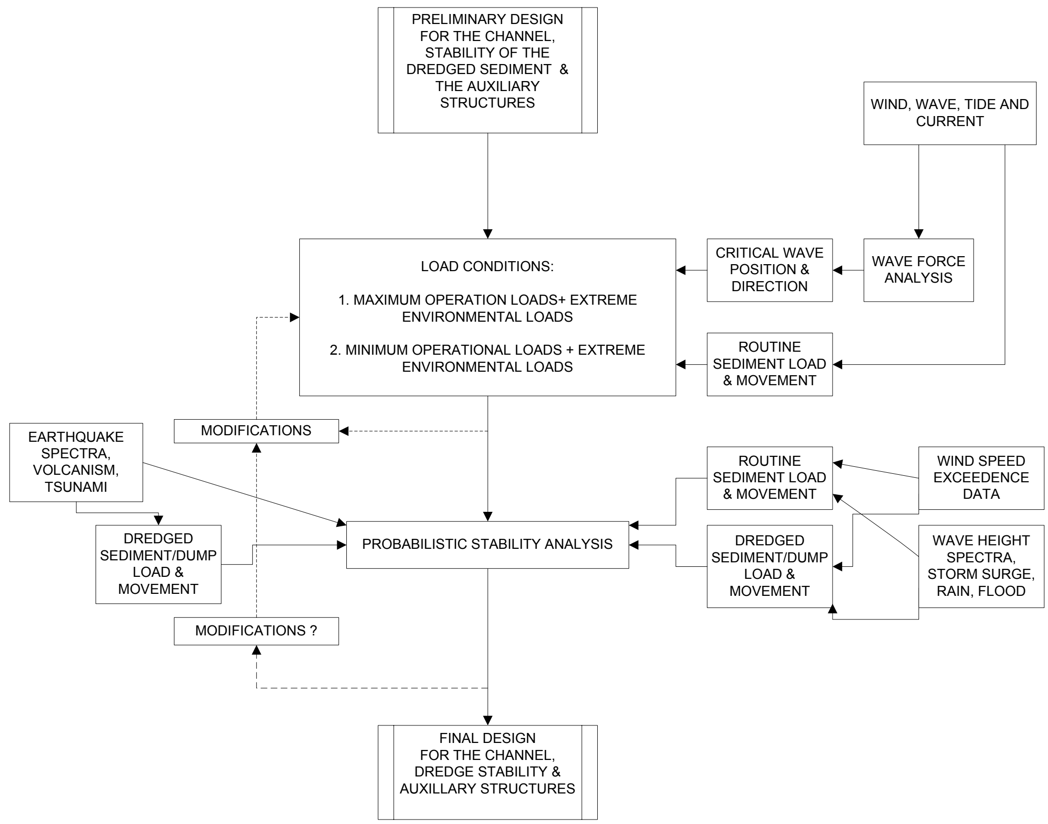
2) The plan to dump the dredged material safely, and

3) Buildings and other Structures that shall be necessary for the regular functioning and maintenance of the canal.

The general philosophy followed worldwide in designing an offshore structure is as follows:

"Predictions about the ocean environment have to be made first. This should be based on the history of the environment. Ideally, hundreds of years of data should be used to calculate the distribution of waves, currents, or winds and their expected maximum values. In actual fact, the data for a particular location usually cover a much shorter period, and therefore, are a poor basis for predicting the future from the oceanographer-statistician's point of view. Despite this, valid operating and design values can be obtained by one of several methods. ***The objective of the designer or operator of offshore structures, pipelines, vessels, etc., is to arrive at a design likely to survive but also capable of being reconstructed at reasonable cost after failure. Thus the correct selection of the extreme environmental condition the structure is going to encounter during its life, assumes crucial importance.*** Once the extreme environmental conditions have been evaluated, the designer can, after calculating the risks and costs specify the design criteria and proceed to select the size, shape and configuration of the structure." (A.K.Malhotra - "*Ocean Science and Technology*" p-32 , 1980)

Fig.1. The required process of design for the SSCP



So, to know what design the channel should have, we need to know the ocean environment of the Palk Bay and Adam's Bridge (and Gulf of Mannar) in very definitive terms.

3. Sources for the database on the ocean environs of the area - Index

To know about the ocean environment of Palk Bay, Adam's Bridge (and Gulf of Mannar) in very definitive terms, we need to have a thorough database on: 1) the coast, 2) sea bed, 3) wave, tide & current dynamics, 4) sedimentation 5) tectonics and 5) meteorology of the area.

Let us index the most important research data so far collected by various researchers first; we shall involve ourselves in an elaborate discussion of these datasets and make our inferences in later chapters.

3.1. The Coast:

The geo morphological signatures available in this area that help explain the geological past of the area are:

1) The raised coral reef along Rameshwaram island; the now destroyed but well studied (Stoddart and Pillai,1972) raised coral reef that once existed at Manarkadu point at the east of Pamban pass in the Rameshwaram island, (C.S.G.Pillai, "Scleractinian Fauna" in thr proceedings of the workshop on 'Biodiversity of Gulf of Mannar", MSSRF, Feb'1998.)

2) Existence of Beach Ridges up to 32 km inland from the present day coast (S.M.Ramasamy et al., 'Rapid land building activity along Vedaranyam coast and its possible implications" Current Science, Vol.75, No.9, 10 November 1998),

3) Beach Ridge patterns between Nagapattinam and Rajamadam, from Rajamadam to Devipattinam, from Devipattinam to Kilakkarai (V.J.Loveson et al., 'Remote Sensing applications in the study of sea level variation along the Tamilnadu coast, India" in G.Victor Rajamanickam ed., 'Sea level variation and its impact on coastal environment", Tamil University, Thanjavur, 1990, p-185-186),

4) Beach Terraces around Pamban island (G.Victor Rajamanickam et al., "Results of Radiocarbon Dating from some beach terraces around Rameshwaram island, Tamil Nadu" in G.Victor Rajamanickam ed., 'Sea level variation and its impact on coastal environment", Tamil University, Thanjavur, 1990, p-390-393),

5) Presence of Micro-deltas formed by small rivers (V.J.Loveson et al., "Environmental impact of micro-deltas and swamps along the coast of Palk Bay, Tamil Nadu, India", in G.Victor Rajamanickam ed., 'Sea level variation and its impact on coastal environment", Tamil University, Thanjavur, 1990, p-166),

Other than these geo-morphological signatures, there are also other evidences that throw light on the environmental history of the coast. They are:

1) Spit formation near Manamelkudi, Vedaranyam, Arimunai and Talaimannar,

2) Marine archeological studies conducted near Thondi, Periyapattinam and Kurusadai Island,

3) Usha Natesan's study using remote sensing on the changing coastline of the area; Chandramohan et al's study on the changing beach facies at Puduvalasai.

3.2 The Seabed:

Bathymetry data collected over the past century throw light on the changing depth of the sea. They also tell us the dramatic differences in water depths among the Bay of Bengal, Gulf of Mannar, Adam's Bridge and the Palk Bay.

Soil and subsoil studies conducted so far in this area are very minimal to help understanding the soil structure of the seabed of this area.

3.3. Studies on Waves, Tides and Currents:

Studies on waves, tides and currents are minimal for this area. NEERI has done wave studies while doing the EIA.

3.4. Sedimentation Studies:

Attempts to calculate the total sedimentation load for the Palk Bay have been made by Chandramohan et al; studies on sedimentation dynamics have been attempted by Agarwal, Loveson et al., and Jena (in Gulf of Mannar using bathymetric map of different years); Studies to determine the pattern of movement of the sediments during various seasons have been made by Chauhan et al., N.Chandrasekaran, Sanil Kumar et al., Usha Natesan etc.; Hydrobiological study by Murthy and Udayavarma is also worth mentioning here. Studies conducted by NEERI for the EIA also includes in it sedimentation studies. We may also include here the radiotracer studies conducted at the Adam's Bridge area by the Pallavan Transport Consultancy Services in the year 1996.

3.5. Tectonics and Volcanism:

Studies on this topic are minimal. Data on the earthquakes over the past century is available. Study on the sea bed morphology of GOM had been initiated by the Indian Ocean Expedition of 1975; Murthy et al. have expanded that study; Cursory data on Tsunami is available.

3.6. Meteorology:

Extensive data is available on this topic from India Meteorological Department (IMD). Many researches and descriptions on the monsoons, inter-monsoonal periods, depressions and cyclones are available.

4. The Data Base

4.1. Physiography – General description

The proposed canal passes through the Adam's Bridge and the Palk Bay. The structure and function of the Adam's Bridge and the Palk Bay are influenced by the ocean dynamics of the Gulf of Mannar (which is an extension of the Indian Ocean (IO)) and the Bay of Bengal. Palk Bay, Adam's Bridge and the GOM are bound in east and west by the Sri Lankan and Indian Peninsular land masses.

Adam's Bridge is 31 km long with an average depth range of less than 5meters. It extends between the Rameshwaram and the Mannar islands. It is a formation of shallow ridge of Holocene conglomerate and sandstone mantled with islands (17 in number) and shoals of shifting sand, which is all resting upon Miocene limestone. (Cathcart, 2003). The average length of these islands is 0.8 km to 3 km. The total length of islands and shallows of this area is around 9km. The remaining 22 km stretch is open water.

Palk Bay has a width ranging from 57 km (Palk Strait) to 107 km (Thiruppalaikudi to Poonagari coast). Its length (from the midpoint of Adam's Bridge to the mid point of Palk Strait) is around 150 km. It is very shallow and its depth varies between 3 to 15 meters. The bay is largely occupied by sand banks and shoals. It also has two major coral reef formations: one having a width ranging from 1-2 meters to 300 meters extending between Munakad and Thonithurai. This is around 5.5km long. The other reef formation is 25 to 30 km long with a width generally less than 200 meters. This extends between Thangachimadam and Agnitheertham (Rameshwaram). (Mahadevan and Nagappan Nair, 1969).

Contrary to the sea beds of PB and AB, the sea beds of GOM in the south and the Bay of Bengal in the north east have a very deep throw. They fall steeply to depths of 1000 to 2000 meters within a matter of few kilometers from the Adam's Bridge and the Palk Strait.

So, the ocean beds of PB and AB can be thought of as highly elevated (but submerged) dam like structures that separate the deep ocean beds of Indian Ocean (here GOM) and BOB.

4.2 The Changing Physiography

Geomorphology:

4.2.1. Vedaranniyam – Jaffna Peninsula sector:

"Satellite data acquired in 1998 has shown huge accretion of sediments and rapid land building activity off Vedaranniyam coast. The geomorphic interpretations carried out using IRS IA imagery and ^{14}C and archeological dating of such geomorphic features have shown that such ongoing sediment accretion phenomena off Vedaranniyam nose might in future connect the Vedaranniyam part of Indian peninsula with Jaffna peninsula of Sri Lanka if the sediment accumulation continues unabated.

The ^{14}C dates evaluated for the beach ridges show that the sea has gradually regressed due to the rapid accumulation of sediments and the development of cuspate landforms in between Chettipulam and Kodiyakkarai during the past 6000 years. The data collected by the study has shown that the sea has regressed by 10 km in 439 years from Chettipulam to Maranganallur, by 4 km in 2076 years from Maranganallur to Tettagudi, by 8km in 2270 years from Tettagudi to Vedaranyam, by 8 km in 220 years from Vedaranniyam to Kodiyakkarai and by 28 km in 1020 years from Kodiyakkarai to present day offshore bars. These show that the beach ridges have grown at the approximate rate of 23 meters/year from Chettipulam to Maranganallur, 2 m/y from Maranganallur to Tettagudi, 3.5m/y from Tettagudi to Vedaranniyam, 36 m/y from Vedaranniyam to Kodiyakkarai, 27.5 m/y from Kodiyakkarai to recently developed offshore bars of 1990.

The above observations show that there is no strict linear relation between the rate of sediment accretion and the time period. Infact, under such dynamic coastal regimes, linear relationship cannot be expected because of varying degrees and duration of fluvial and physical oceanographic processes. But, however in average (excluding Maranganallur to Tettagudi and Tettagudi to Vedaranniyam) the land building activity is around 29 m/y and if this accretion rate is maintained, Vedaranniyam nose will get connected to Jaffna peninsula, just 12 km from the offshore bars in another 400 years.

Regionally from Chettipulam to present day offshore bars, the land has grown to a distance of 58 km in 6085 years, at an average rate of 10m/y. At this rate the offshore bars will provide a land connection with Jaffna peninsula in another 1200 years. The graphical projection of the locations of the beach ridges versus their ages has shown a coarse linear relationship indicating that the Vedaranniyam nose will get connected with Jaffna peninsula in another 2400 years.

The sediment building activity due to littoral currents seems to be very rapid in this area with the rate of 29 m/y and hence there is a possibility for such land building / connection in another 400 years.

Ramasamy and Balaji (1995) on the basis of satellite imagery interpretation have identified that the Mio-Pliocene sandstone of Vedaranniyam area is undergoing an upliftment in post Mio-Pliocene period. Ramasamy et al (1995) have observed an anticlockwise rotational migration of Cauvery River in the area and north-west of Chettipulam-Kodiyakkarai area. Ramasamy and Karthikeyan (1997) have observed further geomorphic and hydrogeochemical anomalies favouring ongoing land emergence in Vedaranniyam area.

It is obvious therefore, ***that tectonic upliftment has contributed substantially for such sediment accretion brought by littoral currents in Kodiyakkarai-Jaffna peninsular sector*** and hence it can be confidently said that Vedaranniyam land segment will get connected with jaffna peninsula ultimately." (S.M. Ramasamy , D.Ramesh, M.A.Paul, Sheela Kusumgar, M.G.Yadava, A.R.Nair, U.K.Sinha, T.B.Joseph, "Rapid land building activity along Vedaranniyam coast and its possible implications" in Curr. Sci Vol.75, No.9, 10 November 1998, pp 884-886)

4.2.2 Nagapttinam – Rajamadam Coast

'In the coastal sector between Nagapattinam and Rajamadam beach ridges are arranged in unique and peculiar pattern. The beach ridges are arranged in triangular pattern. This suggests the involvement of coastal tectonical force in shaping the pattern which is very much like the cuspate foreland formation of Dungees in England.

The inland beach ridge is located about 32.5 km from the coastline and trending NE-SW direction. Later stages of beach ridges changed their disposition to E-W and N-W directions. The beach ridge pattern reveals that there is every possibility of ancient Cauvery river confluences near Vedaranyam through Thiruthuraipoondi area.

As the beach ridges tell about the paleo sea level variation, here, the complex pattern of arrangement of ridges reveal the sedimentological events with reference to sea level variations. There are about 8 major sea level stand which have been represented by respective beach ridges. Each major ridge contains about 2 or 3 sub-ridges which are representing the local transitional stage of aggradation by tidal/marine processes. Among the 8 major stages, the first two stages of beach ridges are trending towards NE-SW direction, denoting the old disposition of shorelines. A gap is observed in the middle part of the first two ridges which is inferred to be of paleo-river course of Cauvery, in turn, evidenced by the long narrow irrigation channel. After exposure to some marine fluvial activities which favoured the next beach ridge system, the marine activities might have dominated. The sediments brought by river system is expected to have been sorted by marine action and deposited in the beach side. The presence of pocket swampy area suggests the shallow sea at the time of 3rd stage of beach ridges. From fourth stage onwards, trend of the beach ridge system changed completely from NE-SW direction to E-W and N-S direction. At the 6th stage of beach ridge, the sea level has further been regressed and due to shallowness of nearby coastal area, swampy area has come into existence. The 7th and the 8th stages are later stages of beach ridge formation which suggest the gradual regression in sea level.

Through this 8 stages of beach ridges in this area, one can clearly delineate the boundaries of the different sea level stand in the recent past.' (V.J.Loveson, G.Victor Rajamanickam, K.Anbarasu, 'Remote sensing application in the study of sea level variation along the Tamil Nadu coast, India' in G.Victor Rajamanickam ed., 'Sea Level Variation and its impact on coastal environment', Tamil University, Thanjavur, 1990, p- 186)

4.2.3. Kodiakkarai – Rajamadam coastline

'The northern part of the Palk Bay i.e., the coastline between Kodiakkarai to Rajamadam, indicates the seaward migration of shorelines. Since drainage network is absent in this area, the *shoreline change is attributed to the accumulation of marine sediments only.*

This swampy coastline is provided with two major creek systems. Through the creeks, sea water being loaded with littoral sediment enters into swampy area at high tide time and retreats at low tide. In this phenomenon, the suspended sediments are retained and only water without silts return back to the sea. By repeated action of such tidal siltation, the littoral sediments get deposited and results in growth of swampy areas.' ((V.J.Loveson, G.Victor Rajamanickam, N.Chandrasekar, 'Environmental impact of micro-deltas and swamps along the coast of Palk Bay, Tamil Nadu, India' in G.Victor Rajamanickam ed., 'Sea Level Variation and its impact on coastal environment', Tamil University, Thanjavur, 1990, p- 168)

'According to Agarwal, both the flow and ebb currents are having the speed of 0.5 knots, but acting in opposite directions. The currents, when meet each other being nullified in their speed, they favor the back drop of sediments carried by these currents. This phenomenon has encouraged the siltation and gradually, the Palk Bay is getting shallower leading to advancement of swampy coastline.' (Ibid, p-168-169).

'Agarwal (1988) has noted a significant change within thirty years in the bathymetry of Palk Bay. The regular supply of sediments from littoral currents and seasonal supply from terrestrial sources display the sources for sediments to perform shallowness. Also the nature of current of the coastal waters and protected environment of Palk Bay encourage the deposition of sediments. The 10 meter contour projected in 1920 charts, are found to have disappeared in the admiralty prepared in 1986. If this process continue in the near future, Palk Bay is expected to become much shallower having water depth 3-4 meters leading to the possible lagoon.' (Ibid, p171)

4.3.4. Rajamadam – Manamelkudi coastline

Erosion by small rivers (Agniar, Ambullar, Vellar etc.,) aided by rainwater is significant in this area. The main causes of this erosion are considered to be the less compactness of sandstone and sloping of the terrain. The removal of sediments from the plain alluvium is comparatively lesser than the vertical cutting which is in the process of the formation of gorges.

The terrestrial base sediments which are placed for the sudden deposition at the confluence point due to change in alkalinity, cause the growth of micro-delta. Due to this progradation and coastal deltaic formation, the shoreline gradually drifts bringing in force a change in the dynamics. The protruding nature of these deltas faces the waves and tides in its own way, in contrast, with the straight paleo shoreline. With reference to this action, the physical change of the energy in the coastal waters has been observed. It is evidenced from the formation of sub-aquous shoals and bars resulting in a variation in the bathymetry of the Palk Bay. ((V.J.Loveson, G.Victor Rajamanickam, K.Anbarasu, 'Remote sensing application in the study of sea level variation along the Tamil Nadu coast, India' in G.Victor Rajamanickam ed., 'Sea Level Variation and its impact on coastal environment', Tamil University, Thanjavur, 1990, p- 169)

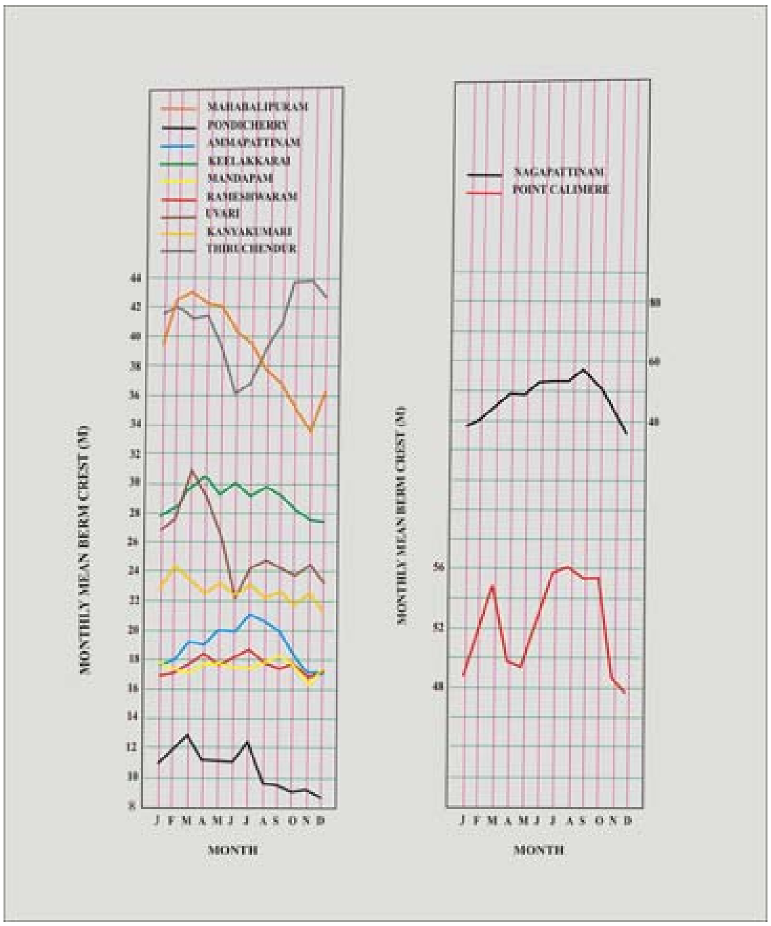
'The spit growth in Manamelkudi is of the order of 0.75 meters per year… (It is interesting to see that the maritime surveys conducted between 1960 and 1986 reveal the change of contour to the tune of 6 meters shallowness in the Palk Strait. That shows that around 24 cm per year is being silted off in the Strait.) Similarly, one can visualize the growth of spit from the Talaimannar side. If both the spits grow in the existing rate of growth, one can visualize the merger of this two within the next 50 years. Once these spits join, the Palk Strait will become into two lagoons of north and south.' (G.Victor Rajamanickam "Sethusamudram Canal: The Life of tamil Nadu" in National Seminar on Ecological Balance and Sethusamudram Canal held at Alagappa University, Thondi Campus, 1-3 October 2004, p. 29-30)

4.3.5. Raja madam – Devipattinam Beach Ridges

'Single series of beach ridge has been recognized along the coast between Rajamadam to Devipattinam. The beach ridge is small, narrow, linear and little elevated. ***The inland geomorphology consists of paleo delta, concentric paleo tidal lakes, etc. which suggest probably, the sudden uplift of the area. As interpreted from ridge patterns, the sea level oscillation is less when considering relief and extent of coastal features. It is assumed along with land area, the sea could also have been uplifted with reference to WNWESE oriented Vedaranyam fault and NW-SE fault of Vaigai river.***' (V.J.Loveson, G.Victor Rajamanickam, K.Anbarasu, 'Remote sensing application in the study of sea level variation along the Tamil Nadu coast, India' in G.Victor Rajamanickam ed., 'Sea Level Variation and its impact on coastal environment', Tamil University, Thanjavur, 1990, p- 187)

4.3.6. Berm Crest* Data from Nagapattinam, Point Calimere, Ammapattinam, Mandapam and Rameshwaram (1977-1988)

A critical analysis of the berm crest data collected (Usha Natesan, 'Sesonal shoreline oscillation of Tamilnadu coast' in Curr. Sci., Vol.65, No.9, 10 November 1993, p-667-668) for Nagapattinam, Point Calimere, Ammapattinam, Mandapam and Rameshwaram for the years 1977 to 1988 yield the following conclusions:



a) Annual mean berm crest fluctuation decreases as we go from north to south from Nagapattinam to Rameshwaram from 20 meters to 2 meters.
b) Accretion is high always in the period between June and August. It is low (or say erosion is high) in the period between November and January (Here Mandapam is an exception as there is accretion in January). There

* Berm is a large reservoir of loose dry sediments making up the beach above the high-tide line. Berm crest is an elevated ridge in the berm, the above shore sand reservoir on the beach. (Keith Stowe, 'Essentials of Ocean Science').

is a deviation from this trend in April in Point Calimere, where there is a sudden decrease in accretion (or an increase in erosion) in the month of April.

This data indicates to us that the southern portion of Palk Bay is accretionary though out the year where as the northern portion experiences both erosion and accretion. Accretionary tendency is greater during the South West Monsoon period (June to August) and it is low (or erosion is high) during the North East Monsoon (October to January).

4.3.7. Beach Ridges, Terraces and Coral Reefs at Pamban and Rameshwaram Island

'Raised reefs are indicators of geological changes and sea-level variations in several parts of the globe. Walther (1991) reported on the raised reef along Rameshwaram Island which he could not study in detail. A well preserved raised reef at Mararcadu Point at the east of Pamban pass in Rameshwaram Island existed until two decades ago. The elevation was 1 to 1.5 meters from the present MSL. Stoddart and Pillai (1972) studied this in detail (This reef is also not in existence at present). The morphology was described and the faunal assemblage listed. ^{14}C assay of a sample of Porietes from this reef yielded a value of 4020$\pm$ 160 years B.P. ***This clearly indicated a mid Holocene uplift either due to eustasim or local tectonism.*'** (C.S.Gopinatha Pillai, 'Scleractinian Fauna' in 'Biodiversity of gulf of Mannar Marine Biosphere reserve', MSSRF Proceedings, Feb., 10-11, 1998, p-110).

'The terraces in Pamban area are composed of 5 small beds, each averaging 0.5 to 1.5 meters with alternate fossiliferous bed. When these beds are extended to other areas of the island, a thick coralline terrace, almost in continuity with those beds, has been noticed in the village near Ariyangundu. These corals are noticed to extend even in the low tide regions with varying height of 1.5 to 3 meters… Around Rameshwaram Island, mainly Northeast of Pamban, large numbers of coral stags is recorded. ***The nature of their presence with the formation of sharp pinnacles and debris around them, suggests the possible resultant effects of regression of sea level and the subsequent denudational processes probably, in the surf zone.***

The age determination by means of ^{14}C method for the five samples are found to be varying from 5440 $\pm$ 60 years B.P. to 140 $\pm$ 45 years B.P. Jinadasa (1988 & 1989) has also reported similar aged coastal sediments fro the western coast of Sri Lanka.

The uppermost terrace in Ariyangundu in the Rameshwaram Island gives an age of 5440 $\pm$ 60 yrs. B.P., while the next terrace at about 10 cm below the previous sample level indicates an age of 3920 $\pm$ 160 yrs.B.P. The upper terrace located at Mandapam shows an age of 3670 $\pm$ 65 yrs.B.P. and just 20 cm below that one gives an age of 2630 yrs. B.P.

A coral sample which seems to be recent, occur in the level of MSL at the east of Ramakrishnapuram near Rameshwaram shows an age of 140 $\pm$ 45 yrs.B.P. ***The coastal terrace found in Rameshwaram Island has***

shown that the coral growth has been initiated around that period in that island and continue to emerge or withdrawal of sea level might have caused the second terrace around the years of 3920 ± 160 yrs. B.P. in the island. The other terraces younger in nature in the island must have been available in the same place because of the continuity of coral existence even today in the low tide region, probably, much in deeper portions. At the same time, the corals, very closely placed and just opposite to the island, indicate an age of 3650 yrs.B.P. as the upper most limit. This may be interpreted as the period of first coral growth initiated in the Mandapam beach. The period earlier than that might not have been suitable for coral growth in that region or the area must have been submerged to encourage nearshore coral growth. Since that period, coral growth must have flourished both in the island and in the mainland areas.

When the landsat imagery has been scrutinized, the corals which have shown 5440 yrs. B.P. at Aryangundu is found to be in distinct horizons within the island, making perhaps an older coral zone. Thankachimadam and Mandapam region display similar spectral signatures, but differing from the earlier one, noticed at Aryangundu. It is considered to be of younger in nature. From the existing data, it is inferred that there was a coral island existing even before the formation of Mandapam ridges. From that, Rameshwaram patch, Aryangundu area must have been developed later than 5000 years and subsequently, the Pamban extensions. During the period earlier to 5000 years, the channel between mainland and Rameshwaram must have been somewhat deeper or the Vaigai river must have debouched the sediments in thechannel and made the channel unworthy for coral growth." (G.Victor Rajamanickam, V.J.Loveson, ' Results of radiocarbon dating from some beach terraces around Rameshwaram Island, tamil Nadu' in G.Victor Rajamanickam ed., 'Sea Level Variation and its impact on coastal environment', Tamil University, Thanjavur, 1990)

4.3.8. Devipattinam – Kilakkarai Beach Ridges

'The coastal zone between Devipattinam to Kilakkarai, define interesting piece of land furnished with peculiar arrangement of beach ridges, This sharp, triangular strip of land might have been drawn the support of tectonic activity mainly caused by Vaigai fault system during the course of its development. The coastal area lying north side of Vaigai river is comparatively having 2 to 3 series of beach ridges whereas the southern side is furnished with 6 to 7 series of beach ridges. It may be suggested that area of southern side of Vaigai River is attended by intensive marine action and deposition compared to northern area. The beach ridges along southern part of Vaigai river are curvilinear and showing complex pattern of arrangements of beach ridges extending from Mandapam point to Kilakkarai. While studying the cross profile between Ramanathapuram and Periyapattinam coast, the displacement of beach ridges shows the same arrangement pattern around the present day Coleroon river. By comparing this, one can suggest that once Vaigai might have been flowing along Ramanathapuram to Periyapattinam coast. This is also confirmed by the bathymetric study around Periyapattinam offshore area (Loveson &

Rajamanickam, 1989).' (V.J.Loveson, G.Victor Rajamanickam, K.Anbarasu, 'Remote sensing application in the study of sea level variation along the Tamil Nadu coast, India' in G.Victor Rajamanickam ed., 'Sea Level Variation and its impact on coastal environment', Tamil University, Thanjavur, 1990, p- 187-188)

Sedimentation:

4.3.9. Rameshwaram Island sand spit

'East of Rameshwaram, a long sand spit of about 20 km length is formed and it tends to grow longer and wider. The width of this sand spit is about 2 km near Uthalai, reduced to 1250 m at Mukkuperiyar, 750 m at Dhaushkodi and 150 m at just east of Arimunai and converges on the tip at Arimunai. The beach berm is found to be highly elevated along the sand spit bordering GOM, but very low and flat along the side bordering Palk bay. There is a marked depression in the sand spit level between Palk Bay and GOM, between Dhabushkodi and Arimunai. Due to such level difference, the water overflows during spring tide particularly from Bay carrying the fine sediment to the backshore regions. Most of the time, the water is stagnant and remains along the trough of the spit. This low lying region is fully occupied by water column during monsoon season.' (NEERI EIA, p-1.12)

4.3.10. Sediment Load to Palk Bay and Gulf of Mannar

'The sediments carried by the rivers and by the surf zone currents as littoral drift get partly deposited in permanent, semi-permanent and temporary sinks along the Indian coast. The Gulf of Kachchh, Gulf of Khambhat, Gulf of Mannar, Palk Bay and Sandheads act as major sinks. In order to identify the extent of their significance for the sediment deposition, a study was undertaken to evaluate the long-term sediment deposition in the above regions.

Vaigai, Vaishali and Valryar rivers and the littoral transport by various sources from the northern part of the Tamil Nadu coast are the major sediment sources entering the Palk Bay region. It is largely occupied by sand banks, numerous shoals, sand spits and islands. Occurrence of cyclonic storm during north-east monsoon is common in the Nagapattinam–Poompuhar region, which causes an erosion along this region. The sediments are transported southerly and deposited in the Palk Bay. Low wave action inside the bay and protection from the southerly waves encourages the deposition of sediment. In the present study, the estimation based on eq. (1) covering the area of 117 km × 105 km, shows that 0.3×10^{10} m^3 sediment got deposited over a period of 51 years. Assuming that the rate of accumulation is uniform over the years, it is estimated that between the years 1931 and 1982, the sediment deposition has caused a reduction in water depth of about 0.32 m, i.e. 0.006 m per year. The depositional feature observed in the present study agrees with the formation of very shallow areas in the Palk Bay. The enlargement of the Manamelkudi sand spit and the emergence of sand banks between Point Calimere and Point Pedro (Sri Lanka) across the entrance of the Palk Bay are the evidences of the depositional features occurring in this region. Usha and Subramanian stated that the accretion pattern was observed in the Palk Bay at Ammapattinam, Mandapam and Rameswaram. Loveson *et al*. have discussed that large amounts of sediments from the pediments are removed constantly by rainfall and carried by minor rivers and dumped into the Palk Bay.

Along the Gulf of Mannar, the sea–land boundary is almost uniform and regular but for inundation in a few places, where it is intercepted by rivers forming tidal inlets. Tambraparni, Vembar and Vaipar and some other inlets are present in this region. At present, Vembar river is not supplying sediments into the sea, except during the rainy days in the north-east monsoon period. Wave action is low during most of the time and hence, the formation of sand dune is common in this region. The estimation using equation (1) covering an area of 19.5 km × 13.5 km at the Gulf of Mannar, shows that 0.02×10^{10} m^3 sediment got deposited over a period of 75 years. Assuming that the rate of deposition is uniform over the years, it is found that the deposition between years 1906 and 1981 has caused a reduction in water depth of about 0.72 m, i.e. 0.010 m per year. There are a number of coral banks and islands present in the Gulf of Mannar. Formation of sandy islands off Tuticorin region shows as sinks having accumulation of sand. Large beach storage of sands between Manapad and Tiruchendur, Vembar and Valinokkam and along Rameswaram island indicates depositional features of the littoral sediments. (P. Chandramohan, B. K. Jena, and V. Sanil Kumar, "Littoral drift sources and sinks along the Indian coast", in CURRENT SCIENCE, VOL. 81, NO. 3, 10 AUGUST 2001, p-295)

4.2.11. Study of suspended sediments using remote sensing

Prakash Chauhan et al., have used remote sensing technique to study suspended sediments along the Tamil Nadu coast both during the monsoonal (ie., North East monsoon; imagery dated 17-12-1990) and the non-monsoonal periods (image dated 18-04-1990). The maps they have prepared will be useful here for us and hence they are reproduced here.

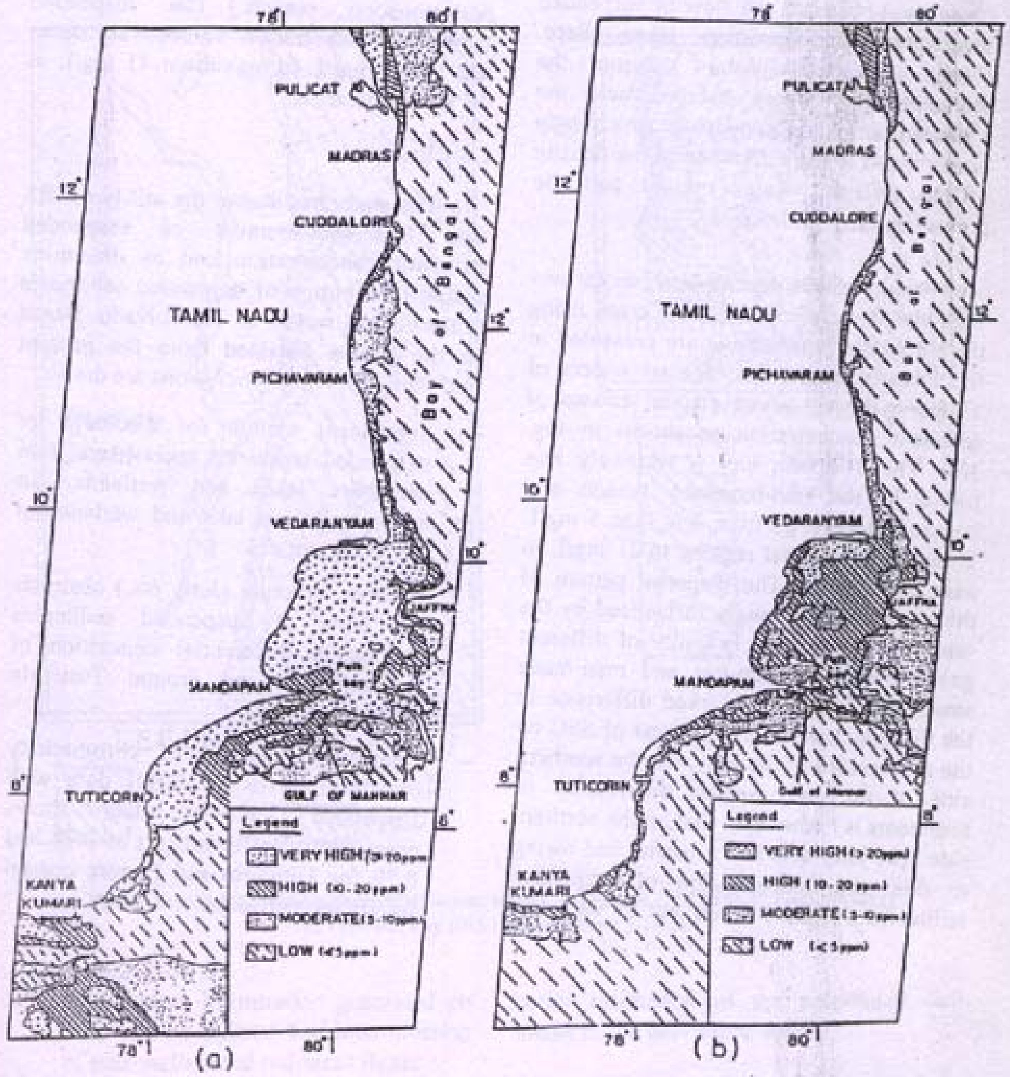


Fig. 3(a). Suspended sediment concentration in Tamil Nadu coastal waters - Monsoon season (17-12-1990), based on IRS LISS I data.

Fig. 3(b). Suspended sediment concentration in Tamil Nadu coastal waters - Non-monsoon season (19-4-1990), based on IRS LISS I data.

They have noted that 'during the non-monsoon season the sediment boils were observed near Vedaranyam and Mandapam.' This they say 'may be attributed to the difference of the density of the different water masses and the prevailing current direction.' (Prakash Chauhan, Sailesh Nayak, R.Ramesh, R.Krishnamoorthy, S.Ramachandran, "Remote Sensing of Suspended Sediments along the Tamil Nadu Coastal Waters", in Photonirvachak, Vol.24, No.2, 1996, p-105-114).

An attempt to study the sedimentation dynamics using remote sensing off the Vedaranyam coast has been made by Usha Natesan recently. ('Role of satellites in monitoring sediment dynamics', in CURRENT SCIENCE, VOL.

86, NO. 8, 25 APRIL 2004, p-1068-1069). Let us note the salient points from her article:

"Vedaranyam, the study area is located in the southeast coast of India and has a peculiar projection, which is of interest for geologic and geomorphic studies. Tamil Nadu coast experiences a climate strongly influenced by the southwest (June–September) and northeast (October–December) monsoons. Formation of Point Calimere projection is due to two constantly opposing wave directions, such as northeast and southeast, with one set of waves predominant over the other. Further, the foreland formation is determined by the rate at which the stream delivers the sediment and the rate at which the waves can winnow and move the sediments in either direction away from the mouth. The coastline is consequently affected predominantly by waves from the northeast. This is clearly reflected by the shape of the foreland, which has veered windward.

Sediment distribution at Vedaranyam during different seasons is depicted in Figure 2 *a*–*c*. From the figures, the direction of sediment movement can be clearly identified. Sediments move towards north during southwest monsoon (Figure 2 *a*, *b*) and vice versa during northeast monsoon (Figure 2 *c*). As the sediments are transported by the longshore currents, the directions indicate the movement of currents. The above observations from satellite data agree with the longshore current direction perceived through conventional methods.

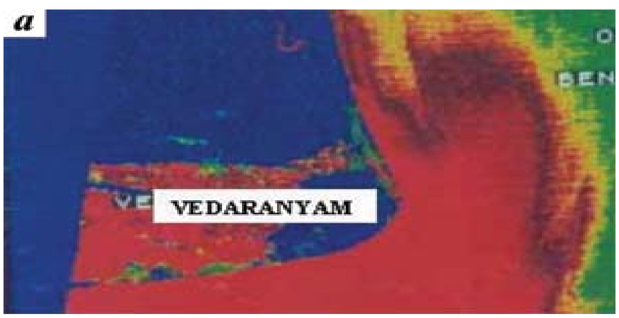


Fig. 2.a. Sediment distribution at the onset of SW monsoon

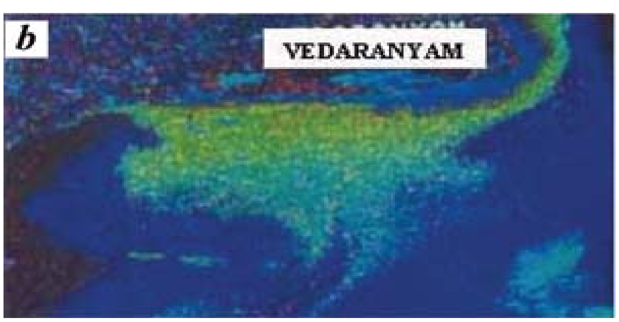


Fig. 2. b. End of SW monsoon

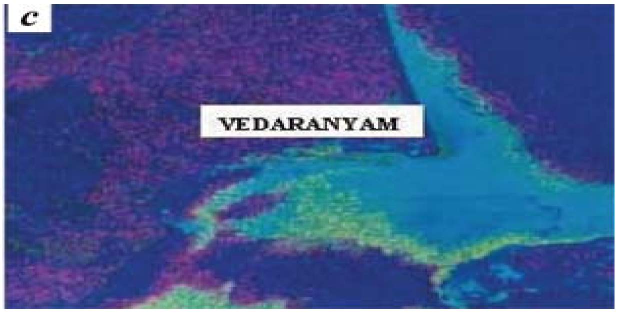


Fig. 2. c. Sediment distribution during NE monsoon

Table 1. Data products used		
Date of acquisition	Sensor Bands	Season
13–06–1988	TM 3	Onset of southwest monsoon
28–09–1983	MSS FCC 4, 2, 3	End of southwest monsoon
23–11–1989	MSS FCC 4, 2, 3	during northeast monsoon

With the onset of southwest monsoon, sediments were disturbed considerably (Figure 2 *a*). Tidal flats at Vedaranyam acting as a source for sediment is clearly identified from the image. Daniel observed that the sediments are discharged from tidal flats due to soil erosion. The retreat of seawater eroding the banks of tidal flats contains high amount of sediments in suspension. This appears bright red in colour around the mouth of tidal flats. As the sediments move towards the north due to the longshore currents, their concentration is reduced which is indicated by yellow colour in Figure 2 *a*. At the end of the southwest monsoon, initial disturbances are very much reduced. Sediments moving towards the north are obstructed by the projection at Vedaranyam (Figure 2 *b*). Therefore, it takes a turn near that tip and then follows the coastal configuration.

In contrast, during the northeast monsoon season, sediments transported from north are unable to take a bend around the Vedaranyam tip and hence dissipate a greater part of it (Figure 2 *c*). A portion of the sediment is moving towards the east and the rest of it moves downsouth of Vedaranyam along with the longshore currents.

From the conventional data seasonal sediment distribution patterns in near-shore/ offshore are almost impossible to obtain. Satellites are the only source of providing such information. The present study proves that the satellites play a significant role in monitoring the sediment dynamics.”

4.2.12. Physico-chemical parameters of Palk Bay

"This area is under the spell of both southwest and northeast monsoon. Southwest monsoon contributes little towards the total annual rainfall of this area. Rain is moderate to heavy during October to January (northeast monsoon). The mean annual rainfall varies from 820 to 1650 mm. The monthly average temperature of the waters of the Palk Bay ranges between 24.6° and 29.1°C (minimum during December and the maximum during May). The tidal elevation is around 1m. Palk Bay is practically calm except during the northeast monsoon when turbulent condition prevails (Gopinadha Pillai, 1969). The salinity of the water decreases gradually along an axis in the southwest direction running from the strait. High saline water is 'pocketed' in the south-west corner of the bay. This may be due to the incursion of the Gulf of Mannar water through Pamban pass. The density of the water also decreases along an axis on the southwestern direction from the Strait.

The North-east wind velocity at Nagapattinam is about 8 to 10 knots (North of Palk Bay) and at Pamban the wind strength reduces between 2 and 4 knots (South of Palk Bay). Temperature, salinity, density and dissolved oxygen values of the surface waters of the Palk Bay would indicate that the Bay of Bengal waters entering into the Palk Strait influence the hydrographic condition of the Palk Bay, unlike the Gulf of Mannar waters whose influence on the hydrological parameters of the Palk Bay is only minor (Murty, A.V.S. and P. Udayavarma, 1964. The hydrobiological features of the waters of Palk Bay during March. *J. mar. biol. Ass. India,* 6(2):7-216.).

The bottom sediments of Mandapam consist of silt and clay, clayey silt and sand, fine to medium sand, coarse sand and coarse sand with gravel. Distribution of various size classes indicates that the offshore sediment in this area is usually unimodal with the primary mode around 1.5 to 2 (medium sand) and a secondary mode around 3.5. Beach samples have prominent mode around 2.25, 1.75, 2.75 and 3.25 suggesting the polymodal nature of the sediments. Grain size parameters of the Palk Bay samples near Mandapam are shown in Table 28. The distribution patterns of heavy minerals are shown in Table 29 (Mallik, 1983). Most of the offshore areas contain a high amount of opaques (16-80%) with maximum concentration in small patches. Majority of opaques consist of ilmenite. Other minerals are magnetite, rutile, hydroxide of iron and minor amounts of pyrite (Mallik, 1983). (p-58)

Inshore waters of the Palk Bay during the monsoon become muddy due to the presence of suspended sand and silt stirred up from the sandy shore by wave action. The large degree of silt settlement has a remarkable effect especially during the northeast monsoon. Cyclonic winds during monsoon season, with high velocity, cause enough mechanical damage to the corals of this area. Huge quantity of silt settlement during the northeast monsoon has a remarkable effect on the distribution and diversity of the coral reef associated plants and animals. (p-66)" ('CORAL REEFS OF INDIA' - State-of-the-art report, *ENVIS Publication Series :*

4/2001, ENVIRONMENTAL INFORMATION SYSTEM CENTRE, Centre of Advanced Study in Marine Biology, Parangipettai - 608 502, Tamil Nadu, India)

4.2.13. Longshore currents and sediment transport

"The objective of the work was to study the variations in wave climate based on the data collected in two different years, longshore currents and sediment transport along the Nagapattinam coast.

The daily variations of longshore current estimated based on Longuet–Higgins equation (*V*L) and Galvin's equation (*V*G) with the measured current at three stations shows that the average longshore current speed was 0.25 m/s at all stations, and it was predominantly towards north during March–October and towards south during November–February. This matches with the earlier study carried out in the region.

During 1998–99, strong longshore currents (> 0.5 m/s) were observed in November and December. Longshore current was relatively weaker (< 0.5 m/s) during the rest of the year. During 1995–96, strong longshore currents (> 0.6 m/s) were noticed in May, June, November and December. Longshore current was relatively weaker (< 0.3 m/s) from January to April. The computed longshore current speed estimated based on Galvin and Longuet–Higgins was about 50% of the measured one. The average correlation coefficient between measured and computed data was around 0.75.

The annual longshore sediment transport was 0.175×10^6 m^3 in the northerly direction (March to October) and 0.273×10^6 m^3 in the southerly direction (November to February). The annual net sediment transport was 0.098×10^6 m^3 in the southerly direction and the annual gross sediment transport was 0.448×10^6 m^3.

The study shows that the average annual net sediment transport was 0.095×10^6 m^3 in the southerly direction and average annual gross sediment transport was 0.432×10^6 m^3. The net sediment transport is towards the south, since the wave activity is strong mainly during the northeast monsoon period for this coast. The annual net sediment transport computed using the estimated breaker angle gives a value of 0.098×10^6 m^3 and the difference between the estimated sediment transport rates based on the two methods is around 3.5%. This is due to error in observation of the surf zone width, which is based on visual observation. Also the wave–wave and the wave– current interactions in the surf zone are not considered. Hence the sediment transport rates estimated based on CERC formula using the measured wave characteristics can be taken as the representative value for this coast.

An earlier study shows that transport rate was around 0.1×10^6 m^3/month in November and December, and was low (< 0.03×10^6 m^3/month) in March, April and July. The predominant direction of transport is northerly from March to October and southerly from

November to February. Though the annual gross transport was found to be 0.6 × 10^6 m^3/year, the annual net transport was very low showing less than 0.006 × 10^6 m^3/year (towards the north). ***The difference in longshore sediment transport rates between the present study and the earlier study was that in the present study the wave direction of the sea and swell waves was considered in estimation, whereas it was neglected in the earlier study. The energy at the second peak was more than 50% of that at first peak in 46% of the data collected. The coastal inclination of the study area is 359° with respect to north. A wave direction more than 89° will cause a northerly sediment transport and one less than 89° will cause a southerly transport. The average direction of sea waves was 106° and that of the swell waves was 99°. Hence a small error of the order of 0.5° in the estimate of the breaker angle may cause a change in direction of the sediment transport rate. The error in wave directions can lead even to a wrong direction for the net calculated sediment transport. The present alignment of the coastline is found to be sensitively balanced, since any slight increase in approaching wave angles may significantly increase the volume and may also alter the direction of sediment transport in this region. For a coastal inclination of 4° with respect to the north (5° more than the present alignment), the net sediment transport increases to 1.85 times the present value, and for 354° (5° less than the present alignment) the value reduces to 0.12 times the present value.***

It is important to notice that no cyclone had occurred during both the study periods, which is otherwise common during the northeast monsoon period. It has been observed that for the occurrence of every cyclone, there was a permanent loss of beach due to erosion1. As the Palk Bay is well protected for southerly waves, no mechanism is set to transport these deposited materials towards the north.

The comparison of the wave data collected during 1995–96 and those collected during 1998–99 shows that the statistics of the wave parameters was almost the same during both the periods, but the events did not occur at the same time. The average value of the breaker angle for the sea waves was – 3.3° and that for the swells was 2°; the breaking sea and swell waves were mainly from the southerly direction during March–October and mainly from the northerly direction during the rest of the year. The ratio of spectral energy at the first and second spectral peaks estimated shows that the energy at the second peak is more than 50% of that at first peak in 46% of the data collected in 1995–96 and 43% collected in 1998–99. The daily longshore currents measured show that the average longshore current speed was 0.25 m/s; the longshore current was predominantly towards the north during March–October and towards the south during the rest of the year. The difference between the estimated sediment transport rates based on the two methods is around 3.5%. This is due to the error in observation of the surf zone width. The annual net sediment transport was 0.098 × 10^6 m^3 in the southerly direction and annual gross sediment transport was 0.448 × 10^6 m^3, and this contributes to the supply of sediment to the Palk Bay.” (V. Sanil Kumar, N. M. Anand and R. Gowthaman, “Variations in nearshore processes along Nagapattinam coast, India”, in CURRENT SCIENCE, VOL. 82, NO. 11, 10 JUNE 2002, p-1381 – 1389)

4.2.14. Studies conducted on the Wave Climate, Tides and Currents by the NEERI EIA

‘The winds blowing over the ocean surface has the direct effect on wave generation as it is related to wind speed, extent of fetch and wind duration. The south west monsoon influences this pattern from June to September. The average speed of the wind during south west monsoon period is about 35 km per hour frequently rising up to 45-55 km per hour. The average speed of the wind during north east monsoon (October to January) prevails around 20 km per hour. Tropical storms known as cyclones frequently occur in the Bay of Bengal during October to January.

Wave Measurement

The observations on wave measurement show that significant wave height varied from 0.46 to 1.12 in March, 0.33 to 1.18m in April, 0.46 to 1.74 m in May, 0.71 to 1.78 m in June, 0.68 to 1.6 m in July, 0.68 to 1.49 m in August, 0.64 to 1.76 m in September, 0.54 to 1.35 m in October, 0.40 to 1.13 m in November, 0.40 to 1.12 m in December, 0.35 to 1.03 m in January and 0.35 to 1.23 m in February.

The maximum wave height varied from 0.67 to 1.78 m in March, 0.44 to 1.73 m in April, 0.66 to 2.81 m in May, 0.98 to 2.72 m in June, 0.91 to 2.45 m in July, 0.89 to to 2.48 m in August, 0.89 to 2.96 m in September, 0.66 to 2.94 m in October, 0.59 to 1.60 m in November, 0.48 to 1.73 in December, 0.47 to 1.68 m in January and 0.45 to 1.79 m in February.
The wave direction (with respect to north) mostly prevailed 140^0 to 230^0 in southwest monsoon (June to September), 85^0 to 150^0 during north east monsoon (October to January), and 90^0 to 200^0 during fair weather period (February to May). The wave direction is highly variable in January and May. The zero crossing wave period predominantly varied 3 to 8 s in December to April, 4 to10 s in May and 4 to 9 s during rest of the year.

Wave refraction

Arimunai to Vedaranyam

This segment of the coastline lies in Palk Bay and waves propagating from south (during south west monsoon and fair weather period) do not enter this region. Studies are indicating that even during the north east monsoon, waves are found not entering the bay and get attenuated across the shoals of middle banks and south banks between Vedaranyam and Matakal (Sri Lanka). Part of wave energy with less magnitude enters the bay through Pedro Channel and reach the coast between Puduvalasai and Gopalpatnam. Wave refraction between Arimunai and Vedaranyam during NE monsoon is shown in the following figure.

Wave Period

During SW monsoon, the wave period predominantly persisted 9 to 10 s between Vembar and Keelamundal, and 6-8 s between Uthalai and Dhanushkodi. During the NE monsoon, it predominantly persisted 5-10 s between Vembar and Keelamundal, and 5-8 s between Uthalai and Dhanushkodi east. In fair weather period, it remained 6-10 s along Vembar to Keelamundal and 9-10 s along Uthalai to Dhanushkodi. The study shows that the waves approaching the coastline consist of both seas and swells.

Tides and Currents

The tides in this region are semidiurnal. The various important tide heights with respect to chart datum near Pamban pass are as follows:

Mean Higher High Water Springs	=	0.70 m
Mean High Water Neaps	=	0. 48 m
Mean Sea Level	=	0.41 m
Mean Low Water Neaps	=	0.32 m
Mean Low Water Springs	=	0.06 m

It shows that the average spring tidal range is about 0.64 m and the neap tidal range is about 0.16 m.

Longshore Currents

The longshore current speed remained weak (< 0.1 m/s) throughout the year between Keelamundal and Vedalai and along the northern coast of Rameshwaram from Arimunai to Ariyaman. Consequently, it was relatively moderate (>0.1 m/s) throughout the year between Sippikulam and Naripaiyur and along the southern coast of Rameshwaram i.e. from Uthalai to Mukkuperiyar.

The spit between Dhanushkodi and Ariyaman in Gulf of Mannar experienced relatively stronger currents during fair weather period (March to may) and remained weak during southwest monsoon and northeast monsoon periods (June to February). It indicates that the stronger currents prevailing in the adjacent coasts during SW/NE monsoons becoming weaker between Dhanushkodi and Arimunai. This phenomenon of sudden weakening of littoral currents causes the littoral drift to deposit and form series of sand shoals near Arimunai. Such prolonged deposition of littoral drift over many years can be attributed to formation of numerous islands and shallow shoals across the strait between Arimunai and Talaimannar (SriLanka) called Adam's Bridge.

The Uthalai coast facing Gulf of Mannar experienced stronger longshore currents (0.2 – 0.5 m/s) throughout the year, followed by a segment of

the coast between Vembar and Naripayur (0.2 – 0.4 m/s) with exposure to relatively high wave energy environment.
The prevalence of weak longshore currents between Keelamundal and Vedalai is causing deposition of littoral drift on either side, as evidenced by the occurrence of many offshore islands and submerged shoals.

Although the Pamban Pass, connecting Palk Bay and Gulf of mannar break the continuity of longshore current between the mainland and Rameshwaram Island, the magnitude of the current on either side of Pamban Pass is found to be very weak. This reduces the volume of littoral sediments approaching Pamban Pass which in turn reduces the quantity of sediment passing through Pamban pass from Gulf of mannar to palk Bay.

The longshore current direction prevailed northerly during SW monsoon and fair weather period, and southerly during NE monsoon between Sippikulam and Uthalai. The entire coast of Rameshwaram facing Gulf of Mannar, experienced the current in the westerly direction throughout the year, except in June, july. This phenomenon of northerly currents along the mainland and westerly current along Rameshwaram creates a zone, wherein, most of the littoral drift will get deposited. Only a fractional proportion is expected to move from this region by tide induced currents towards the Adam's Bridge and in turn the quantity of sediment entering Palk Bay from Gulf of Mannar. These sediments deposited at shoals is supplied back to the littoral system for the mainland, when the longshore currents move towards south during the ensuing monsoon.

Although the longshore current was extremely weak along the sand spit facing Palk Bay, it tends to be easterly during SW monsoon/fair weather period and westerly during NE monsoon. Similarly, at Ariyaman, the longshore current direction was southerly during SW monsoon / fair weather period and northerly during NE monsoon, indicating just opposite to the phenomenon observed in Gulf of Mannar. Such processes once again indicate the accumulation of littoral drift on either side of Rameshwaram Island during SW monsoon and removal during NE monsoon making this region as a sediment storage reservoir.

Ocean Current Studies

Continuous measurements on tidal current speed and direction were carried out for three seasons at 4 locations viz., 1) stn. C1 – off Arimunai-Adam's Bridge, 2) stn. C2 – off Uthalai (Gulf of mannar), 3) stn. C3 – Pamban Pass, and 4) stn. C4 – of Tharuvai (Palk Bay). The measured currents were resolved into parallel and perpendicular components with respect to the coastline.

SW monsoon (June to September)

Near Arimunai (stn.C1) the average current speed occurred around 0.2 m/s with the maximum and minimum speed of 0.3 m/s and 0.05 m/s respectively both at surface and bottom. The variation of current direction had not followed the tidal phase. It showed consistent northwesterly flow over one tidal cycle and changed to southeasterly flow for the subsequent tidal cycle. It indicates that current shifted its flow direction for alternate tidal cycles rather than flood and ebb tidal phases. The shore parallel component of currents indicates that for larger tidal range, the flow was in westerly direction and for small range in easterly direction. The shore perpendicular component of currents indicates that the flow consistently existed from Gulf of Mannar into Palk Bay. The northwesterly and south westerly currents over different tidal cycles were found to bw equally predominant.

At Uthalai (stn.2) in GOM, the average current prevailed around 0.1 m/s with the maximum and minimum of 0.2 m/s and 0.05 m/s respectively. Similar to Stn.C1, the bottom current was seen responding to tides flowing east over one tidal cycle and west during the subsequent tidal cycle. The direction of flow was predominant in southeasterly direction for larger tidal range and north westerly direction for small tidal range. The shore parallel component of currents indicates that the flow shifted in southeast and north west both at surface and bottom. The shore perpendicular component of currents indicates that the flow shifts towards north east and south west both at surface and remains consistently northeast at bottom.

The current speed near Pamban Pass (stn.C3) was found to be strong showing an average of 0.5 m/s, with the maximum of 1 m/s and minimum of 0.1 m/s. Current direction remained consistently northeast flowing from GOM into Palk Bay. Variation of current speed shows that the magnitude of current speed was more during flood and less during evv tide indicating the influence of tides over the seasonal unidirectional flow. The shore parallel component of currents indicates that the flow is into Palk Bay with high speed during flood tide and low speed during ebb tide. The shore perpendicular component of currents indicates that the flow is across the Pamban with high speed during flood tide and low speed during ebb tide.

At Tharuvai (stn.C4), the average current speed of 0.2 m/s with the maximum of 0.3 m/s and minimum of 0.1 m/s were observed both at surface and at bottom. The flow was unidirectional towards south east but the current speed varied with tidal phase. Current speed was high during flood tide and low during ebb tide indicating the strong influence of seasonal circulation current towards northeast during south west monsoon. The shore parallel component of currents indicates that the flow was towards southeast at surface and bottom. The shore perpendicular component of currents indicates the flow was towards northeast both at surface and at bottom.

The measurement shows that during SW monsoon when tidal range is large, the opposite direction of flow prevails between Adam's Bridge (stn.C1) and Uthalai (stn.2) would cause the water mass to flow from the GOM to Palk Bay. This flow would transport sediments into Palk Bay from GOM. On the other hand, when the range is small, the divergence of flow occurring near the Adam's Bridge and Uthalai would initiate a flow from Palk Bay into GOM through Adam's Bridge.

Northeast Monsoon (October to January)

Near Arimunai (stn.C1), current was generally weak showing an average of 0.1 m/s, with the maximum of 0.2 m/s and minimum of 0.05 m/s. The flow direction remained unidirectional towards west both at surface and bottom. The current speed increased during flood tide and reduced during ebb tide. The shore parallel component of currents indicates that the flow was consistently towards northwest at surface and bottom. The shore perpendicular component of currents indicates the flow prevailed northeast at surface and south west at bottom.

The variation of currents at Uthalai (stn.2), showed an average current speed of 0.08 m/s, with the maximum of 0.15 m/s and a minimum of 0.04 m/s. The bottom flow was nearly unidirectional towards southeast. The shore parallel component of currents indicates that the flow was oscillating in southeast and northwest at surface and remaining consistently southeast at bottom. The shore perpendicular component of currents indicates that the flow was towards northeast both at surface and bottom.

The currents at Pamban pass (stn.C3) prevailed strong with the average of 0.1 m/s, maximum of 1.4 m/s and minimum of 0.5 m/s. Currents remained consistently unidirectional around 225^0. The change in tidal phase caused the variation in current speed showing stronger currents during ebb tide and reduction in current speed during flood tide. It indicates that the flood tide propagates fro GOM to Palk Bay and vice versa. The shore parallel component indicates that the flow was consistently from Palk Bay into GOM both during ebb and flow tides. The shore perpendicular component of currents indicates the flow was across the Pamban from Rameshwaram to Mandapam.

The current was found to be weak off Tharuvai at Palk Bay (stn.4) showing the average speed of 0.1 m/s, maximum of 0.13 m/s and minimum of 0.04 m/s. Similar to stn.C3, the current flow was unidirectional towards 250^0, but the speed was high during ebb tide and low during flood tide. The shore parallel component of currents indicates that the flow was towards northeast both at surface and bottom. The shore perpendicular component of currents indicates that the flow was towards southwest both at surface and at bottom.

The observation during northeast monsoon indicates thet the current flow was more influenced by seasonal flow than by tides. Stronger currents were observed during ebb tides flowing from Palk Bay into GOM through Pamban pass. The currents were generally weak in GOM and Palk Bay (stns.C2 and C4). Significant flow from Palk Bay was observed through Adam's Bridge also. Such current pattern during NE monsoon can transport and exchange the sediments from Palk Bay into GOM.

Fair weather period (February to May)

The current at Arimunai (stn.1) was generally weak showing average of 0.1 m/s, with the maximum of 0.2 m/s and minimum of 0.05 m/s. The current flow was found to be unidirectional towards northwest both at surface and bottom. The shore parallel component of currents indicates that the flow was towards northwest both at surface and at bottom. The

shore perpendicular component of currents indicates the flow was changed in direction in north east and south west both at surface and bottom.
At GOM (stn.C2), the current was weak with average of 0.1 m/s, maximum of 0.2 m/s and minimum of 0.04 m/s. The flow remained unidirectional consistently towards 305^0, but the current speed varied randomly between 0.04 and 0.12 m/s. The shore parallel component of currents indicates that the flow was towards northwest both at surface and bottom. The shore perpendicular component of currents indicates the flow changed the direction from northeast to southwest both at surface and bottom.
The flow through the Pamban Pass (stn.C3) was quite distinct, showing the average speed of 0.3 m/s, maximum of 0.6 m/s and minimum of 0.04 m/s. Current flow was noticed towards 45^0, i.e., into Palk Bay during flood tide and towards 225^0, i.e., into GOM during ebb tide. The shore parallel component of currents indicates that the flow was into Palk Bay during flood tide and into GOm during ebb tide. The shore perpendicular component of currents indicates the flow was changing its direction across the Pamban Pass between Mandapam and Rameshwaram.

During fair weather period, the change in current was observed over the tidal phases at Pamban Pass. The study shows that the current flows mostly parallel to the coast. The general circulation of current in northwesterly direction dominates the tide induced current. This would help the sediments to move by tide induced currents from GOM to Palk Bay prevailing through Pamban pass and to some extent through Adam's Bridge. (NEERI EIA, p- 2.2 – 2.11).

4.2.15. Studies on Sedimentary Transport by the NEERI EIA

General Information

Rameshwaram Island, the geological formation of coral atoll with huge sand cover between India and Sri Lanka plays a vital role on the processes of exchange of littoral drift between east coast and west coast. It separates the sea in the north by Palk Bay and south by Gulf of Mannar. The wave sheltering effect due to Sri Lanka Island, the large siltation in Palk Bay, the presence of numerous offshore islands in GOM, the growing sand spit along Dhanushkodi and the shallow reef (Adam's Bridge) between Arimunai and Talaimannar (Sri Lanka) largely modify the sediment movement. It is strongly evident that the coastal processes taking place around the Rameshwaram Island and the exchange of the littoral drift between GOM and Palk Bay significantly determine the supply of sediments to the rest of the east coast and in turn the stability of the region.

Longshore sediment transport

During SW monsoon, the longshore sediment transport was considerable ($>10X10^3$ m^3/month) along the spit facing GOM and negligible on Palk Bay side. Very close to the tip i.e., near Arimunai, the longshore transport direction dominated in easterly direction indicating the movement from GOM to Palk Bay through Adam's Bridge.

During NE monsoon, the values of longshore transport rate was relatively low along the spit facing GOM and negligible in Palk Bay. It is noticed that the long shore sediment transport rate was considerable ($>10X10^3$ m^3/month) in January between Uthalai and Mukkuperiyar. The sediment transport direction was consistently towards west in GOM and east in Palk Bay.

In fair weather period, the longshore sediment transport was low along the spit facing GOM and Palk Bay. The transport direction was observed to be westerly near the tip facing GOM. It shows that in February, April and May the sediment drifts from Palk Bay to GOM and the net quantity is found to be 8000 m^3, 6000 m^3, 20000 m^3 respectively. Consequently, in March, June, July, August and September, it drifts from GOM towards Palk Bay and the respective quantities are 8000 m^3, 35000 m^3, 10000 m^3, 4000 m^3 and 1000 m^3 respectively. There was no significant movement of sediment observed during October to January. It means that during SW monsoon, sediments move from GOM to Palk Bay and during fair weather period from Palk Bay to GOM. No noticeable exchange due to wave induced longshore transport takes place in NE monsoon. It is noticed that over a period of one year, a net volume of 27000 m3 sediments as a wave induced longshore transport move from GOM to Palk Bay around Adam's Bridge.

The sediment transport rate is practically negligible throughout the year, particularly between Valinokkam and Kondugal in GOM, and between Arimunai and Ariyaman in Palk Bay. The geomorphological formation of inner part of GOM and the presence of many offshore islands are the main reasons for wave attenuation and reduction in sediment transport.

The coastal segment between Tuticorin and Valinokkam experienced relatively higher sediment transport rate during NE monsoon, but remains calm during the rest of the year. However, the small stretch between Vembar and Naripaiyur experienced relatively higher sediment transport rate also during SW monsoon. The only coastline between Uthalai and Arimunai experienced relatively higher sediment transport rate both during SW monsoon and fair weather period, with relatively low sediment transport during NE monsoon.

The direction of sediment transport during SW monsoon remained easterly between Tuticorin and Arimunai except near Kondugal and Dhanushkodi, where it was in the opposite direction i.e., towards west. Due to the reversal of sediment transport direction near Kondugal, the easterly transport gets deposited in the vicinity of Pamban Pass, Kurusadai Tivu and Shingle Tivu. Once again easterly transport along Vedalai terminates near Dhanushkodi which would cause the formation of shoals in the vicinity of Arimunai. Such formation of submerged shoals was observed south of Arimunai during the study period. The prevalence of easterly transport at Arimunai might cause part of the sediments deposited as shoals to migrate towards Adam's Bridge and enter into Palk Bay. This process of sediment migration was noticed close to Adam's Bridge. Hence a small proportion of littoral drift deposited during SW monsoon close to Pamban Pass and Arimunai has the tendency to enter Palk Bay.

During the NE monsoon, the sediment transport rate was very low moving in southerly direction between Tuticorin and Valinokkam and it was negligible between Valinokkam and Mandapam. Between Kondugal and Arimunai, the transport was relatively low in westerly direction. It implies that there will be a deposition of littoral drift in the vicinity of Pamban Pass. Due to the low littoral drift taking place during NE monsoon, the quantity of sediments entering GOM from Palk Bay will be much lower than the quantity moving from GOM to Palk Bay during SW monsoon.

During fair weather period, the sediment transport rate along the entire study region except between Uthalai and Arimunai remains negligible. The sediment transport between Uthalai and Arimunai exists relatively low in westerly direction for which the source of sediment is expected from Palk Bay through Adam's Bridge.

Due to low sediment transport prevailing in the study region, which comprises of about 10 percent compared to the rest of Indian east coast, the volume of sediment exchange is expected to be low, During SW monsoon, the sizeable portion of littoral drift from west coast passing around Kanyakumari is seen deposited before reaching Tuticorin. This deposited sediment is supplied back for the westerly transport during NE monsoon. Such deposition is evidenced from the occurrence of large beach deposits and elevated dunes along Tiruchendur – Manapad region. Similarly, the southerly transport along the east coast during NE monsoon gets deposited between Vedaranyam and Manmelkudi in Palk Bay, which is supplied back to the littoral drift cycle during SW monsoon.

Thus the study indicates that there is a break in the chain of littoral drift at Tuticorin on the south and Vedaranyam is relatively low and there exists limited quantity of exchange through Pamban Pass and Adam's Bridge.

It signifies that theregion around Adam's Bridge forms as significant sink for the littoral drift. ***The prolonged accumulation may lead to the emergence of new islands. In case of occurrence of cyclones in GOM, such prolonged deposition of sediments move north and enter in Palk Bay through Pamban Pass and Adam's Bridge. Once the sediments enter Palk Bay, the environment favours immeadiate deposition. Hence the occurrence of cyclones in GOM and the associated high northerly waves might exchange more sediments from the southern part of Peninsular India to the***

northern part of the east coast. Similarly any cyclones moving in Palk Bay, would generate large southerly waves and transport sizeable amount of deposited sediments into GOM. In the event of absence of cyclones, the deposition will increase causing the enlargement of sand spit across Adam's Bridge, but the order of sediment exchange will be limited. (NEERI EIA, p- 2.12 – 2.22)

4.2.16 Spit Configuration

The numerical modeling study for the region around Rameshwaram indicates that due to tidal currents, in SW monsoon, the sediment transport is 6000 m^3 and 30000 m^3 through Pamban Pass and Arimunai respectively moving from GOM to Palk Bay. The same phenomenon continued in fair weather period indicating 3000 m^3 and 16500 m^3 through Pamban Pass and Arimunai respectively moving from GOM to Palk Bay.

On the other hand, during NE monsoon, about 1500 m^3 and 21000 m^3 of sediments are being transported through Pamban Pass and Arimunai respectively from Palk Bay to GOM. It shows that in an annual cycle, a net exchange of 6000 m^3 of sediment is found to move from Palk Bay to GOM through Pamban Pass and 25,500 m^3 of sediment moves from GOM to Palk Bay through Arimunai. The modeling study indicated that the volume of sediment exchange due to tidal current (25,500 m^3/year) is very close to the volume being transported through littoral drift in breaker zone (24000 m^3/year).

The annual gross longshore sediment transport rate along the study region remained less than $0.1X10^6$ m^3/year, which shows only 10 percent of the rest of the Indian east coast.

In February, April, May the wave induced littoral drift is taking place from Palk Bay to GOM and the net quantity is found to be 8000 m^3, 6000 m^3, 2000 m^3 respectively. Consequently, in March, June, July, August and September, it drifts from GOM to Palk Bay and the quantity is 8000 m^3, 35000 m^3, 10000 m^3, 4000 m^3 and 1000 m^3 respectively. There was no significant movement of sediment between October and January. Over a period of one yea, the net volume of 24000 m^3/year of sediments moves from GOM to Palk Bay. Adam's Bridge forms as noticeable sink for the littoral drift. The prolonged accumulation leads to the emergence of new islands.

Season	Pamban Pass (m^3)	Adam's Bridge (m^3)
SW monsoon	-6000	-30000
Fair Weather	-3000	-16500

NE monsoon	+15000	+21000
Net	+6000 m^3/year	-25500 m^3/year

(-) = Towards Palk Bay

(+) = Towards GOM

The modeling study indicates that over an annual cycle, the net volume of sediment exchange due to tidal current is 6000 m^3, from Palk Bay to GOM through Pamban Pass and 25500 m^3 from GOM to Palk Bay through Arimunai.

The satellite imageries show that the spit gets deflected towards Palk Bay during SW monsoon indicating erosion of GOM side and deposition on Palk Bay side. During NE monsoon, the spit gets deposited on GOM side and eroded in Palk Bay side, but the overall length increased by 150 m towards Adam's Bridge.

The sand spit extended 455 m in seven years indicating an average growth of 65 m in a year; the width increased 200 m at 1 km distance from the tip. (NEERI EIA, p-2.22 – 2.33)

4.3. Cyclones

4.3.1 General Information

'As the cyclones evolve from a loosely organized state into mature, intense storms, they pass through several characteristic stages. The four important stages of storm development were defined as, tropical disturbance, tropical depression, tropical storm and hurricane. There are some variations in the definition and names of these stages of storm's intensity in one region to other. In the North Indian Ocean, these stages are divided into six categories depending on the maximum sustained surface winds associated with the system. These are given in the following table (IMD Classification):

Sl.No.	Category of System	Maximum sustained surface winds
1.	Low (L)	Less than 17 kt (31kmph)
2.	Depression (D)	Between 17 and 27 kt (31-49 kmph)
3.	Deep Depression (DD)	Between 28 and 33 kt (50-61 kmph)
4.	Cyclonic Storm (CS)	Between 34 and 47 kt (62-88 kmph)
5.	Severe Cyclonic Storm (SCS)	Between 48 and 63 kt (89-117kmph)
6.	Very Severe Cyclonic Storm (VSCS)	Between 64 and 119 kt (118-220 kmph)
7.	Super Cyclonic Storm (SUCS)	More than 119 kt (221 kmph or more)

…Roughly 7% of the total global genesis of tropical cyclones occurs in the North Indian Ocean. The average number of tropical cyclones is about 5.6 with standard deviation of 1.85. About 6 tropical disturbances reach tropical storm intensity in the region each year with variations from 1 to 10 during the past 104 years (1891 – 1994). These form from cyclonic disturbances (depressions and deep-depressions) whose annual frequency is about 15.7 with a standard deviation of 3.1. Roughly 35% of these initial disturbances reach tropical storm strength while 45% of these tropical storms reach the hurricane stage. There are 5-6 times more tropical disturbances in the Bay of Bengal than in the Arabian Sea.

The tropical cyclogenesis is highly seasonal in the region. The number reaching tropical storm intensity has a bi-model distribution with the primary maximum in November and a secondary maximum in May. Between these periods, there is a relatively suppressed period of activity. Although rare, storms do occur from January through March.

The India Meteorological Department (IMD) has records since 1877 of the tracks of cyclones and statistics of the frequency of formation and movement in various parts of the basin. It has published the Storm Atlas "Tracks of Storms and Depressions 1891 -1970". The tracks of storms and depressions subsequent to the year 1970 are published periodically by IMD in its quarterly journal 'Mausam'.

A large number of studies are available on the cyclone frequency and probability of their crossing the coast in the Indian region. Raghavendra (1973) carried out a statistical analysis of the number of tropical cyclones and Depressions in the Bay of Bengal for the period 1890 – 1969. Mooley and Mohile (1983) studied cyclone incidence on different sections of the coast around Bay of Bengal. Mandal (1991) gave the district-wise frequency of cyclones crossing the east and west coasts. Ramasastry (1984) presented statistics of distribution of number of cyclones affecting the Bay of Bengal and the Arabian Sea.' (Akhilesh Gupta, 'Tropical Cyclone in Indian Seas: Observations and Prediction" in 'Cyclone Disaster Management' National Interactive Workshop held at Tamil Nadu Agricultural University, February 25-26, 2002. p.21-24)

Details of various types of wind systems that formed in the Bay of Bengal and affected the east coast of India during the period 1891–2000. (Antonio Mescarenhas, 'Oceanographic validity of buffer zones for the East Coast of India: A hydrometeorological perspective' in Curr. Sci., Vol.86, No.3, 10 February 2004, p-400)

Type of disturbance	Cyclonic disturbance	Depression/deep depression	Cyclonic storm	Severe cyclonic storm
Number	1087	635	279	173
Maximum (1891–1991)	158 (Aug.)	131 (Aug.)	51 (Oct.)	38 (Nov.)
Minimum (1891–1991)	4 (Feb.)	1 (Mar.)	0 (Feb.)	1 (Jan.)
Yearly average	10	6	3	1.5
Per cent of total	–	58	26	16
Wind speed (km/h)	31–118	31–61	61–88	88–118

'A total of 440 (452 in 1891-2000) cyclones formed in the Bay of Bengal during the period of 104 years (1891-1994). Out of these 440 cyclones, 256 (58%) have crossed India, 68 (15.5%) Bangladesh, 33(7.5%) Myanmar, 5(1%) Sri Lanka and as many as 78 (around 18%) weakened or dissipated over the sea area before making landfall on any of the above countries.

There were a total of 103 Very Severe Cyclonic Storms (VSCS V_{max}>118kmph) during the above period, roughly one fourth of the total number of cyclones in the Bay of Bengal. About 52% (54) crossed Indian Coast, 25% (26) Bangladesh, 10% (10) Myanmar, 1% (1) Sri Lanka and 12% (12) weakened or dissipated over the sea.

Out of the 256 cyclones which crossed the Indian coast during 1891-1994 period, Orissa has the largest share of 94 cyclones (37%) followed by Andhra Pradesh 65 (25%), West Bengal 49 (19%) and Tamil Nadu 48 (19%). However, out of the total 54 hurricanes (VSCS) which crossed the Indian coast, West Bengal has the highest number of VSCS i.e 16 (30%) followed by Andhra Pradesh 15 (28%), Orissa 14 (26%) and Tamil Nadu 9 (16.5%).

No cyclones cross the coastal states of West Bengal, Orissa and Andhra Pradesh during January to March and West Bengal and Orissa coasts in April. On the other hand, Tamil Nadu has zero frequency in March and during the south west monsoon months of June to September. Orissa doesnot have any cyclone in December. West Bengal has the highest frequency during July and August. Andhra Pradesh shows very high frequency of 20-25 cyclones during the months of October and November whereas Tamil Nadu has the highest frequency of 27 cyclones in the month of November.

West Bengal has 1% probability of 5 or more cyclones in a year, whereas Orissa has the same probability (1%) for 4 or more cyclones in a year. The east coast as a whole, however, has 1% probability of 7 or more cyclones crossing in a year. In fact 1943 is the only year during the above said 104 years in which 7 cyclones crossed the east coast, 3 in Orissa and 2 each in Andhra Pradesh and Tamil Nadu. Orissa has the highest probability (56%) of at least one cyclone. Andhra Pradesh, West Bengal and Tamil Nadu have respectively 46%, 36% and 27.5% probabilities of atleast one cyclone making landfall per year. There is 98% probability that atleast one cyclone will cross the eat coast of India. It may be mentioned that 1920, 1965 and 1975 were the three years during which not a single cyclone crossed the east coast of India. (Akhilesh Gupta, 'Tropical Cyclone in Indian Seas: Observations and Prediction" in 'Cyclone Disaster Management' National Interactive Workshop held at Tamil Nadu Agricultural University, February 25-26, 2002. p.21-26)

4.3.2. Attributes of a Cyclone

"A cyclone causes damage in three ways:

1. The ***storm surge*** which is an abnormal rise of sea level causing inundation of the coastal areas.

2. Very strong ***winds*** that damage buildings and other structures.

3. Heavy ***rain*** that causes floods, as well as erosion of structures."

(S.Raghavan, "The May 1990 cyclone and its predecessors" in Journal of Applied Hydrology, Vol.IV, No.1&2, 1991. p-1)

4.4.3. Classification of the East Coast of India based on Storm Surge values

'Apart from the cyclone characteristics like its intensity, time of landfall, speed of movement, angle at which it strikes the coast, etc., the peak surge over an area mainly depends on the coastal structure known as bathymetry.

By the considerations of past recorded surge values, the entire East Coast of India can be classified into four main coastal stretches which are highly prone to surges due to cyclones of the Bay of Bengal.

The first area of importance is the coastal area of Bengal and Bangladesh in the head Bay of Bengal. Some of the noteworthy storms, which caused phenomena storm surge s of the order of ascent 13 meters, were reported only in this stretch. The second vulnerable area is the coastal stretch between Paradeep and Balassore in Orissa where storm surges of the range 5 meters to 7 meters were reported on many occasions. In the case of the False Point (Orissa) cyclone of 22nd September 1885 a surge of 8 meters was reported at several places. The third area is the coastal stretch between South of Masulipatnam and Kakinada in Andhra Pradesh. The frequency incidence of storm surge is highest in this stretch, where surge height ranges between 5 meters and 7 meters. The area particularly between Coringa and Masulipatnam gets inundated repeatedly and several structures were rebuilt several times.

As regards Tamil Nadu, the coastal area south of 10^0N between Pamban and Nagapattinam is highly vulnerable to storm surges and this stretch has also experienced storm surges of the range 3 m to 5m on several occasions. The 23rd December 1964 storm is a typical example, when a storm surge of height reaching 5 meters washed away the entire Dhanushkodi Island and the Pamban Bridge.

The west coast of India is almost free from disastrous storm surges. Historic records however show that surges are frequent in Gujarat coast where astronomical tides are quite high and the surge heights are of the order 2-3m. Only a very few incidences of storm surges was reported around Bombay area and near Honavar. Kerala and Goa coasts are almost free of storm surge.

Thus, based on the details of peak storm surge, the entire Indian coast can be categorized into four zones:

1) Very high risk prone (surge heights greater than 5 meters),

2) High risk prone (surge heights between 3 to 5meters),

3) Moderate risk prone (surge height rising between 1.5 m and 3 m), and

4) Minimal risk prone (surge height less than 1.5 m).

Coastal areas of Bangladesh, North Orissa and West Bengal are the most vulnerable zones to storm surges of height greater than 5 m and so also is the Krishna estuary in Andhra Pradesh. South Orissa, north coastal Andhra Pradesh, South Tamil Nadu are areas where surge height between 3 m to 5 m can be expected. Only Saurashtra Kutch coast is vulnerable to storm surges of height 3 m. Kerala, South Karnataka, Goa coasts are the minimal surge prone zones recording less than 1.5 meters. (N.Jeyanthi, "Cyclone Disaster Risk in Coastal Region", in 'Cyclone Disaster Management'

National Interactive Workshop held at Tamil Nadu Agricultural University, February 25-26, 2002. p.54-55)

Location, maximum wind speed, observed height of associated storm surges and actual inland penetration of sea water during some severe tropical cyclonic events that affected the east coast of India. (Antonio Mescarenhas, 'Oceanographic validity of buffer zones for the East Coast of India: A hydrometeorological perspective' in Curr. Sci., Vol.86, No.3, 10 February 2004, p-400)

Period	Coast affected	Max. wind speed (km/h)	Max.surge height (m)	Hinterland inundation (km)
October 1737	Hoogly river, W.B	272	12.1	100
May 1823	Balasore, Orissa	–	–	10
November 1867	East of Calcutta, W.B	60	1.8	–
October 1942	Medinipur, West Bengal	–	5.0	40
October 1949	Masulipatnam–Kakinada, A.P.	137	4.5	15
November 1952	Nagapatnam, T.N	88	1.2	8
October 1955	Kalingapatnam, A.P.	111	1.5	–
November 1955	Rajamadam, T.N.	193	4.5	16
December 1955	Tanjore, T.N	200	5.0	3–8
October 1963	Cuddalore, T.N.	139	6.0	–
December 1964	Rameshwaram, T.N	278	6.0	–
October 1971	Paradip, Orissa	170	6.0	10–25
November 1973	North of Paradip, Orissa	137	4.5	–
August 1974	Contai, West Bengal	139	3.0	–
September 1976	Contai, West Bengal	160	3.0	–
November 1977	Nizampatnam, A.P.	193	5.0	8–15
November 1977	Divi–Machilipatnam, A.P.	120	5.0	12
November 1978	Ramanathpuram, A.P.	204	5.0	–
May 1979	South of Ongole, A.P.	160	3.6	–
November 1989	Near Kavali, southern A.P.	222	4.0	1–2
May 1990	Nellore, A.P.	102	5.0	16
November 1991	Karaikal, T.N.	89	–	< 1
November 1992	Tuticorin, T.N.	113	1.0	–
December 1993	Karaikal, T.N.	133	4.0	2
October 1999	Paradip/Balasore, Orissa	252	9.0	35

4.4.4. Consequences due to Cyclonic disturbances

Modifications of coastal landforms by cyclones

Severe cyclonic events are responsible for dramatic modifications of the landscape. The cyclone of October 1999 resulted in heavy sedimentation near the coast of Orissa; the receding waters brought additional silt. Extreme events result in severe shoreline changes and hence affect coastline configuration: beach and dune erosion, modifications of dune complexes, dune breaching, over wash, inlet formation and, at places, complete elimination of sand-dune complexes is documented. In West Bengal, more and more land is being eroded following violent storms.

Effect on ports and fishing harbors

In November 1966, a tidal bore battered Madras port. Tuticorin harbor was directly hit in November 1992; breakwater and pier heads were damaged. Harbors were paralyzed along Digha–Haldia sector in August 1997. Minor ports of Machilipatnam and Krishna delta were affected in November 1977, and trawlers got drowned in Haldia in August 1997 . Should a seaport be shut down, as witnessed at Paradip in October 1999, the overall losses are beyond contemplation.

(Antonio Mescarenhas, 'Oceanographic validity of buffer zones for the East Coast of India: A hydrometeorological perspective' in Curr. Sci., Vol.86, No.3, 10 February 2004, p-400 -401)

Location and impact of some severe cyclones that affected Indian coasts during the last 25 years.

Period	Location	Impact/Damage
19 Nov. 1977 .	Divi, Krishna River delta, A.P	10,000 lives lost; standing crops washed away; persistent flooding even 11 days after the cyclone struck.
27–29 May 1989	24 Parganas/Medinipur, W.B.	485 lives lost; 2,02,468 houses damaged; standing crops washed away; 239 km of protective works destroyed; dune barrier breached.
4–10 May 1990	Machilipatnam, mouth of River Krishna,A.P	967 deaths; 6,00,000 houses destroyed; 21,600 cattle, 3 5,00,000 poultry, 42,700 goats perished, damage to agriculture.
11–17 Nov. 1992	Tuticorin, T.N.	170 killed; 160 missing; 1 to 2 m storm surge at Tuticorin.
1–4 Dec. 1993	Near Karaikal, T.N.	111 killed; 1 to 1.5 m storm surge.
29–31 Oct. 1994	Chennai and around, T.N.	304 killed; 1 to 2 m storm surge; 1,00,000 huts destroyed; 60,000 hectares of crops damaged.
7–10 Nov. 1995	Gopalpur, Orissa	96 killed; 1.5 m surge; 2,84,253 hectares of crops damaged.
5–7 Nov. 1996	Kakinada, A.P.	978 killed; 2 to 3 m surge; 1375 missing; 6,47,554 houses damaged; 1,74,000 hectares of crops damaged.
22–24 August 1997	Digha–Haldia, West Bengal	400 fishermen missing; 1,60,400 people homeless; coastal hotels inundated; 40 trawlers drowned; 10,000 houses destroyed; over 600 m of seawalls and embankments devastated; prawn hatcheries swept away; harbors paralyzed.
29–31 Oct. 1999	Balasore/Paradip, Orissa Super Cyclone	7–9 m surge; inundations up to 35 km from coast; 9885 persons died; 2142 people injured; 12 lakh houses damaged; over 2 lakh cattle killed; 13 lakh hectares of crops affected; port activity paralyzed.

4.3.5. Frequency and Intensity of the Cyclones of Bay of Bengal – The changing scenario

'Observational records suggest that, while there has been a rising trend in all-India mean surface air temperature, the number of monsoon depressions and tropical cyclones forming over the Bay of Bengal and Arabian Sea exhibits declining trend since 1970. There have been a number of studies that have considered likely changes in tropical cyclones in a warmer atmosphere. Some recent global climate model experiments suggest a future decline in tropical cyclone frequency1. Jones *et al*.performed an analysis of tropical cyclones from a 140-year simulation with regional climate model (RCM) nested in A–O GCM. This analysis indicated that there was a small decrease in tropical cyclone formation, although this result is considered preliminary. The pattern of cyclones during phases of ENSO (El Nino – Southern Oscillation) was unchanged, suggesting that the current relationship between cyclone distribution and ENSO may continue. This study, however, reconfirmed an increase in cyclone intensity (10–20%) with CO_2-induced warming as estimated by Tonkin *et al*. and Holland as being likely.

Although no consensus has emerged as yet on the behavior of tropical cyclones in a warmer world based on modeling studies, it is almost certain that an increase in SST will be accompanied by a corresponding increase in cyclone intensity (wind speed). The relationship between cyclone intensity (maximum sustained wind speed) and SST is well discussed in literature. A possible increase in cyclone intensity of 10–20% for a rise in SST of 2 to 4°C relative to the threshold temperature of 28°C is very likely. Thus, while it is not yet certain that tropical cyclone frequency may change the available data strongly suggest that an increase in its intensity is most probable.

Storm surges are generated by the winds and the atmospheric pressure changes associated with cyclones. At low latitude land-locked locations such as the Bay of Bengal, the tropical cyclones are the major cause of storm surges. Any increase in SST is likely to cause greater convective activity, leading to an increase in wind speed. The stress exerted by wind on water underneath is proportional to the square of the wind velocity. Amplification in storm surge heights should result from the occurrence of stronger winds and low pressures associated with tropical storms. Thus, an increase in SST due to climate change should lead to higher storm surges and an enhanced risk of coastal disasters along the east coast of India.' (M.Lal, 'Tropical cyclones in a warmer world', in CURRENT SCIENCE, VOL. 80, NO. 9, 10 MAY 2001, p-1103-1104)

4.3.6. Coasts most vulnerable for severe Tropical Cyclone – Recent statistical elucidation

'Among the different segments of Bay (of Bengal) coast under consideration (East Sri Lanka, Arakan (Burma), Tamil Nadu, Bangladesh, Andhra Pradesh, Oriss – West Bengal), ***the coasts of Tamil Nadu and Bangladesh are most vulnerable for Severe Tropical Cyclones as the anticipation of occurrence of such weather calamities are difficult over these two coasts.'*** (Sutapa Chaudhuri, Surajit Chattopadhyay, 'Identification of coasts vulnerable for severe Tropical Cyclones – Statistical Evaluation' in *Mausam*, 55, 3 (July 2004), p-507).

4.3.7. Tamil Nadu Data

Frequency distribution of the cyclones over the coastal districts of Tamil Nadu 1891-1995

District	Number of Cyclones
Chengalpattu including Chennai	21
S.Arcot including Pondicherry	13
Thanjavur including Pudukottai	14
Ramanathapuram	6
Tirunelveli	3
Kanyakumari	4
Total	**61**

The month wise frequency of cyclonic storms that crossed the Tamil Nadu coast during the period 1891 – 2000

CS – Cyclonic Storm SCS – Severe Cyclonic Storm

Month	**Frequency CS**	**Frequency SCS**	**% of SCS out of total cyclone**
January	3	1	33
February	1	1	100
March	1	-	0
April	2	1	50
May	3	1	33
June	-	-	-
July	-	-	-
August	-	-	-
September	-	-	-
October	6	2	33

November	34	22	64
December	14	8	57
Annual	**64**	**36**	**55**

(Ref: N.Jeyanthi, "Cyclone Disaster Risk in Coastal Region", in 'Cyclone Disaster Management' National Interactive Workshop held at Tamil Nadu Agricultural University, February 25-26, 2002. p.51-54).

4.4.8. Cyclones of Palk Bay – some examples

1. Severe cyclonic storm of 17 – 24 November, 1978:

'Under the influence of a low pressure area moving westwards across Malaya Peninsula and south Andaman Sea, a low which lay over southeast Bay concentrated into a depression on the morning of 17th with its centre near 6.5^{0}N, 91^{0}E. Moving slowly northwards, it intensified into a cyclonic storm near 8^{0}N, 91^{0}E on the morning of 20th as identified by the satellite pictures. A dim 'eye' was also noticed by the satellite. It developed a core of hurricane winds by the morning of 21st when it was centered near 7.5^{0}N, 88.5^{0}E. The storm progressively intensified further and took a west-south-westerly and later a north-westerly course and crossed Sri Lanka coast on 23rd night near Batticola. According to satellite pictures the storm reached its peak intensity on 23rd morning when the estimated maximum winds were 120 kt (222.24 kmph). The storm retained the hurricane intensity even over land, till it emerged into Gulf of Mannar. It moved south of Pamban and crossed Tamil Nadu coast between Kilakkari and Roche Mary Nagar in Ramanathapuram district on 24th evening as a severestorm and emerged into the Arabian Sea off Kerala coast as a deep depression on 25th morning.

Tidal waves of 3-5 meters affected the Rameshwaram Island and the coastal areas of Ramanathapuram district between Tondi and Devipattinam. According to press reports and information obtained from State Govt., the coastal taluks, namely Ramanathapuram, Tiruvadanai, Mudukulathur and Rameshwaram of Ramanathapuram district were worst affected by the cyclone.

About 5,000 huts were damaged in these taluks. A large number of trees were uprooted. About 1,000 country boats and mechanized fishing vessels were damaged in Rameshwaram, Pamban, Kilakkarai, Mandapam, Vedalai and Morepannai areas. Boat building yards at Mandapam and Morepannai were also damaged. Materials and machinery stored for construction of road bridge near Pamban were washed away. There was also extensive damage to roads in Ramanathapuram district due to heavy rain. Crops of sugarcane, chillies, betel vines and plantain were also damaged in the interior taluks of Sattur, Paramakkudi, Aruppukkottai, Srivilliputtur, Rajapalayam and Virudhunagar. The total damage to property was estimated to be about 5 crores of rupees. Thanjavur and Thirunelveli districts also suffered some damage to roads. Road and rail communications were disrupted in southern Tamil Nadu.

As reported in the press, this storm was the worst to hit Sri Lanka in the last half a century. The toll of human lives in Sri Lanka was estimated to be about one thousand. Serious loss to property was also reported.' (V.Srinivasan, A.R.Ramakrishnan and R.J.Jambunathan, 'Cyclones and depressions in the Indian seas in 1978', in *Mausam,* (1980), 31, p.501-502)

2. Deep Depression of 13 – 15 December, 1973.

'A low pressure area formed over extreme south east Bay on 10^{th} and became well marked on the 11^{th} and 12^{th}. It concentrated into a depression at 1200 GMT of 13^{th} near 7^0N, 88.5^0E. Moving west-north-west, it became deep on the morning of 14^{th} with its centre near 8^0N, 85^0E. Continuing to move west-north-west, it crossed south Tamil Nadu coast near Pamban on 15^{th} night and emerged into Lakshadweep – Maldive area on 16^{th} as a low.

In association with this system, fairly widespread rain with isolated heavy falls occurred in Tamil Nadu from 15^{th} to 17^{th}.' (George Alexander, C.A.George and R.Jambunathan, 'Cyclones and depressions of 1973 – Bay of Bengal and Arabian Sea', in *Indian Journal of Meteorology and Geophysics, July & Oct., 1974*, Vol.25 Nos. 3&4. p-357-358)

3. Depression of 2-4 December, 1982

A low which lay over southeast Bay on 1^{st}, moved westwards and concentrated into a depression over southwest Bay by 2^{nd} evening centered at 1200 GMT near 7.5^0N, 84.0^0E. Thereafter moving initially northwestwards and then west-northwestwards it crossed Tamil Nadu coast near Tondi in the morning of 4^{th} and weakened over land. This system caused generally widespread rain/ thunderstorm in Tamil Nadu and Kerala on 4^{th} with isolated heavy to very heavy falls in Tamil Nadu. (A.A.Ramasastry, A.K.Chaudury, and N.C.Biswas, 'Cyclones and depressions over the Indian seas in 1982', in *Mausam*, (1984), 35, 1, p.7)

4. Nagapattinam Cyclone of 8-12 November, 1977

A low pressure area moved westward across south Andaman Sea into southeat Bay on the morning of 8^{th} November and concentrated into a depression on that evening with its center near 8^0N, 92^0E. Moving northwestwards initiall and later in a westerly direction, the depression intensified into a cyclonic storm on the morning of 10^{th} and into a severe cyclonic storm on the morning of 11^{th} when it was centered near $11.^0$N, 82.5^0E. The storm crossed Tamil Nadu coast within 10 km to south of Nagapattinam in the early morning of 12^{th} (around 2230 GMT of 11^{th}). It weakened into a cyclonic storm by that evening over interior parts of

Tamil Nadu and emerged into Lakshadweep off nort Kerala coast on the morning of 13th as a deep depression.

This system caused generally widespread rain in Andaman and Nicobar Islands from 8th to 10th and in Tamil Nadu and Rayalseema on 12th and 13th with heavy to very heavy falls in Tamil Nadu on 12th and 13th and in Kerala on 13th… Gales reaching about 120 kmph lashed Thanjavur, Trichy and Pudukottai districts uprooting many trees. Electric and telegraph posts were bent and twisted in Thanjavur district, the worst affected taluksbeing Nagapattinam, Mannargudi and Thiruthuraipoondi. Roofs of pucca buildings were blown off in these areas. Madurai, Pudukottai and Trichy districts were worst affected by floods.

No tidal waves were associated with this storm.

(P.S.Pant, A.R.Ramakrishnan and R.Jambunathan, 'Cyclones and depressions over the Indian seas in 1977', in Mausam, (1980), 31, 3, 343-344).

4.4.9. Miscellaneous information on some Palk Bay Cyclones

' During 1960's the fishermen of Palk Bay region bitterly complained about the disappearance of large beds of algae owing to the cyclone in 1964, and turtles and dugongs almost disappeared in this area. Fishermen now report that the algal beds have sprung up once again (i.e. after almost 20 years)'. (NEERI EIA, p-3.63)

'Cyclones have sustained winds with speed ranging from 65 to 120 kmph. High speed winds cause extreme wave action that break coral into rubbles and sometimes large amounts of sand and other materials may be dumped onto the coral reef. Due to 1969 cyclone a large area of coaral was buried under the sand in Rameshwaram area of Gulf of Mannar.' (NEERI EIA, p-3.67).

"The Dutch records of April 1627 tells us of a great storm that had occurred a month earlier on the southern and central sections of Coromandel, in which vessels from Sao Tome (now Chennai), Covelong, Porto Novo, Karaikal, Thirumullaivasal and Nagapattinam capsized in substantial numbers; the losses were estimated at over two hundred vessels, and bodies, timber and goods were washed ashore for days afterwards." (Quoted from 'Algemeen Rijksarchief, The Hague .Overgekomen Brieven en Papieren .Verenigde Oost-Indische Compagnie. 1085. Dagh-Register op't Cust, 9/4/1626 – 17/9/1628, fls.37v-38' by Sanjay Subrahmanyam in "The Political economy of commerce: southern India, 1500-1650", Cambridge University Press, 1990, p-49)

4.4. Seismo-tectonics, Volcanism, Tsunami

4.4.1. Earthquakes, Tectonics:

There are two earthquake events that have been recorded in the area just south of the project area in the recent past.

The first record belongs to the year 1938. Its epicentre was supposed to be in 07.50 N, 79.00 E, which is just south of the project region. Its magnitude is questionable but is thought to be 5.8. Its intensity has been recorded as VII.

The second record is from 1993. Its epicenter was at 06.818 N, 78.301 E. Its depth (D) was identified to be 10.0 km; Its Body Wave Magnitude (Mb) was 5.2; Its Surface Wave Magnitude (Ms) was 4.7.

There is a record that an earthquake which originated at the Car Nicobar islands on 31 December 1881 (with an Mw 7.9) had generated a ***tsunami*** in the Bay of Bengal and this had been felt at Pamban. This fact stresses the importance of studying the history of the earthquakes in an area roughly around 300 km around.

The 26th June 1941 earthquake of Andaman Islands (12.500 N, 92.500 E) (Mw7.7) had also generated a ***tsunami*** and this had reached Chennai.

The first recorded Bay of Bengal earthquake is on 28th January 1679. It is suspected to have originated at the Andaman Islands.

The more recent Pondicherry earthquake of 26th September 2001 had its epicenter in the ocean crust (11.945 N, 80.227 E, Mw 5.4.

NEERI EIA mentions the role of tectonics in relation to the reduction in the sea bed depth in Gulf of Mannar area. Let us quote this passage in some detail:

'Recent depth contour map of 1999 has been compared with bathymetry map of 1975 (that is a 24 year period); it reflects that the sea floor level has decreased along the coastal areas and around the islands in the study area. It might be due to the emergence of land or lowering of sea (due to tectonism) and sediment deposit…. The average depth reduction of sea floor along the coast has been estimated as 0.51m over this period. .. The annual sediment deposit on the GOM sea floor is about 0.001m/year (Basanta Kumar Jena 1997), or 0.024m for a period of 24 years. As found from the present study, the decrease of depth for the period of 24 years is about 0.51m. Sedimentation accounts for about 0.024m reduction in the total of 0.5m from clearance depth. The remaining 0.486 m reduction in depth may be due to emerging of land or lowering of sea level (by tectonic activities). Based on the above data, the rate of emerging of land or lowering of sea level can be estimated as 0.02m/year." (NEERI EIA p.2.26)

4.4.2. Under Sea Volcanoes

Let us quote from GRK Murthy et al. (1994) at length to get an idea about the tectonic setup of the GOM depression and also about the submerged volcanoes present in it.

'The international Indian Ocean Expedition of 1975 had collected a good deal of magnetic and gravity data on the southern part of the Gulf of Mannar depression to understand the tectonics and evolution of the basin. (Udintsev, 1975) Nainini and Talwani (1982) and Kahle et al (1976) have brought out the isostatic gravity anomaly map of the Mannar depression. Sastri et al (1973, 1981), Prabakar and Zutshi (1993) have studied the structure and basement morphology from seismic information of the adjoining areas.'

'According to Eremenko and Gagelganz (1966), the Ind-Ceylon trough/GOM is considered to belong to the Mesozoic-Cenozoic group of basins. The regional alignment of tectonic features is NE-SW, parallel to the Eastern Ghat trend. They have opined that the basement has a horst-graben configuration resulting from faults with considerable throw. The depth of the basement is nearly 1 to 6 km in all the three depressions (the other two are the Palk and the Cauvery depressions), but the thickness of the sediments is slightly less in the Mannar depression. Kumar (1983) has reported ***the presence of basltic rocks from the borehole drilled in the northern part of the Mannar depression*** *(emphasis ours)*.'

'The bathymetric contours (NHO Chart, 1974) clearly reveal the physiography of the GOM. A broad bathymetric trough trending nearly NE-SW between water depths 1000 and 3000 m is noticed. The bathymetric data along AA' also indicate a broad trough between water depths 2000 and 2500 m. the profile also indicates a channel like feature of about 15-20 km width lying within the trough. It is interesting to note that the maximum and minimum of the anomaly are lying over the flanks on either side of the axis of the trough.'

'Due to complex horst graben structure of the sub basins in the GOM, we attempted to explain the total observed anomaly assuming uniform magnetization in the modeling. The basement depth at 4 km obtained from spectral analysis is in agreement with the observations of Eremenko and Gagelganz (1966). But the modeling indicated a relief in the depth of 5 to 11 km to the top of the anomalous body. If this is assumed to be the basement structure then the model indicates the presence of a sediment thickness of about 7 to 8 km to the top of the anomalous body. If this is assumed to be the basement structure then the model indicates the presence of a sediment thickness of about 7 to 8 km in the central portion of the profile AA'. However there is no evidence of the presence of sediment thickness of this order in the area. This suggests the possibility of an intrusive body within the basement. Carl (1966) has reported a shallow earthquake of magnitude less than 7, very close to AA′. The location of the epicenter of this earthquake lies over the northward extension of the fractures trending in N-S direction. ***Volcanoes with underwater summits were also reported (Udintsev,1975 and Sastri et al., 1981) in this area and are shown in the above figure. This suggests the presence of volcanic vents in the area. So the anomalous body inferred from magnetics could be related to such volcanic vents.*** The high susceptibility value of 0.02 cgs suggests that the body could be more basic in nature.'

'The spectral analysis of the marine magnetic data along AA′ across the Gulf of Mannar reveals two depths at about 4 and 9 km from the sea surface. The two dimensional model under the constraint of spectral depth shows the presence of an anomalous body within the basement. The depth to the top of the body varies from 5 to 11 km from the sea surface with a regional relief, of about 6 km. This relief coincides with a broad gravity low. ***The reported volcanic vents in the vicinity suggest the possibility of the anomalous body and the volcanic vents in the vicinity may together indicate the presence of a major tectonic structural feature in the Gulf of Mannar.'***

5. Discussion

5.1. The Issue

Navigation channels have so far been dredged in the East Coast of India only near the shipping ports. This is the first time that an effort is being made to dredge a channel that is not located near any shipping port. This probably is the first effort by India to dredge a navigation channel that is to be located 30 to 40 km away from the coast. This, again, is the longest sea bed dredging project planned so far in India.

Navigation channels of ports of the East Coast of India have been facing two major problems persistently. They are 1) problems due to sedimentation and 2) problems due to the Tropical Cyclonic disturbances.

Sethusamudram Shipping Canal Project will also be facing these two problems persistently, during its operation. The examples of the silted pre-modern ports of Thondi, Devipattinam, Alankulam, Adhirampattinam, the examples of the cyclone devastated Pamban Bridge and Dhanushkodi and the cyclone battered boat building yards of Mandapam and Morepanai that are located in the Palk Bay coast, highlight the importance of studying these issues thoroughly during the design phase of the SSCP itself.

The Technical Feasibility Report (TFR) and the rapid Environmental Impact Assessment (EIA) for the SSCP, both completed by the National Environmental Engineering Research Institute (NEERI), are the two sources of study on the basis of whom the SSCP authorities are claiming that the project would be safe and stable.

Accepting these two reports as thorough going studies on the SSCP, on the problems it would face in the future from the environment around, its effect on the environment, and the ways and means to overcome both these problems, the Ministry of Environment & Forests (MoE&F) has given a No Objection Certificate (NOC) for the project recently.

The Tamil Nadu Pollution Control Board (TNPCB) is yet to give its clearance for the project. It has arranged a series of Public Hearings from 19^{th} to 30^{th} December 2004 and has invited the civil society to represent its opinion on the issue.

The present monograph is one such opinion. It is based on the published literatures from various scientific journals, proceedings of various seminars conducted on the environmental and geological problems faced by the Palk Bay.

This monograph is of the opinion that the TFR and the EIA, as of present, are only partial studies of the issue of sedimentation that the SSCP would be facing. The monograph has also found that the TFR and EIA have not considered the issue of the effect of cyclones on the project.

This monograph feels that it would be premature to conclude, at the present juncture (based on these incomplete study reports), that the SSCP would have the ability to remain stable and operate safely in the environment of Palk Bay.

The following portion of the monograph provides the necessary proofs for this statement. It also presents important data unconsidered, at present, by the TFR and the EIA.

5.2. General conclusions:

1. Palk Bay is one among the five major sediment sinks of India. (Chandramohan et.al., 2002) *(TFR & EIA have not stated this explicitly)*

2. Tamil Nadu coast bordering Palk Bay (between Nagapattinam and Mandapam) is classified by the India Meteorological Department (based on the past storm surge values) as a 'High Risk Prone' coast to cyclones. (N. Jeyanthi, 2002) *(TFR & EIA are, at present, blind to this finding).*

3. Sea Surface Temperature of Bay of Bengal is increasing; this is likely to induce the formation of more intense cyclones (and thus more severe storm surges) in the Bay in the future. (M.Lal, 2001) *(TFR & EIA are, at present, blind to this finding).*

4. Out of the six major coastal regions of the Bay of Bengal, the coastal regions of Bangladesh and Tamil Nadu are most vulnerable for Severe Tropical Cyclones as the anticipation of occurrence of such weather calamities are difficult over these two coasts. (Sutapa Chaudhuri et al., 2004). *(TFR & EIA are, at present, blind to this finding).*

5. The Sethusamudram Shipping Channel is to be located in an oceanographic environment having the above said attributes.

5. 3. The issue of Sedimentation

Palk Bay receives its sediments from Gulf of Mannar, Bay of Bengal (Nagapattinam coast) and from the Indian and Sri Lankan rivers draining into it.

Waves, Tides and the longshore currents are responsible for transporting these sediments to different locations.

5.3.1. Net annual quantum of sediment transported into Palk Bay – Problems yet to be solved

Chandramohan et al (2002) have calculated the annual sediment load on the Palk Bay. According to their study, this is about 0.30 X 10^{10} m^3/51 years (1931 – 1982) for an area of 12,285 sq km. This is 0.00588 X 10^{10} m^3/year (or 58.8 X 10^6 m^3/year).

Sanil Kumar et al (2002) have calculated the net annual quantum of sediment transported by longshore currents from the Nagapattinam coast into the Palk Bay for two cyclone free years (1995-1996 and1998-1999). This is 0.095 X 10^6 m^3/year.

NEERI EIA (2004) has presented a calculation of the net annual quantum of sediment transported by tides and longshore currents into the Palk Bay from Gulf of Mannar through the Pamban Pass and the Adam's Bridge. The net annual contribution by the longshore current (from Dhanushkodi west to Ariyaman) is 2,46,200 m^3 (or 0.2462 X 10^6 m^3). The net annual contribution by the Tides is 19,500 m^3 (or 0.0195 X 10^3 m^3). Thus, the total net annual quantum of sediment transported into the Palk Bay from Gulf of Mannar through Pamban Pass and Adam's Bridge is 2,65,700 m^3 (or 0.2657 X 10^6 m^3). (NEERI EIA, p- 2.22 to 2.33).

The annual sediment load	=	58.8000 X 10^6 m^3
The net annual quantum of sediment transported by longshore currents from the Nagapttinam coast into the Palk Bay	=	00.0950 X 10^6 m^3
The total net annual quantum of sediment transported by tides and longshore currents into the Palk Bay fro Gulf of Mannar through Pamban Pass and Adam's Bridge	=	00.2657 X 10^6 m^3
The net annual quantum of sediment for which the source is not yet pinpointed (58.8000 X 10^6 m^3 –(00.0950 X 10^6 m^3 + 00.2657 X 10^6 m^3)	=	58.4393 X 10^6 m^3

So, we are yet to have studies that pinpoint the source for 99.386% of the net annual quantum of sediment entering into the Palk Bay. Studies on the quantum of sediment transported in the Palk Bay during cyclonic disturbances are non existent.

Here, let us briefly analyze the sedimentation data presented in the NEERI EIA.

1. The EIA *has made a selective attempt* to present the data on the net annual quantum of sediment transported by tides and longshore currents into the Palk Bay from Gulf of Mannar *only*. It has not tried to calculate the quantum of sediments deposited into the Bay by the rivers, and also it has not attempted to present the data on the quantum of sediment entering into Palk Bay from the Bay of Bengal.
2. The EIA *has not referred the most recent studies* conducted by various research groups on the sedimentation problem of Palk Bay. For instance, it has included P.Chandramohan's paper titled 'Distribution of longshore sediment transport along the Indian coast based on empirical model' in its bibliography. This paper was presented in a conference held in December, 1989. Since then, he and his colleagues at the National Institute of Oceanography (NIO) Goa and the National Institute of Ocean Technology (NIOT) Channai, have published their further studies in sedimentation in various journals like 'Journal of Coastal Research, Indian Journal of Marine Science and Current Science'. Data presented on the net annual quantum of sediment transported by the longshore currents in the Nagapattinam coast in the studies published as late as 2001 have been rejected summarily by the studies published in 2002 (Sanil Kumar, 2002). Hence, in this fast improving field of research, quoting a study that is almost 15 years old and neglecting the more recent important ones does not seem a right scientific practice.
3. The EIA, instead of analyzing the total sedimentation issue of Palk Bay, *has tried to underplay the issue* by presenting statements like: 'The east coast between Chennai and Paradeep experiences a gross transport rate of more than $1X10^6$ m^3/year. On the other hand, along the study region, it remained always less than $0.1X10^6 m^3$/year (?), which shows only 10% of the rest of the Indian east coast.' (EIA, 2.19). This comparison is made between the *gross* sediment transport rate of the coastal stretch of Chennai – Paradeep and the *net* transport rate calculated for the the Dhanushkodi-Ariyaman coastal stretch (shouldn't the gross sedimentation rate for this stretch be $0.476 X 10^6$ m^3/year?); first of all, this comparison is an incorrect one, as it should have been a comparison between the *net* sediment transport values of the two coastal stretches; while comparisons made among the various coasts will help us to form a picture of our study area in relation to the other stretches, they will not help us much in devising our planning strategies, as each coastal stretch has its own unique characteristics.

5.3.2. Calculations on the extent of sediment deposition in various sections of the PalkBay – The yet to be answered questions:

I) S.M.Ramasmy et al (1998) have calculated the accretion of sediments and the extent of land building activity in the Vedaranyam offshore area. They have concluded that in the Vedaranyam – Jaffna peninsular stretch of Palk Bay, the sediment building activity due to littoral currents seems to be happening at the rate of 29 meters/year and hence they have opined that there is a possibility for such land building activity to connect Vedaranyam to the Jaffna peninsula in another 400 years.

This is an empirical finding backed up by ^{14}C dating. Usha Natesan's study (published in April,2004) explains, using satellite imagery, how such an accretion and land building in the Vadaranyam offshore area is possible. It describes how the SW monsoon disturbs the sediments of the tidal flats in the northern portion of Palk Bay and how these sediments are obstructed in their northerly movement by the Vedaranyam land projection; it also describes how the sediments transported from north during the NE monsoon are unable to take a bend around the Vedaranyam tip; it also describes that a portion of these sediments start traveling eastwards and the rest move down south along with the longshore currents.

An earlier study done on the extent of shoreline oscillation of the Tamil Nadu coast (Usha Natesan, 1993) presents some interesting findings:

a) Annual mean berm crest fluctuation decreases as we go from north to south from Nagapattinam to Rameshwaram from 20 meters to 2 meters.
b) Accretion is high always in the period between June and August. It is low (or say erosion is high) in the period between November and January (Here Mandapam is an exception as there is accretion in January). There is a deviation from this trend in April in Point Calimere, where there is a sudden decrease in accretion (or an increase in erosion) in the month of April.

This data indicates to us that the southern portion of Palk Bay is accretionary though out the year where as the northern portion experiences both erosion and accretion. Accretionary tendency is greater during the South West Monsoon period (June to August) and it is low (or erosion is high) during the North East Monsoon (October to January).

V.J.Loveson et al (1990) have stated that since drainage network is absent in the coastline between Kodiakkarai to Rajamadam area, the seaward migration of this shoreline can be attributed to the accumulation of marine sediments only.

Sanil Kumar et al (2002) have given the value of the annual net quantum of sediments transported by the longshore currents (during cyclone free years) from the Nagapattinam coast into the Palk Bay as is 0.095×10^6 m^3/year.

Chandramohan et al (2002) have stated that the depth of Palk bay is getting decreased by 0.010 meters (1 cm) every year.

The foregoing findings throw up the following questions:

1. How can the finding of the sea depth reduction of 1 cm/year explain the empirical observation that the coast of Vedaranyam is migrating seawards at the rate of 29 meters / year?
2. Can 0.095 X 10^6 m^3 of sediments transported by the longshore currents from the Nagapattinam coast annually explain the 29 meters per year seaward migration of the Vedaranyam coast?
3. V.J.Loveson et al state that the seaward migration of this coastal stretch is due to the accumulation of marine sediments only. Usha Natesan (1993) states that accretion of sediments in this coast is happening during the SW monsoon and erosion during the NE monsoon. She also notes that there is erosion in this coast during the pre-monsoonal month of April. Prakash Chauhan et al (1996) have noted that 'during the non-monsoon season sediment boils were observed near Vedaranyam and Mandapam.' This they say 'may be attributed to the difference of the density of the different water masses and the prevailing current direction.' How do all these findings help us explain the 29 meters / year seaward migration of the Vedaranyam coast?
4. 64 cyclones have crossed the Tamil Nadu coast in the period between 1891 – 2000 A.D. 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 in the period between 1891–1995 A.D., 6 have directly crossed the Palk Bay; 14 have crossed the Nagapattinam coast; 3 have crossed the Gulf of Mannar. What would have been the pattern of sedimentation during these? What would have been the role of these cyclones in causing the 29 meters / year seaward migration of the Vedaranyam coast? No studies have been conducted so far on this topic of cyclones and sedimentation for this area. (However, some observations do exist on this issue. For instance, the NEERI EIA states: 'The studies carried out by NSRDC signify that the region around Adam's Bridge forms a significant sink for littoral drift. The prolonged accumulation in this area may lead to emergence of new island. In case of occurrence of cyclone in Gulf of Mannar, such prolonged deposition of sediments move north and enter Palk Bay through Pamban Pass and Adam's Bridge. Once the sediments enter Palk Bay, the environmental condition favors immediate deposition. Hence the occurrence of cyclone in Gulf of Mannar and the associated northerly waves might, exchange more sediment from southern part of Peninsular India to Northern part of east coast. Thus the quantity of maintenance dredged spoil will increase in the channel across Adam's Bridge in the event of cyclone.' (p-6.4) Sanil Kumar (2002) notes: 'It has been observed that for the occurrence of every cyclone, there was a permanent loss of beach due to erosion (Jena, B. K., Chandramohan, P. and Sanil Kumar, V., *J. Coast Res.*, 2001, **17**, 322–327). As the Palk Bay is well

protected for southerly waves, no mechanism is set to transport these deposited materials towards the north.')

5. What are the factors that are responsible for the 29 meters / year seaward migration of the Vedaranyam coast?

Pertinent answers to these questions are necessary for designing 'the course and the structure' of the proposed 54.2 kilometer length of the channel that is to be dredged in the northern portion of Palk Bay. Moving forward with the project with out these answers might turn out to be costly for our Nation in terms of money and honor.

II) G.Victor Rajamanickem's paper (2004) states: 'The spit growth in Manamelkudi is of the order of 0.75 meters per year… (It is interesting to see that the maritime surveys conducted between 1960 and 1986 reveal the change of contour to the tune of 6 meters shallowness in the Palk Strait. That shows that around 24 cm per year is being silted off in the Strait.) Similarly, one can visualize the growth of spit from the Talaimannar side. If both the spits grow in the existing rate of growth, one can visualize the merger of this two within the next 50 years. Once these spits join, the Palk Strait will become into two lagoons of north and south.'

The findings of this paper are different from that of Chandramohan et al (2002). This paper notes that the spit in Manamelkudi is growing at the rate of 75 cm/ year; Palk Strait has become shallower by 6 meters in 26 years i.e. it is becoming 24 cm shallower every year. On the contrary Chandramohan et al (2002) state that it is only 1 cm/year for the whole Palk Bay. What should we conclude from these findings?

We may safely conclude that a few portions of Palk Bay are more prone for excessive sedimentation than other areas. The finding of Chandramohan et al (2002) is an average value for the whole Bay and so to have a real picture of the sedimentation regime in the Palk Bay, ***we require micro level studies in the various portions of the Bay having different sedimentation patterns.*** In this context, we shall note here that Agarwal (1988) has studied the Manamelkudi area; Chandramohan et al (2000) have studied Puduvalasai coast.

The proposed alignment of the Sethusamudram Shipping Canal Project passes through three different sections of Palk Bay having three different sedimentation regimes. The northern leg of the channel is 54.2 km long and it passes through Palk Strait. The southern leg of the channel is 20 km and it passes through Adam's Bridge. Both these regions are noted for their high sedimentation profile. The central leg of the channel is 78 km long and has a comparatively lower sedimentation profile. Dredging is proposed only for northern and southern legs and the central leg would not require any dredging.

Knowledge on the sedimentation regimes existing in these three sections is sketchy at the present time. A series of studies on the sedimentation patterns and dynamics existing in these sections both during cyclone free years and during the cyclonic years is a basic necessity for designing 'the structure and the alignment' of the canal.

It is important to note here that both the NEERI EIA and the TFR have not consulted any of the studies (even though they are only preliminary) that have been conducted by various research groups to understand the sedimentation pattern and dynamics of these three sections of Palk Bay.

Thus accepting these reports as scientifically complete ones would definitely prove hazardous for the future of the canal.

5.4. Handling the Dredged Spoils

The total quantity of spoils that would come from capital dredging is supposed to be 81.5 to 88.5 X 10^6 m^3. The quantum of dredged spoil that would come from maintenance dredging is supposed to be 0.1 X 10^6 m^3 / year.

The top clayey layer that will be dredged from the Adam's Bridge leg of the canal is supposed to be 7-8 million m^3 (7 to 8 X 10^6 m^3) in volume. The lower dredged stratum is supposed to be sandy and it will be 24.5 to 25.5 million m^3 (24.5 to 25.5 X 10^6 m^3)in volume. About 50 to 55 X 10^6 m^3 of dredged spoil is supposed to come from the northern leg of the canal.

The nature of the dredged spoil is ***presumed*** to be clayey and sandy for both the legs but there is an uncertainty here. For the northern leg of the channel passing through Palk Strait, no borehole investigation has been done so far. ***Unlike the Adam's Bridge section, hard substrata are expected by NHO. In such a scenario, blasting might be required for the canal excavation and strategies to dump these rock spoils be devised freshly.***

The net annual sediment load to Palk Bay (Chandramohan et al, 2002) is 58.8 X 10^6 m^3 (for an area of 12,275 sq km).

Capital dredging, thus, would generate a sediment load that is 138.61 % of the net annual sediment load to the whole Palk Bay; or in other words, a sediment load that will be deposited in a time span of roughly 16 months in Palk Bay would be excavated from the channel from an area of 22.26 sq km.

The site chosen for dumping the upper layer dredged spoil of the Adam's Bridge section lies between Rameshwaram and Dhanushkodi and its area is 7.53 sq km (753 hectares). The lower sandy stratum of dredged spoil from the Adam's Bridge is supposed to be dumped in an area in the Gulf of Mannar 25-30 km away from the Adam's Bridge where a depth of 30-50 meters is available. The exact site is yet to be fixed. If the dredged material from the Bay of Bengal leg of the canal turns out to have a high silt content, then land disposal in proximity to dredging area (which shall avoid the ecologically sensitive locations like Point Calimere Bird Sanctuary) is being thought of. Also, as this area is close to Bay of Bengal where depth more than 40 meters is available, disposal in sea is being thought of. Here also, the exact site of disposal is yet to be decided.

Thus, specific dump site has been identified only for 8.5 to 9.5 % of the total dredged spoil. Idea about the nature of the dredged spoil is available presently, only for about 38.5 to 40.5 % of the total dredged spoil. No idea exists at the present time on the nature of the dredged spoil that would be generated for 59.5 to 61.5 % of the total dredged material. We do not know the exact dump sites for about 90.5 to 91.5 % of the dredged material.

Palk Bay is an oceanographic environment where we see areas of higher and lower sedimentation rates. Dredging and dumping these dredged spoil in the area around, will not only change the physiography of the area but also is bound to change the sedimentation dynamics existing in the area so far.

Knowledge about the nature of the dredged material, its exact dumping location, the area of the dump sites and how it would behave during the many changing environmental conditions is a must for giving a clearance for the project, as all the above factors will have a great bearing on the future of the canal, physiography of the area and the life forms present in the environment around.

The dredged spoil from the upper layer of the southern leg of the canal is equivalent to about 12% of the annual net sedimentation load of the Palk Bay. This is to be dumped just in an area which is just 0.06% of the total area of the bay. Similar will be the case for the dredged material from the other components of the canal.

How will these dumps behave during the SW, NE monsoons and the fair-weather periods? How will they behave during the times of cyclonic disturbances?

Can the embankments planned (proposed by NEERI) for the Dhanushkodi dump site protect the dump from leaching and erosion due to the storm surges created by cyclones? (1964 and 1978 cyclones had produced storm surges with 6 and 5 meter heights respectively). What would happen to the environment around if this dumping yard is washed into the Bay as the 1964 storm surge had engulfed the Pamban Bridge and Dhanushkodi?

Don't we need specific answers to these questions before giving a clearance for this project?

All the studies we have cited so far tell us that in the event of cyclones (in Gulf of Mannar, Nagapattinam coast) sediments move into Palk Bay. What would happen to the dredged spoil (equivalent to 126% of the annual net sedimentation load of the Bay) that would be placed south (?) of Adam's Bridge and (possibly) north or north east of the Palk Strait, in the event of cyclonic disturbances? How will these dumping sites behave during cyclone free years? What would happen to them, the Dhanushkodi dump, the Channel proper and the auxillary buildings and structures (remember the fate of Mandapam & Morepanai boat building yards in the 17-24 November,1978 cyclone) during the cyclones that would cross the Palk Bay in the future?

Experts have been warning over the past few years that the recent increase in the Sea Surface Temperature (SST) of the Bay of Bengal Sea is bound to produce more intense cyclonic storms, which in turn will produce higher storm surges. Sutapa Chaudhuri et al (2004) have concluded in their study that prior prediction of cyclones that are to cross the Tamil Nadu and Bangladesh coasts will have a higher uncertainty component than the predictions done for the Andhra, Orissa, Bengal, Arakan (Burma) and the SriLankan (east) coasts. Thus, the time required for prior preparedness to safeguard from the storm will be less when compared to the other coasts. This fact has made them to classify Tamil Nadu and Bangladesh coasts as the most vulnerable ones among the many coastal regions of the Bay of Bengal, for Severe Tropical Cyclones.

Shouldn't we consider these findings while designing the channel, the dump sites and the auxiliary buildings and structures?

The NEERI EIA and the TFR have not consulted them.

Nevertheless, the Ministry of Enviroment & Forests has given a clearance for the project.

This, we feel, is rather unfortunate.

6. Conclusion

1) The NEERI EIA and the TFR have not consulted the recent studies on the sedimentation dynamics of the Project Area (Palk Bay).
2) They have totally neglected the number one risk factor in the Project Area, namely Cyclonic disturbances.
3) The EIA has analyzed (albeit partially) the sedimentation dynamics in the Adam's Bridge area of the Palk Bay only. It has ignored totally, the sedimentation dynamics in other parts of the Bay and especially in the Palk Strait area where the northern leg of the channel is to be dredged.
4) The substratum of the northern leg of the channel is yet to be studied. The study is important as it will reveal the method of excavation (dredging or blasting) for this part of the channel. Knowledge of the nature of the material excavated or dredged is necessary for planning safe disposal strategies.
5) Plans to identify dump sites that will be safe to the environment around and will have the capacity to withstand the harsher realities of the environment are yet to be drawn.
6) Micro area sedimentation studies within the Palk Bay are absolutely necessary for planning a safe and stable channel design, navigation course, dredged dump and auxiliary structures.
7) The EIA and the TFR are incomplete in their content in the above said parameters.
8) The Expert Committee formed by the Ministry of Environment & Forests has cleared the project recently. However, keeping the issue of the honor of our Nation and the future costs of possible failures, the Committee should muster the courage to withdraw its decision of clearing the project.
9) If the MoE&F fails to overcome its departmental ego, the Tamil Nadu Pollution Control Board should muster all its energies to wean the central ministry from its delusion.
10) Both the MoE&F and TNPCB should direct the Tuticorin Port Trust to withdraw the EIA and TFR as they are incomplete in their content in the above said parameters.
11) They should request the Central and the State Governments to direct and encourage the institutions (like NIO, NIOT, IMD, GSI, Anna University, Institute of Atmospheric Sciences) involved in basic researches to take up studies that would have the capacity to throw more light on the environmental dynamics of the Palk Bay.
12) They should direct the TPT to ask NEERI to come out with a thorough Environmental Impact Assessment and Technical Feasibility Reports in the future.

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A personal note

The author wishes to thank the many individuals who were responsible for inducing his intrest in the issue.

Barathidasan, an incorrigible lover of birds, is a friend. Seeing his agony about the possible plight of thousands of birds that roost in the Dhanushkodi area of the Rameshwaram Island in the event of SSCP completion, the author wished to give him a series of counseling sessions that would help him overcome his mental distress. Preparations for the counseling session sucked the author into the world of researchers on the Palk bay and have landed him, at the present time, in this monograph. The counseling sessions are yet to begin.

Sivakumar, a freelance journalist friend, had raised so many questions related to the SSCP during the innumarable chats over the last few months, and these questions had helped the author in his search for the literatures on the topic.

Duraipandi, a computer programmer friend, challenged the author (whose hobby happens to be image processing), whether he can develop a DEM (Digital Elevation Model) for Palk Bay using the hydrographic charts of the area (used by the many research studies quaoted above). John Child of Terrainmap.com's BLACK ART made that dream a reality. Kudos to John! Thanks to NOAA for the overlay draped over the DEM. Thanks to Visualization Software LLC for providing 3DEM, a really great DEM rendering software.

Dr.V.Pugazhenthi, a gold medalist during his undergraduate years but who had opted to work as a barefoot doctor among the dalit / fisherfok community at Sadurangapattinam near Kalpakkam, had been communicating to the author, almost nonstop, the anguish that the SSCP has induced among the fisherfolk of the east coast. The personal anguish of such a socially dedicated friend had the effect of changing the otherwise placid personal psychological environment of the author, into a turbulent one. This turbulence, inturn, set the pace of this work.

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The request made by the honorable Collector of Ramanathapuram District to send him the electronic version of the preliminary draft of this monograph (presented to the TNPCB at the Ramanathapuram Public Hearing meeting on SSCP held on 16 September 2004) was a great source of encouragement.

The photo of the anchor in the Cover is from N.Athiyaman & P.Jayakumar's publication in 'Current Science' (Vol.86, No.9, 10 May 2004, 1261-1267) titled 'Ancient anchors off Tamil Nadu coast and ship tonnage analyses. This is an anchor salvaged off the Thondi coast in 1986, and has engravings of the words 'Guerigny' '1864' on it.

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