Use of geospatial techniques in maritime archaeology with reference to the Tamil Nadu coast

Sundaresh*, R. Mani Murali, A. S. Gaur and M. Dhivya Sri

CSIR-National Institute of Oceanography, Dona Paula, Goa 403 004, India

Geospatial analysis of shoreline changes at a particular place includes topographic sheets, satellite imageries and field data. The remains of maritime activities along the Indian coast have been traced dating back to the 4th millennium BCE. Subsequently, due to shoreline changes, many past habitations have been submerged in the sea or located far in the hinterland. Archaeological sites play a major role in determining palaeo-shoreline. The present article discusses the use of geospatial techniques in determining ancient coastal habitations along the Tamil Nadu region of the Indian coast.

Keywords: Archaeological sites, coastal habitation, geospatial analysis, satellite imageries, shoreline changes.

Introduction

REMOTE sensing is one of the non-destructive methods of exploration for archeological studies. Though remote sensing cannot completely replace ground-based exploration, it can do away with a lot of difficult and destructive ground work by geospatial methods. Culturally significant objects also have a context of their existence at a place on a site such as their orientation, the surrounding material, type of terrain where they are found, geographic peculiarities in their immediate neighbourhood, etc. Similarly, every site also has a context of its own regarding its proximity to a water body, the surrounding landform, vegetation around and topographic set-up of the land mass where it is located. While all objects, including soil material can be removed from the site and studied in the laboratory, the natural context cannot. Aerial photography of the site before removing the objects remains one of the ways to preserve their context. Unexplored archaeological sites often lie in not well travelled and inaccessible areas where ground maps are not available. Ground surveys in such areas can be aided by aerial photographs to make pre-field logistic estimates. Besides, other extraneous details such as trees, rocks, specific landforms, etc. help the surveyor in fixing his position. Aerial photographs are also known to be used for mitigation purposes, i.e. to preserve the unknown cultural resources before earmarking a land for development or another purpose. In several instances, aerial photographs are taken of a vast land mass before it is acquired for some other purpose. This helps archaeologists to infer at a later date how a given landscape looked years before man changed its appearance.

Maritime archaeologists work in coastal areas, including shallow sea and up to a few kilometres hinterland depending on the morphology of the coast. Archaeologists have noticed several archaeological sites either submerged in the sea or in intertidal, or earlier linked with the sea but now lying far inland. Archaeological sites in the coastal areas are an excellent indicator of shoreline in the past and present. Maritime archaeologists in collaboration with experts in remote sensing from the CSIR-National Institute of Oceanography (NIO), Goa have made an attempt to trace the palaeo-shorelines of Gujarat[1] and Tamil Nadu[2]. Satellite images have been used extensively to determine the palaeo-shoreline changes that occurred a few decades earlier. Also, digitization of the ancient maps and comparing with the present topography help in understanding the palaeo-shoreline and other morphological features. The present study deals with the application of geospatial techniques in marine archaeological investigations by CSIR-NIO.

The shoreline position changes continuously because of longshore sediment movement due to waves, tides, storm surges, etc. The coastlines have played a significant role in the human settlement since the beginning of the hunting and gathering way of life, and continued till today. Many Mesolithic and Neolithic sites are located along the coastal belt of India which indicates the exploitation of marine resources[3]. The changes in shoreline directly affect the stability of the settlements along the coast. It has been known to archaeologists that coastlines have been the centre of human activities and thus archaeological sites are the most hopeful indicators of ancient shorelines, particularly of the Holocene period.

The port towns that existed along the coastlines have played a major role in the overseas trade and commerce, and other maritime activities. Several ancient texts, including Sanskrit and Tamil literature refer to the

*For correspondence. (e-mail: sundares@nio.org)

submergence of prosperous settlements, situated in the coastal areas. The traditions, such as submergence of Dwarka mentioned in the *Mahabharata*, submergence of the city of Poompuhar mentioned in *Manimekhalai*, the Sangam period literature and popular belief of submergence of the temples of Mahabalipuram, 'Kumari Kandan' traditions of Tamil Nadu are well known as they are inherited as a local tradition[4]. The Marine Archaeology Centre of CSIR-NIO has studied score sites along the Indian coast (Figure 1) which include Dwarka, Bet Dwarka, Porbandar, Navibandar, Somnath, Ghogha, Kodinar, Vijaydurg, Sindhudurg, Goa, Mahabalipuram, Poompuhar, etc.

Attempt has been made to delineate the palaeo-shoreline of Rann of Kachchh based on the location of archaeological sites[1]. The Kachchh region which is a presently a least populated area of the country was once populated moderately around 3rd millennium BCE; this indicates that the environmental condition must have been different from those prevailing today[5]. The British explorers have also recorded several stories associated with the Rann of Kachchh as palaeo-sea. Based on all this information a digital elevation model (DEM) was used to raise few metres of water in the Rann of Kachchh to show the extent of submergence of the area in the event of higher sea level. This simulation successfully suggested that the Rann was navigable during Harappan times[1].

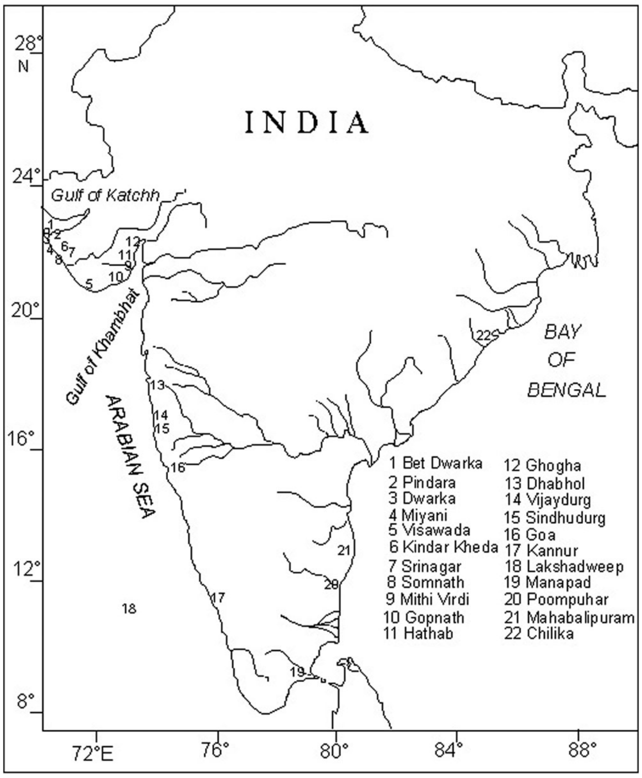

Figure 1. Sites explored along the Indian coast.

Data and methodology

Geospatial analysis of shoreline changes at a particular place includes topographic sheets, satellite imageries and field data (Table 1). In this study, topographic sheets and satellite imageries are used to detect the shoreline shift at various parts over a period of time. The topographic sheet of 1954 was scanned and geometrically registered in image processing software with RMS error less than 1.0. LANDSAT satellite imageries of different years were downloaded (www.earthexplorer.usgs.gov), and on-screen manual digitization of shorelines was done to obtain the shorelines of different years. ESRI ArcGIS 10.1 software was used in this process. All the images and toposheets were re-registered and brought to the common UTM projection and WGS datum. After getting the vector layers of the shorelines of different years, the Digital Shoreline Analysis System (DSAS) version 4.3 which computes the rate-of-change statistics from multiple historical shorelines was used. Results display the spatial shift of the shorelines during various years.

Archaeological sites along the Tamil Nadu coast

Tamil Nadu with its little over 900 km long coastline played a dominant role in the trans-oceanic trade. This has been attested through the archaeological discoveries in Southeast Asian and West Asian regions. The entire coast is dotted with several ancient ports, including Mahabalipuram, Arikamedu, Kaveripattinam, Tranquebar, Nagapattinam, Alagankulam, Korkai and Periyapattinam. An unknown Greek writer of the *Periplus*[6] has described ports on Tamil Nadu coast such as Camara (Kaveripattinam), and Sopatma (Mamallapuram) which had maritime contacts with the Roman Empire during the early centuries of the Christian era[7]. Many such port towns that existed in the coastal region vanished or were submerged in the sea, due to coastal erosion, sea level changes and neotectonic activity.

Archaeological investigations at a few sites, including Mahabalipuram, Poompuhar and Korkai demonstrate a direct or indirect connection with shoreline changes which have been examined in detail on the present shoreline[8]. The shoreline mapping to quantify erosion and deposition was done for 25 years at Korkai, 41 years at Mahabalipuram and 36 years at Poompuhar using geospatial techniques such as remote sensing images, digital image processing tools and geographic information system (GIS).

Mahabalipuram

Mahabalipuram, also known as Mamallapuram, a famous centre of art and architecture, is located about 55 km south of Chennai. This place was referred to as Kadal

Table 1. Data used in the study

Year	Data used	Toposheet no./path and row
1954	US army map service (toposheet)	NC-44-2, NC-44-5
2000	LANDSAT 7 (ETM)	Path-142, Row-52
2017	LANDSAT 8 (OLI/TIRS)	Path-142, Row-52

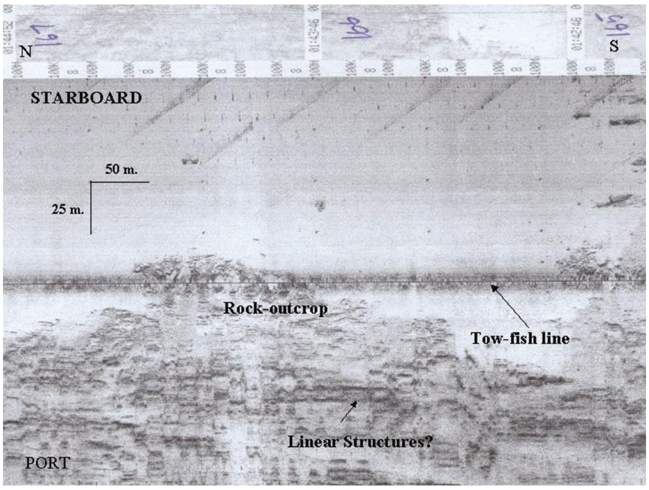

Figure 2. Sidescan sonar image showing the linear structural features in Mahabalipuram waters.

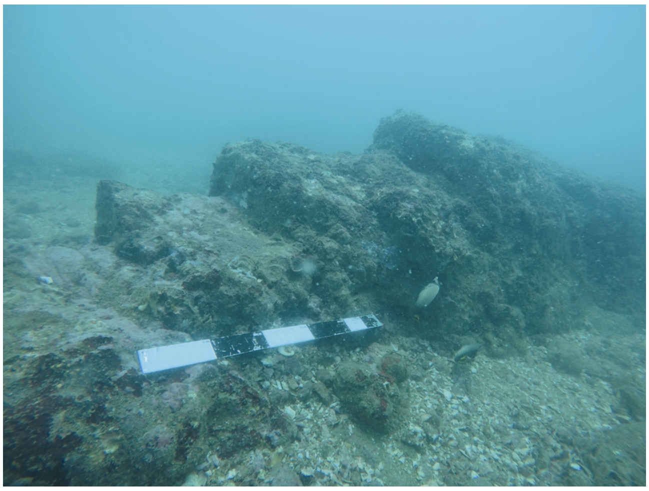

Figure 3. Underwater submerged fallen structure off Mahabalipuram.

Mallai in an 8th century CE Tamil text[7]. The discovery of a few Roman coins from Punjeri suggests that Mahabalipuram was an important trade centre with the Roman world around the Christian era[9]. The inscriptional evidence mentions that Mahabalipuram had maritime contacts with Southeast Asian countries, including Sri Lanka and China. The Pallava emissary and Buddhist monk Vajradanthi sailed to China from Mamallapuram port[7].

European mariners/travellers referred to Mahabalipuram as 'Seven Pagodas' since the 17th century. According to the local tradition, it is believed that all have submerged in the sea over a period, except the Shore temple. European travellers have recorded this folk tradition[7]. Underwater archaeological explorations have been carried out at Mahabalipuram to find out the remains of submerged structures referred in the local tradition[10]. However, a recent study suggested that based on Portolan chart of 1670 CE, all seven Pagodas are on the land which includes the Shore temple, all raths and other monuments[11].

Geophysical surveys off Mahabalipuram comprising shallow seismic, sidescan sonar and echosounder survey suggest that the seabed shows variation from 1 to 6 m depth and between 6 and 15 m depth. Granitic rocks with coarse-grained sand patches are observed on the seabed. On the sonograph, several rectangular and square-shaped features were noticed on the northern part in a regular pattern. The features are mostly irregular, short, linear found parallel to each other. Strong reflections of the imagery suggest that they are properly shaped, massive, hard bodies (Figure 2). Underwater investigations revealed fallen wall and several scattered structural remains, dressed stone blocks having joinery projections, and rectangular and square stone blocks at some places between water depths 5 and 10 m (Figure 3). There are remains of walls running more than 10 m in length, with width of ~2 m. Some stone blocks appear to have figurines carved on them, but due to thick marine growth, it was not possible to identify them. Many of the structural remains are found on a raised platform along with dressed stone blocks[10].

Poompuhar

Poompuhar, an ancient port town of the Early Chola period (300 BCE–300 CE) is located at the confluence of River Kaveri and the sea. Ancient Tamil texts such as *Silappatikaram*, *Pattinapalai* and later ones, including *Manimekhalai*, *Ahananaru* vividly describe the port city. Land excavations at Kilaiyur near Poompuhar brought to light two brick structures described as wharves possibly on the ancient channel of the Kaveri[12,13]. The coastal archaeological explorations in the intertidal tide zone revealed a brick structure and terracotta ring wells at Poompuhar. Four brick structures running parallel to the coast in 1 m water depth were noticed to the extent of 25 m off the present Cauvery temple. A brick-paved structure was found in the intertidal zone at Vanagiri, about 1 km south of Poompuhar (Figure 4).

Geophysical surveys between Tranquebar and Nayakankuppam revealed several isolated objects as rock boulders at a depth of 7–8 and 11–13 m (refs 14–16). The echograms of the shallow seismic survey revealed a submerged palaeo-channel at 10–15 m water depth, having a width of 300–500 m, underlying 20 m below the sea bottom. The objects identified by geophysical surveys were later confirmed by diving at different locations. Some dressed stone blocks, brickbats and early historic pottery, including black and red ware, red ware, buff ware and grey ware were found at 5–8 m water depth off the mouth of the present River Cauvery.

Three objects were found lying in the north–south direction between 22 and 24 m water depth. The first structure was found oval-shaped with a periphery of 140 m located at 23 m water depth. The height of the structure varied between 1 and 3 m, and the width of the arm between 3 and 6 m. About 40 m north of the oval-shaped structure, two small structures of the same material were noticed. These two structures lie in the east–west direction with a distance of 10 m. The circumference of each object was not more than 15 m, and height about 2 m; maximum height was at the centre[17,18].

The geospatial analysis of the coast along Poompuhar between 1954 and 2017 suggested that maximum erosion of 702 m (south of Poompuhar) in 63 years and minimum erosion of 392 m (north of Poompuhar) had taken place (Table 2; Figure 5).

Figure 4. Brick-paved structure found in the intertidal zone at Vanagiri near Poompuhar.

Table 2. Geomorphic assessment details of the study area

	Maximum erosion (m)	
Year	Poompuhar	Tranquebar
1954–1972	457	249
1972–2000	212	171
2000–2017	172	171
1954–2017	702 (79°51′27″E, 11°06′24″N)	393 (79°51′22.32″E 11°03′57″N)

Tranquebar

Tranquebar or Tarangampadi is situated about 15 km south of Poompuhar and has a continuous habitation commencing from the 13th century to till date. It was a major port during Dutch and Danish periods. A fort wall including Masilamani temple (AD 1305) protected the entire Tranquebar village and Dansberg Castle with sufficient distance from the shoreline[19]. This is shown on the map prepared by the Danish rulers in the mid-17th century and displayed in the Dansburg Museum, Tranquebar. At present, remains of the fort wall are found in the intertidal zone. The Masilamani temple is under threat as the sea has destroyed more than 50% of it and is likely to engulf the entire temple in near future (Figure 6)[20]. The intertidal region has two brick wells which are completely exposed now. There is also evidence in Tranquebar about the destruction of modern houses due to the encroachment of sea[2]. Coins of Danish, Chola and Dutch period were collected in the intertidal zone of Tranquebar. The shallow seismic survey has recorded evidence of the extension of submerged river valleys of Nandalar and Uppanar[16].

Habitational evidence such as brick structures, terracotta ring wells, storage jars and brick-paved platforms is found in the intertidal zone. A terracotta ring well was excavated near Chinnavanagiri, where a habitation site was observed. Analysis of pottery at this site suggested that the ring well could have been built during 2nd century BCE. Two other wells found at Vanagiri and Poompuhar may also be attributed to the same period. Similar type of ring wells found at Arikamedu and Vasavasamudram belong to the 2nd century BCE–3rd century CE[1].

Underwater archaeological exploration in shallow water zone at Poompuhar revealed a few well-dressed stone blocks. The underwater excavation yielded a few potsherds which indicate that the habitation site was buried at least 1 m below sediment[21]. The antiquity archaeological evidence in intertidal zone and offshore at Poompuhar suggests a possible time bracket of 3rd century BCE to 3rd century CE. The archaeological evidence in the intertidal zone, hydrographic charts and map of the 17th century at Tranquebar confirm the shoreline recession. These data indicate that about 300 m erosion of shoreline occurred in the last 300 years[22]. If the same trend would have continued for the last 2000 years, then surely ancient Poompuhar must have extended towards the sea from the present coast. Sea-level rise (SLR) is taking place on the coasts where the land margin is also subsiding. It may be mentioned here that the shifting of Kannagi statue about 200 m landward from its original

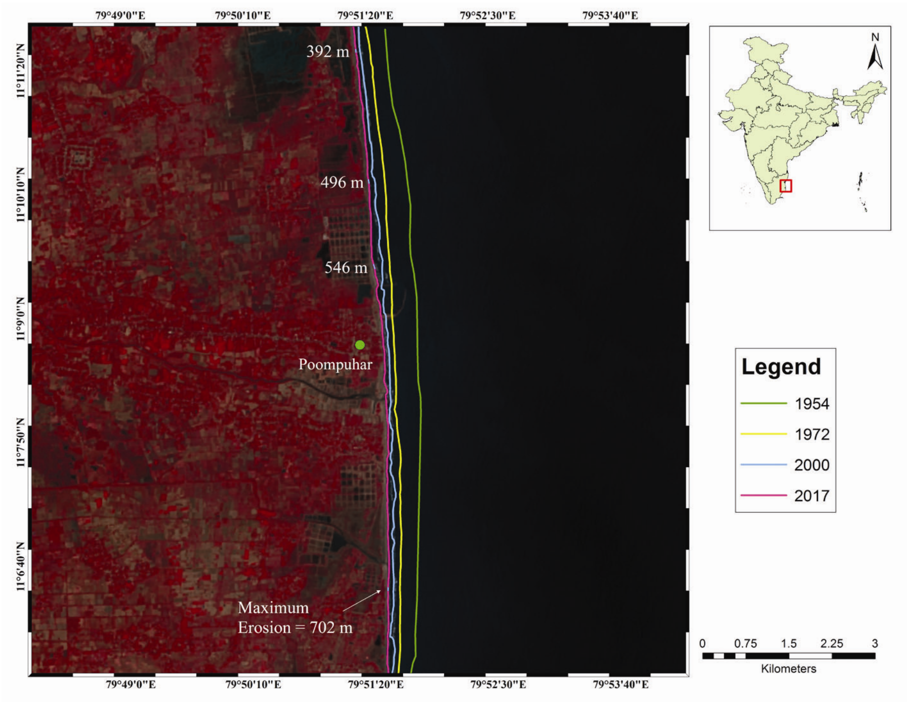

Figure 5. Satellite image of Poompuhar region showing changes in the shoreline.

Figure 6. Partly collapsed Masalamani temple in the intertidal zone at Tranquebar.

location from the high water line is a clear indication of advancement of the coastline[2]. Similarly, wave activity destroyed other monuments also in the vicinity. Geospatial analysis of the coast between 1954 and 2017 along Tranquebar suggested that maximum erosion of 393 m (north of Tranquebar) and minimum erosion of 251 m (south of Tranquebar) took place in 63 years (Figure 7).

Korkai

The ancient port of Korkai located on the mouth of River Tamiraparani, is mentioned in early Tamil literature and the notices of the classical geographers[23]. This was the ancient port capital of the Pandyas, who had maritime contacts with the Mediterranean countries during the 3rd century BCE to 3rd century CE. Korkai has been described in the literature regarding its location on the sea coast[24,25]. This was an important port for pearl fishery[26]. McCrindle[25] mentions that Korkai was situated on the shore. Later when the sea regressed, it was not suitable for carrying out trade. Now the site at Korkai is about 7 km away from the present coast. This shows the shoreline change due to accretion. The rate of accretion near Tiruchendur was noticed at the rate of 0.33 m/year (ref. 27).

Discussion and conclusion

In this study, erosion-susceptible regions were demarcated for the study sites. Mahabalipuram has experienced 177 m erosion in the past 41 years, and Poompuhar 129 m erosion in the past 36 years. Korkai revealed 134 m accretion in the past 25 years (ref. 8).

It is a well-known fact that erosion on sandy coastlines is due to low sediment supply from the rivers and also due to shifting of river mouths[28]. Subsequently, the sea began to erode the coastline, leading to submergence of several ancient coastal structures around Poompuhar and Tranquebar[2]. Global SLR and augment in the storm intensity trigger erosion to a considerable extent[29]. The east coast of India is known for frequent cyclonic activities, which are the main cause of coastal erosion. Approximately, 30 severe cyclonic storms had crossed Tamil Nadu coast between 1891 and 2006 (www.imd.gov.in).

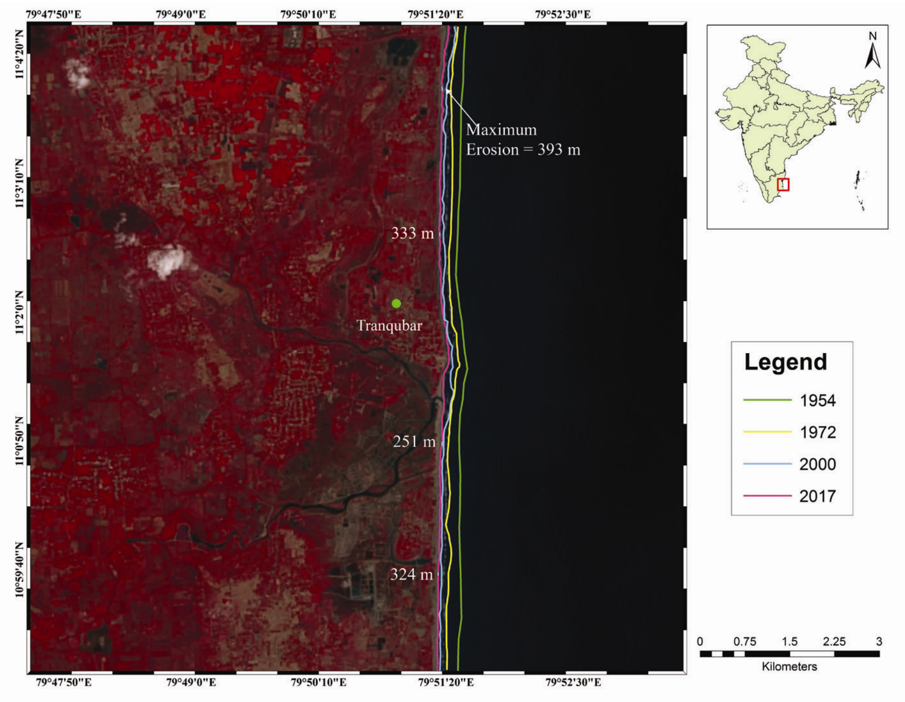

Figure 7. Satellite image of Tranquebar region showing changes in the shoreline.

Another likely factor for coastal erosion could be the narrowness of the eastern continental shelf. This shelf is about 32 km wide. The wave propagation over a narrow shelf results in low frictional loss of energy and thus expends much energy on the coastline, causing extensive coastal erosion.

Geological studies in the central eastern continental shelf of India provide evidence of submerged beaches and beach ridges at a water depth between 20 and 30 m formed during lowering of sea level[30–32]. Srinivasa Rao *et al.*[33] recovered a carbonate sample at 17 m depth in the Nizamapatnam Bay, east coast of India and obtained a radiocarbon age of 8200 yrs BP. Banerjee and Sengupta[34] have broadly identified two low sea level stands, one at around 30 m and the other at around 100 m depth. However, Tamil Nadu coast and its shelf are believed to be different from the rest of the coastline because of the severe tectonic activity. Hence, the sea level record in this region is different compared to other parts of the coast.

It has been observed that Korkai on the coast of Tirunelveli, was a flourishing seaport about 1000–2000 years ago, but is now defunct due to siltation. Its current position inland may be attributed to gradual deposition by the rivers. Along the Tirunelveli coast, in the Valinokkam Bay, several tree trunks of about 0.6 m diameter at the base which are exposed at low tide over a bed of black clay containing oyster and other marine shells clearly indicate earlier prevalence of marine environment[35].

Using LANDSAT satellite images, shoreline changes were studied at the study sites. Results show that Mahabalipuram witnessed changes to the tune of 177 m in 41 years, while it was 129 m during the last 36 years at Poompuhar. Korkai revealed 134 m accretion during the last 25 years. Recent beach measurements indicate severe erosion on the northern side of the Masilamani temple[36].

The man-made structures along the Tamil Nadu coast are prone to erosion[37]. Ramaiyan *et al.*[38] documented coastal erosion at the rate of 3.44 m/year at Poompuhar, Tranquebar, and 0.55 m/year at Mahabalipuram. A recent examination at Chavadikuppam near Poompuhar revealed erosion of 497 m during the last 75 years, which is almost 6.6 m/year; at Tranquebar it was 380 m for 75 years, i.e. 5.0 m/year (ref. 8). Kaliasundaram *et al.*[39] observed erosion rate of 0.15 m/year at Poompuhar, 0.65 m/year at Tranquebar and 1.8 m/year at Nagapattinam, whereas the maximum rate on Tamil Nadu coast was 6.6 m/year (ref. 27).

High-intensity storms, including severe monsoons and cyclones cause maximum erosion in the coastal areas. Global average SLR is 1–2 mm/year. A rise in 1 mm could cause a shoreline recession of 0.5 m per year (ref. 40). This aspect is significant in determining the dates of structures submerged in the sea. The sea level fluctuated in the past between 2 and 6 m during the Mid-Holocene period on both the coasts of India[41]. The history of sea-level fluctuation during the Holocene has been documented on the east coast of India for the last 5000 years (ref. 42). In continuation of general background on the history of sea-level changes, studies have pointed out that the major and significant factor affecting Mahabalipuram coastline is erosion[35,43]. Severe coastal erosion was also reported at Kalpakkam, south of Mahabalipuram due to longshore sediment drift[43]. A study has suggested that the rate of coastal erosion in and around Mahabalipuram is 55 cm/year (ref. 38). If the same rate has prevailed since the last 1500 years, then the shoreline at that time might have been around 800 m eastward. All the submerged structures noticed underwater would have been on land. If the rate of coastal erosion derived for Poompuhar, located 125 km to the south, is applied to Mahabalipuram, then the structures at 5–8 m depth must have been on the land at ~1500 years ago (ref. 2).

Interestingly, due to the construction of a semi-circular breakwater, the shoreline over a stretch of 3 km towards the north of the Shore temple at Mahabalipuram experiences accelerated erosion[44]. There is evidence of tectonic activity around Mahabalipuram during the early Quaternary period[45]. There has been no tectonic activity on the coast in the recent past, as the Shore temple has not been affected[43].

The archaeological evidence indicates violent fluctuations in the sea level/shoreline in the last 2000 years and a clear trend of changing shoreline at many places on the Tamil Nadu coast. From this discussion, it can be surmised that coastal erosion has played a significant role in submergence at well-known coastal sites such as Mahabalipuram, Poompuhar, Tranquebar and Nagapattinam. Sea-level fluctuations played a major role in altering the coast. The deposition at Korkai pushed the site 7 km inland from the coast. Geospatial techniques are inevitable in archeological studies; they have helped marine archeologists to test their hypothesis and generate new knowledge about the old tradition and culture.

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