Turkish Online Journal of Qualitative Inquiry (TOJQI)
Volume 12, Issue 7, July 2021: 6981 - 7002

Research Article

Delineation of coastal geomorphology along the coast of Kanyakumari district, southernmost coast of India

Aran Castro A J[1], Kumar R S[2], Justine K Antony[3], Pagare N S[4], P.Raj Kumar[5], Praveen Raj R[6]

Abstract:

A study to identifying the varied coastal geomorphic characteristics along the coast of the Kanyakumari district has been attempted. Geomorphic features resulting from diverse coastal and landward processes define the study region. According to the evolution process, the coastal landforms in the Kanyakumari district are classified into four main classifications 1) marine landforms, 2) fluviomarine landforms, 3) fluvial landforms, 4) aeolian landforms. Sea level fluctuations and land-sea interaction combine to create diversified coastal geomorphology along the coast. The sandy beaches, dune system, intertidal deposits, Teri sand dunes, wave-cut notches, beach terraces, rocky shores, estuaries, beach berms and cusps, sand bars are described in detail and the significance of their occurrence. The coastal geomorphology of the study area proves sea level changes and fluctuations in climatic conditions in this section of the coast.

Keywords: *Coastal geomorphology; marine landforms;fluviomarine landforms; fluvial landforms; aeolian landforms*

[1]Ph.D. Research Scholar, Department of Earth Sciences, Annamalai University, Tamil Nadu, India , mail id: arancastro17@gmail.com

[2]Professor , Department of Earth Sciences, Annamalai University , Tamil Nadu, India , mail id: rskgeoo@gmail.com

[3]Ph.D. Research Scholar , Department of Earth Sciences, Annamalai University, Tamil Nadu, India , mail id: justinekantony@gmail.com

[4]PhD. Research Scholar, Department of Earth Sciences, Annamalai University, Tamil Nadu, India, mail id: narendra19gis@gmail.com

[5]Project Associate, Centre for Earth Sciences, Indian Institute of Science, Bangalore, Karnataka, India, mail id: prajkumar@iisc.ac.in

[6]PhD. Research Scholar, Department of Earth Sciences, Annamalai University, Tamil Nadu, India, mail id: geopraveenraj@gmail.com

1.Introduction:

Coastal geomorphology is the study of the coast's morphological development and evolution due to wind, waves, currents, and sea-level fluctuations (Leatherman, Davison and Nicholls, 1994). The coast of the Kanyakumari district is well-known for its various coastal geomorphic landforms. The landforms include beaches, dune systems, rocky shores, Teri dunes, estuaries, etc. resulted in distinctive and substantial coastal geomorphology as a result of land-sea interaction, in addition to fluviatile and aeolian activity. Along the Kanyakumari district's coastal stretch, the formation and distribution of coastal

landforms are controlled mainly by wave, current, wind, and other coastal phenomena, as well as anthropogenic activity. The erosion and accretion of the coastal area are regulated by wave, current, wind, and anthropogenic activities.The coastal geomorphic features in this region frequently alter their shape, size distribution, and sediment load (Kaliraj, Chandrasekar and Ramachandran, 2017). The work has been taken up with the following objectives.

1. To map the coastal features along the Kanyakumari district's coast.

2. To record the significance and processes that influenced their formation.

2.Study area:

The Kanyakumari district's coastline constitutes the southernmost part of peninsular India. The study area' lies between the geographic coordinates 77°05' E to 77°36' E longitude and 8°03' N to 8°20' N latitude, with a length of 72 kilometres between Arokiyapuram and Neerodi (Figure 1)

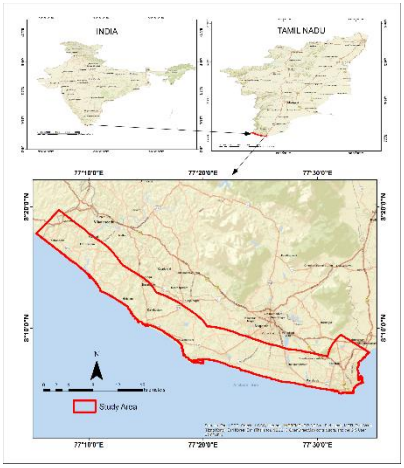

Figure 1 Location map of the study area

2.1 Physiography:

The study area has two distinct types of physiographical landforms: terrestrial and coastal landforms. The terrestrial landforms include coastal uplands and the Western Ghats mountain ranges. Rocky outcrops and rough coastlines characterise the coastal uplands. Complexes of Teri sand dunes are also found in the coastal uplands. Kanyakumari, Muttom, and Kadiyapattanam all have rocky coastlines. In the Muttom area, a Teri sand dune complex is present along the coastline. Sand dunes line the shoreline from Manakudi to Sotthavilai. The coastal elevation of the study area is between 1 and 10 metres above mean sea level; however, the inland elevation is between 100 and 600 metres above mean sea level.

3.Method of study :

The study aims to identify exclusively coastal geomorphic phenomena of the coastal areas of the Kanyakumari district. Between Neerodi to Anjugramam, a study area was investigated to determine geomorphological variability. The features formed by ongoing coastal processes, the features formed by sea-level fluctuations, and the features developed by the fluvial marine process have been identified and described at various locations. Field data and previous research conducted in this area of the coastline (Thamarai, 2008; Hentry *et al.*, 2010, 2017; Kaliraj and Ch, 2012; Parthasarathy and Natesan, 2015; Kaliraj, 2016; Kaliraj, Chandrasekar and Ramachandran, 2017) were used to confirm the features.

4. Results and discussion:

According to the evolution process, the coastal landforms in the Kanyakumari district are classified into four main classifications 1) marine landforms, 2) fluviomarine landforms, 3) fluvial landforms, 4) aeolian landforms.

4.1 Marine origin landforms:

Marine origin coastal landforms are controlled by wave, littoral currents, tides, and wind actions. These marine origin coastal landforms are shaped by erosional factors and depositional features (Walsh *et al.*, 2017). Littoral current is the primary mechanism behind the creation of the depositional features (Balasubramanian, 2011). These Littoral currents can erode sediments in the high wave energy area, transport, and deposit them in the low wave energy area. All along the Kanyakumari district's coast stretch, both erosional and depositional landforms can be seen. Marine origin landforms include sandy beaches, coastal plains, beach ridges, berms, beach cusps, sand bars, shallow marshes, salt pans, mudflats, estuaries, skerry, wave-cut notches are found all along the study area.

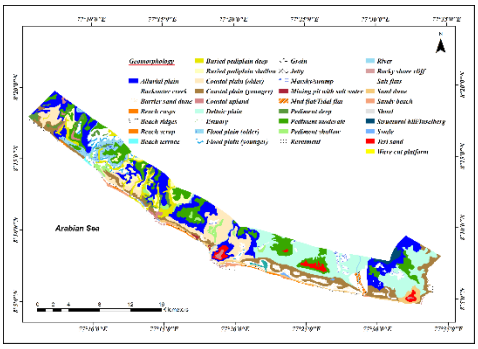

Figure 2 Geomorphological map of the study area

4.1.1 Sandy beaches:

Sandy beaches are the product of waves interacting with a sandy bed at the shoreline (Short and Wright, 1983). They dominate most temperate and tropical coastlines, representing both important recreational assets and buffer zones against the sea (McLachlan, 1983).

The coastal stretch of the Kanyakumari district has a few vibrant sandy beaches. Especially, Colachel, Ganapathipuram Lemur beach, Parikkal beach and the Sotthavillai beach are attractive sandy beaches found in the study area.

Ganapathipuram Lemur beach (Figure 3) is the longest beach in the study area. This beach, also known as locally "AayiramKalPozhimugam". "Pozhi" means estuary. The Lemur beach is one of the places the water from the Pechiparai dam's tributaries flows into the Arabian sea after irrigating many fields. In the monsoon time, only these tributaries conflux with the sea because of the excellent water flow and closed by sand spit during the rest of the year due to negligible freshwater discharge. Colachel beach is another well-known sandy beach in the study area (Figure 3). The sandy beach is situated on both sides of the Colachel fishing harbour. Especially on the Eastern side, the beach is widened because of the coastal accretion. The beach sediments consist of medium to fine sand with many placer minerals like garnet and ilmenite (Hentry, Chandrasekar and Saravanan, 2013). A canal called AVM is running Parallel to the sandy beach on the northern side. The 2004 Tsunami havocked the coastal areas of the Colachel. According to Kurien*et al.*(2006), the Colachel coast appeared to be in the convergence zone (high amplitude) during the Tsunami 2004. Sotthavillai beach is another important beach located in the study area. Sothavilai beach is one of Kanyakumari's significant tourist attractions (Hentry *et al.*, 2017).

The beach is linked to the surf zone, and the surf zone contains dangerous rip currents. Because of the active rip currents, this beach is a dangerous beach for swimming activities.

Because of the seasonal changes of littoral currents and the wave movements, the progradation and the retrogradation process of sentiments create the formation or deformation of the sandy beaches along the various parts of the study area (EVERTS, 1979; Jayappa, Vijaya and Subrahmanya, 2003). Accordingly, the young sandy beaches are developing near the up-drift side of the coastal artificial structures.

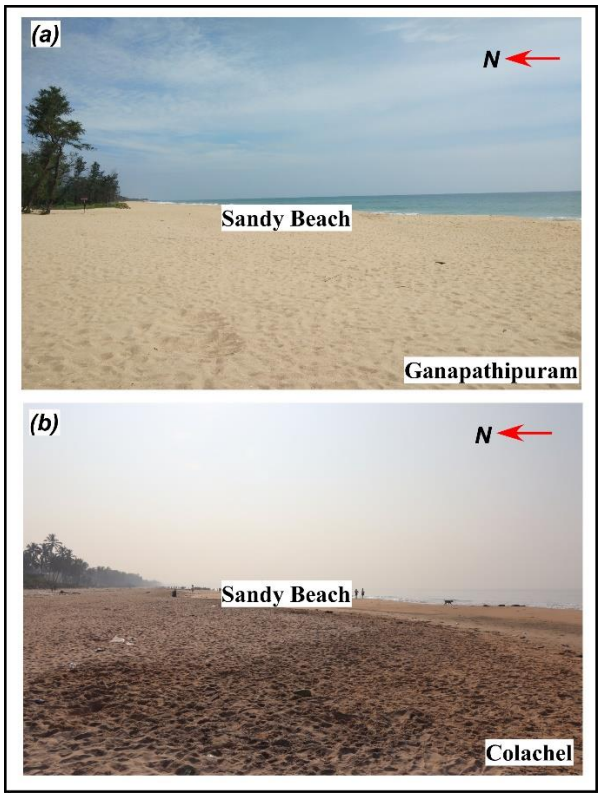

Figure 3 Sandy beach a)Sandy beach in Ganapathipuram b)Sandy beach in Colachel

4.1.2 Coastal Plains:

Coastal plains are the flat and gently sloped landforms found along the backshore region. Mountains and other elevated landforms separate coastal plains from the rest of the inland. In India, the western coastal plains and the eastern coastal plains are met at Kanyakumari, the southernmost tip of India. Coastal Plains commonly was formed through a series of sea-level rises and recessions and subsequent depressional and erosional forces (Siple, 1967).In the study area, coastal plains mainly composed sand, silt and clay particles, plantation (mostly coconut and casuarina), shrub vegetation, and sand dunes (Figure 4).From Manakudi to Pillaithoppu, the coastal plains are older and distributed with sand dunes, barren land, and open shrub vegetation. The coastal plains are younger in the western part of the study area and are connected mainly with alluvial landforms and beaches.

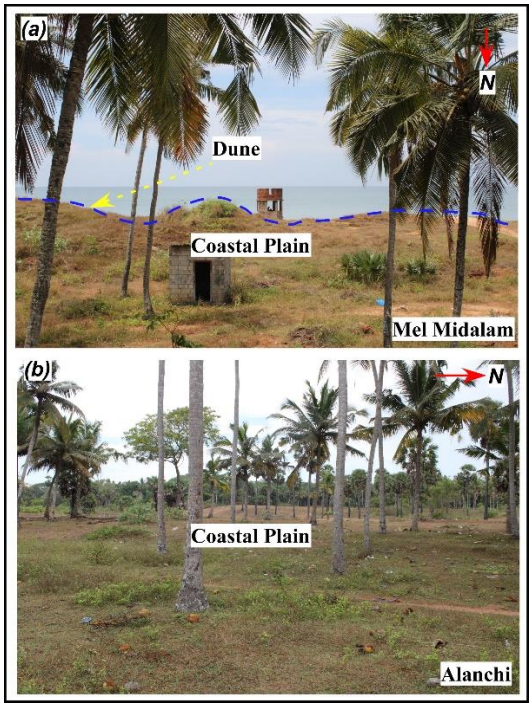

Figure 4 Coastal Plains

4.1.3 Beach ridges:

According to Redman(1864), the Strom waves are considered a possible mechanism by which sand could be deposited to form ridges. More commonly, the ridges are formed because of the high wave energy events (Gushing Woods and Leahy, 1983; Mason, 1990). The Beach ridges can provide past wave regimes, climate conditions, sediment supply, sediment source, and sea-level change (Curray, Emmel and Crampton, 1967; Stapor and FW, 1975; Taylor and Stone, 1996).

On the Eastern side of the Kanyakumari coast, the narrow ridges are founded parallel to the shoreline due to the high energy waves in some places. The elongated beach ridges found in places like Puthallam, Sothavillai, Pallam and Sanguthurai. Mostly these elongated ridges are isolated from the foreshore zone. Once a ridge is separated from the foreshore zone, often protected and preserved by dune cover (Otvos, 2000). Figure 5 shows the beach ridge in Sothavilai associated with the sand dune.

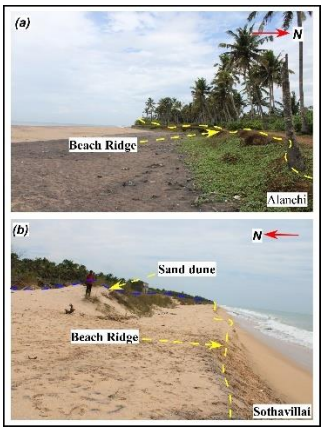

Figure 5 Beach ridges in the study area

4.1.4 Berms & Scarps:

Berms are a depositional feature found on most beaches resulting from the accumulation of sediment at the landward extreme of incident wave run-up (Hanslow *et al.*, 2000) (Figure 6 a). The Berms often known as beach terraces. Typically, when the wave increases (Low energy waves), it brings more sediments and forms berms. Beach berms can be seen in various parts of the study area.From Muttom to Rajakamangalam coastal area can find more this type of landforms. The narrow and tiny patch of berms found in the Sanguthurai, Kesavanputhenthurai and Puthenthurai villages coastal regions. Berms can also be spotted in the northeastern part of the study area, particularly in the Arokiyapuram village. A beach scarp features a slope that exceeds the essential angle of repose of 32 degrees suggested by Soulsby(1997) and a minimum height of 0.25 m (Figure 6b). Beach scarps are nearly vertical seaward-facing sandy cliffs that form part of the cross-shore beach profile. These landforms are frequently connected with eroding (nourished) beaches and can reach 2 -3 metres in height. (van Bemmelen *et al.*, 2020). Thus, they play an appropriate role in nearshore hydrodynamics and sediment transport processes (de Alegria-Arzaburu *et al.*, 2013).In the district, the scarps area small patches in Rajakamangalam, Ganapthaipuram and Chinnavillai coastal areas. The scarps with more than a metre height were seen in the Puthelam coastal area. In Pallam coastal area also the Scarps were noted they formed because of the rip currents.

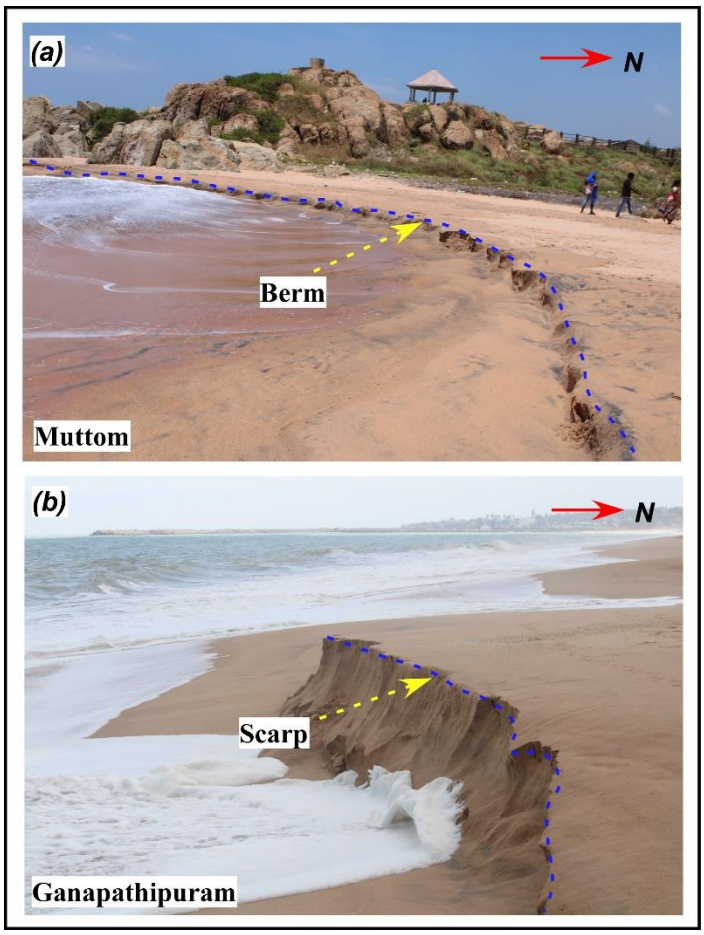

Figure 6 Berms & Scarps found in the study area a) Berm in Muttom b) Scarp in Ganapathipuram coast

4.1.5 Beach Cusps:

Beach cusps are formed by sorting beach sediments in semicircular patterns or curved-shaped indentations with horns and embayment along the seaward slope of the beach (Flemming, 1964; Reddy, Sarma and Kumar, 1984; Sheik and others, 2011). The cusp horns are remnants of an erosive process (Johnson, 1920; Evans, 1938). Figure 7a shows the beach cusps formation in Vallavillai with the horns and embayment. It has also been reported that the formation of beach cusps is linked to the formation of a berm (Russell and McINTIRE, 1965; Dubois, 1981). Figure 7b depicts the relationship between the cusp's formation and the berms on the Enayam coast. The beach cusps are formed by swash action in the coastal areas such as Vallavillai, Enayam, Kovalam and Pillaithoppu.

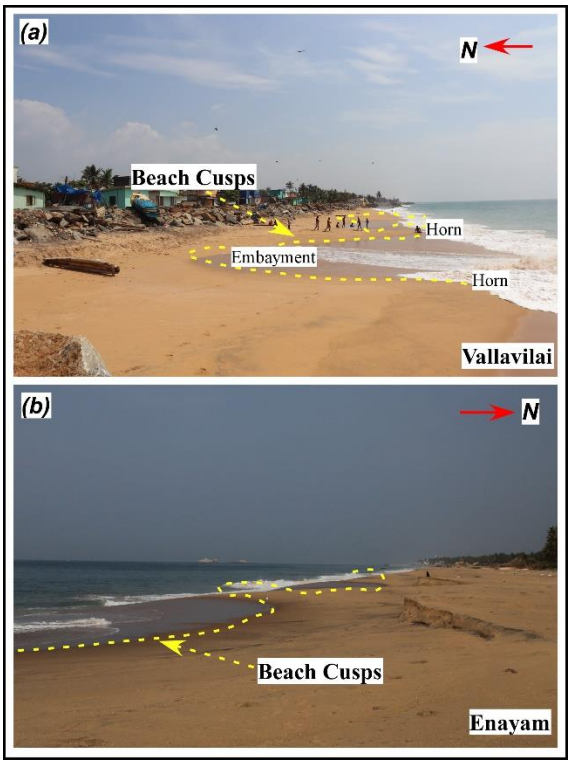

Figure 7 Beach Cusps found in the Study area a) Beach cusps with horn and embayment near vallavillai b) Beach cusps near Enayam forms closer to the berm

4.1.6 Sand Bars:

Typically the sandbars are found in the shallow depths of the sea near the estuary (Sathish and Elango, 2011; Krishnaraj *et al.*, 2014). These shallow depth Sandbars locations shift over time in response to the offshore wave variability and climate variability (Melito *et al.*, 2020). It has been established that in the short term, sand bars tend to migrate offshore in the existence of breaking waves and very energetic wave conditions (Gallagher, Elgar and Guza, 1998; Ruessink and Terwindt, 2000).

Sandbars form seasonally in the river mouths of Thengapattanam and Manakudy estuarine. A seasonally formed sandbar can also be found in Rajakamangalam (Figure 8). In addition, because of offshore rocky outcrops acting as a natural wave breaker, small patches of sandbars form seasonally on the downdrift side of the Kanyakumari coast (Natesan and Subramanian, 1994; Sanjeevi, 1996; Kaliraj, Chandrasekar and Magesh, 2014).

Figure 8 Sandbar near Rajakamangalam

4.1.7 Shallow Marshes or Salt Marshes & Salt pans :

Shallow marshes are coastal wetlands that form in the intertidal zone's low-lying area (Allen and Pye, 1992). These marshes are no longer seen as intertidal wastelands of little benefit to anyone. They are now widely acknowledged to serve a critical role in coastal defence, wildlife conservation, and a crucial source of organic material and nutrients for a diverse spectrum of marine organisms (Boorman, 1999). The Saltmarsh sediments often contain more fine sands and clays from marine origins (Redfield, 1972; Nixon, 1982).

The landforms are often associated with estuaries and found along the estuaries of Thengapattanam, Manakudi, and Coalachel areas. Marshes can also be spotted in Ganapathipuaram due to the presence of backwater creeks (Figure9a). The low-lying part of the Inyamputhenthurai shore is typically swampy.

Yapp, John, and Jone(1917) proposed the process of saltpan formation initially, and they distinguished between primary pans (generally circular, flatbottomed ponds) and channel pans (long, curved, often branching ponds). Primary pans can be found in the Kanyakumari district. Those primary saltpans are associated with the low-lying areas of salt marshes, tidal flats, saltwater ponds, and backwater streams that are clayey in nature (Hentry, 2013).

Salt pans are mostly found on both sides of backwater creeks in Puttalam. Also, the pans found in the Thamarikulam area and the northern part of the Manakudi estuary (Figure 10)

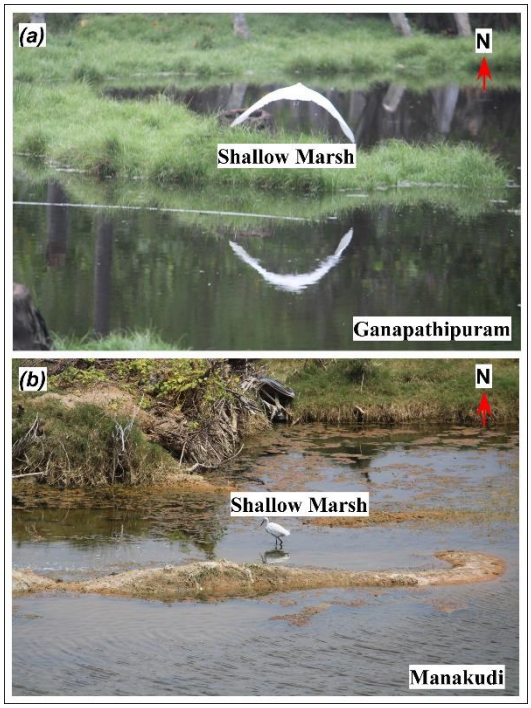

Figure 9 Shallow marshes found in the Study area a)Shallow marsh in Ganapathipuram b) Shallow marsh in Manakudi

Figure 10 Salt pan in Manakudi

4.1.8 Mudflats :

Intertidal mudflats safeguard many thousands of kilometres of the world's coastlines from inundation with just minor defences. They can be found in various environments, including high and low tidal ranges, sheltered estuaries and inlets, and coasts susceptible to considerable wave effects and at all latitudes. Although mudflats are made up of sand and mud, the mud content is high enough for the sediment to be cohesive (Dyer, 1998). In many places, they are limited by lower-lying sandflats, and above high-water neap tide, by a zone where marsh vegetation thrives.

Mudflats are mostly present along the estuaries of Thengapattanam and Manakudi in the research area. In Pozhikarai and Midalam, there were also little mudflat patches. These mudflats are exposed or submerged in certain places depending on the tidal level.

4.1.9 Estuaries :

An estuary is a brackish water coastal body of partially confined water and has a free connection to the open sea. One or more rivers or streams feed it (Pritchard, 1967). Thamiraparai and Pazhayar rivers confluence in the sea in Thengapattanam and Manakudi, respectively. Because of the confluence of the rivers, Thengapattanam and Manakudi are the two significant estuaries in the Kanyakumari district (Hentry *et al.*, 2017). With that, Colachel, Manavazhakurichi, Midalam, and Rajakamangalam have smaller backwater creeks.

Thengapattanam is a tropical bar-built estuary that stays landlocked most of the time (Anitha and Kumar, 2013). However, AVM (Anandan Victoria Marthandavarman Canal) stretches along the west shore towards the estuary. Brackish water in the estuary is greatly influenced by the ebb and flow of the ocean tide, and river movement leads to the development of creeks, salt flats, and mudflats (Ahmad, 1972).

Most notable landforms, such as mangroves and salt marshes, can also be found in the Manakudi estuary (Figure 11). Tidal currents regulate the length and width of this estuary (Chandrasekar *et al.*, 2012). Because the brackish water creek in the Manakudi estuary is impacted by little or no backwater currents, sediments are backed up to the nearby landforms.

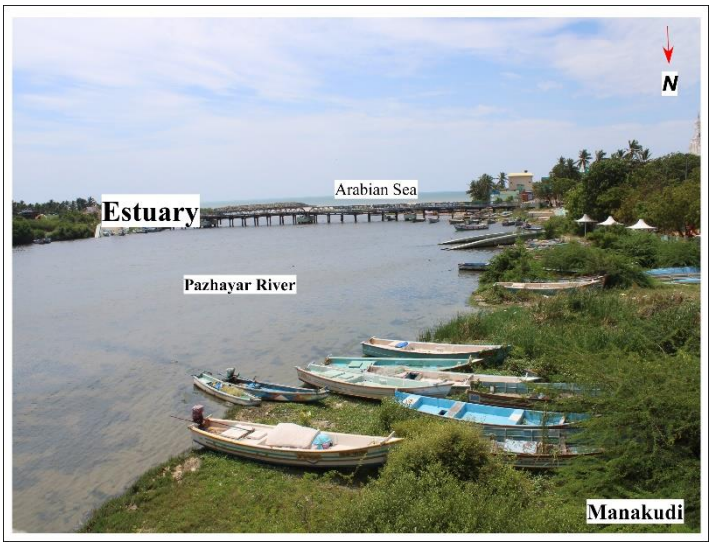

Figure 11 Estuary in Manakudi

4.1.10 Coastal Uplands, Rocky Shores and Skerries :

Headlands, bluffs, sea cliffs, coastal banks, sandplains, and coastal dunes are coastal uplands. Coastal grasslands and heathlands are also included in the coastal uplands (areas characterised by low-growing shrubs mixed with grasses and forbs). From Kovalam to Kanyakumari and from Periyakadu to Sothavillai, coastal uplands can be seen (Figure 12). These uplands are thickly layered by sandstone and Teri sand deposits (Jayangondaperumal *et al.*, 2012). Likewise, Muttom to Kadiyapattanam Teri sand uplands and low elevated sandstone overburdened uplands in the Colachel area has been observed.

A rocky shore is an area of a coast's intertidal zone where rocks predominant. For example, the coastal regions of Muttom and Kanyakumari have rocky shores (Figure 13). By controlling waves and currents, these rocky shores of the coast play a vital role in littoral sediment flow along the surf zone (Kaliraj, Chandrasekar and Magesh, 2014). The rocky shores include sea cliffs and wave-cut platforms formed by the removal of weathered materials.

A skerry is a small rocky islet that is usually too small for human habitation. It could simply be a rocky reef, often referred to as a low sea stack (Johnson and Webb, 2007). There are some skerries in the Kanyakumari district's coastal areas, particularly at Kanyakumari (Figure 14a). A skerry structure can also be found on the Puthenthurai coast (Figure 14b).

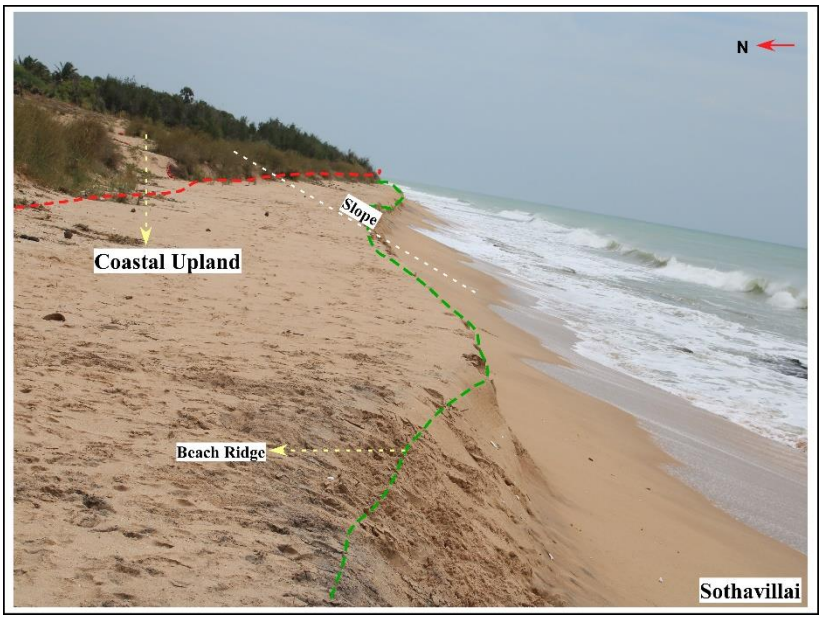

Figure 12 Coastal upland in Sothavillai

Figure 13 Rocky Shore in Muttom

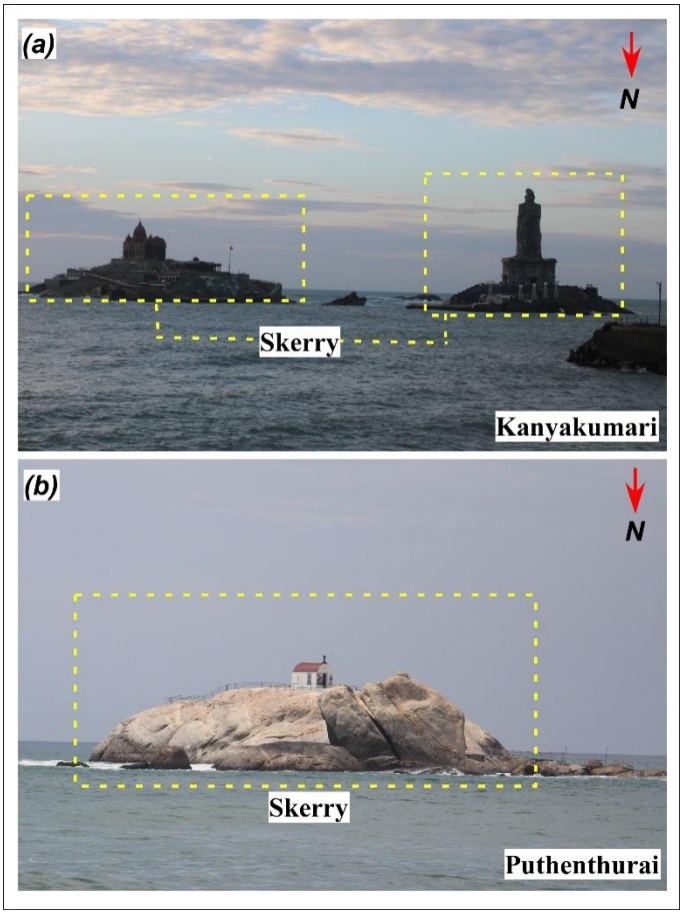

Figure 14 a) Skerry in Kanyakumari b) Skerry in Puthenthurai

4.1.11 wave-cut notches :

Wave-cut notches are grooves or undercut that emerge on vertical cliff profiles due to coastal erosion (Wziatek, Vousdoukas and Terefenko, 2011). Notches are commonly used to indicate current and past mean sea-level locations (Benac, Juračić and Bakran-Petricioli, 2004). Notches presented in the coastal areas of the district corresponding to their sea-level indicate the district's coastal areas' low and long-term uplift movement.

The seaward slope of the rocky shore in the study area has wave-cut notches. The typical wave cut notches can be found on the rocky beaches of Kanyakumari, Kovalam, Muttom, and Colachel (Figure 15).

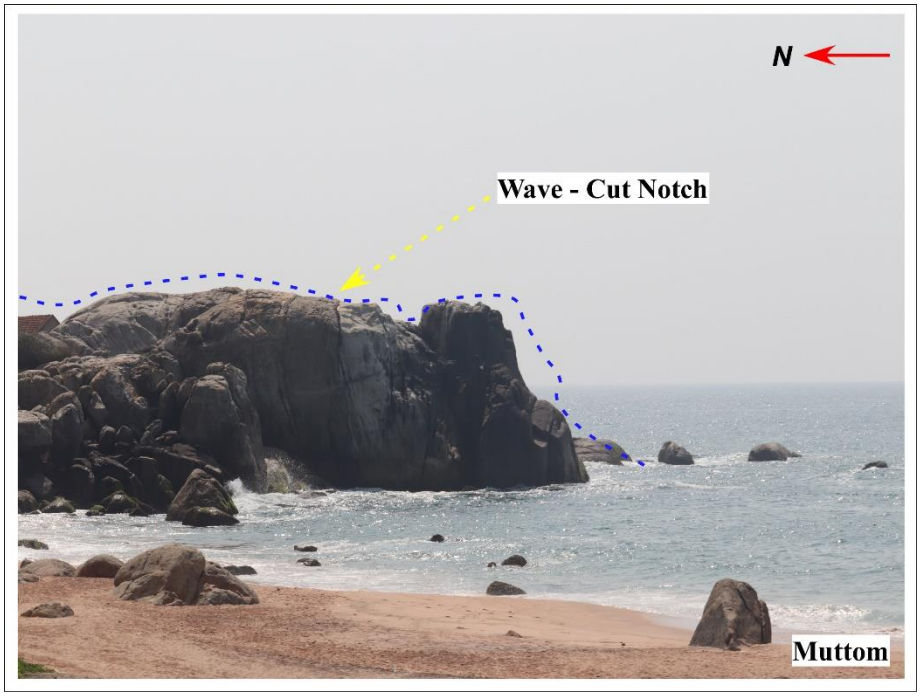

Figure 15 wave-cut notch in Muttom

4.2 Fluviomarine landforms:

The combination of river and marine processes forms the fluviomarine landforms (Ahnert, 1998; Paul, 2002). The distribution and character of the landform, such as shoals and deltaic plains along the coast, are influenced mainly by sediment fed by rivers and marine sources.

4.2.1 Shoals:

Shoals are narrow, linear landforms that form on shallow water bodies where a stream, river, or current from the ocean promotes sediments and granular material due to the shoaling process (Murty and Flather, 1994; Wood and Hine, 2007).The shoals are distinctively formed as sandbars and gravel bars at the mouths of estuaries near the coastal zones of Manakudi and Thengapattanam. Meanwhile, the shoals are most often composed of sand, silt, and pebbles formed by the discharge of river and longshore sediments from the sea by the localised shoaling process.

4.2.2 Swales:

Swales are shallow water channels with saltwater that run along the coast between adjacent strandlines or beach ridges (Bird, 2011). They are found across the study area, including Arokiyapuram, Midalam, Simon Colony, Pallamthurai, Ethamozhi, Kesavenputhenthurai, and the estuaries at Thengapattanam and Manakudi (Figure 16).In the study area's eastern part, swales are distinguished by the interdunal formation of primary dune slacks and several faces of strandlines formed by rivers and waves' transgression and regression process (Revathy, 2002).On the seaward slope of the beach ridges, the western part of the study area developed swales along with single or two-faced strandlines in Mandaikadu and the Midalam coastal areas.

Figure 16 Shows Swale outflow in Arokiyapuram

4.2.3 Deltaic plain:

The deltaic plain is found in the study area along the banks of the Pazhyar and Thamirabarani rivers.The deltaic plain comprises sand, silt, and clay material due to the river's long-term activity (Anbarasu, 1994). The delta landform forms on the plain's downslope at Kottaram because of sediment deposition from river discharge and littoral sediments.

4.3 Fluvial landforms:

Fluvial landforms are developed in a range of space and time periods by the fluvial hydrodynamic process of rivers and channels (Woltemade, 1994). The transportation of sediments and the riverine environment results in the formation of various landforms such as alluvial plains, flood plains, buried pediplains, buried pediments, deltas, and other shallow landforms (Schumm, 1977; Richards, 1982). The fluvial landforms in the study area are developed by the confluence of three major drainage networks, namely the Thamirabarani, Pazhayar, and Valliyar rivers, as well as their tributaries, which flow southerly from the western ghats (Kaliraj, 2016).

4.3.1 Flood plain:

A floodplain, also known as bottomland, is an area of land close to a river that spreads from the channel's banks to the highlands and is prone to flooding during heavy discharge periods. (Goudie, 2004). Due to the river discharge and flooding during the monsoon, the flood plain comprises clay-rich sand and silt particles (Nanson and Croke, 1992; Kaliraj, 2016). The flood plain is separated into two types: older flood plains and younger flood plains. The older flood plain is a zone formed by river sedimentation and is frequently undulated, whereas the younger flood plain is a low-lying waterlogged habitat. The older flood plain is spread over the upper section of the river course, buried pediments, buried pediplains, and freshwater bodies, whereas the younger flood plain is found along the Thamirabarani river's downslope side and in some parts of the Pazhayar river's course.

4.3.2 Alluvial plain:

An alluvial plain is a predominantly flat landform created by the long-term sediment deposition of one or more rivers originating in highland areas and producing alluvial soil (Loveson, Rajamanickam and Anbarasu, 1990). Alluvial plain soils are formed from a variety of materials deposited on a flat to nearly flat slope via fluvial and/or colluvial processes, as well as gravity (Al-Jabri, 2016). Variation in physical, chemical, and mineralogical qualities occurs due to these processes, as does nutrient absorption in the soil. As a result, alluvial soils are frequently more productive than highland soils. Alluvial plains and buried pediplains develop in the western part of the study area due to the action of the river Thamirabarani. And more prominent areas of the alluvial plains have been developed along the course of the Pazhayar river.

4.3.3 Buried Pediplains:

Buried pediplains form because buried pediments with a substantial overburden of weathered materials converge (Kumar, Agarwal and Bali, 2008). According to the weathering and denudation processes, buried Pediplains are classified into two categories: deep pediplains and shallow pediplains (Kaliraj, 2016). The buried shallow pediplains have a levelled surface with a weathered zone extending to a depth of ten metres, and the buried deep pediplain is also flat, but with a weathered zone extending to a depth of more than ten metres. Patches of buried deep pediments with an overburden thickness of 10-20m can be seen in the northern part of the coastal stretch between Colachel to Thengapattanam. The overburdening of these landforms contributes to the formation of alluvial and flood plains throughout the study area.

4.3.4 Buried Pediments:

The buried pediment is a moderately undulated surface that has been suppressed by thinly covered fluvial sediments due to surface runoff sheet flow (Ahnert, 1998). A pediment develops at the foot of a receding elevated source area and is gradually buried by encroaching piedmont alluvium (Lawson and Tolman JR, 1915). In the study area, buried pediments were identified in three distinct forms: pediments deep, pediments moderate, and pediments shallow, all of which were formed by a layer of debris caused by weathering and erosional processes. The landform is characterised by a sparsely covered fluvial soil layer that is dotted with scattered rocky outcrops. The pediment moderate is found in some places of the study area, and it is mainly located adjacent to the shallow pediplain surrounded by alluvial and flood plains.

4.3.5 Wetlands & Waterlogged area:

A wetland is a unique ecosystem submerged by water, either permanently or periodically, where oxygen-free activities dominate (Keddy, 2010). Wetlands function as an essential part of the landscape. They are valuable because many of their functions have proven beneficial to people (Mitsch and Gosselink, 2000). Wetlands are primarily associated with rivers, tributaries, and water bodies. In the western part of the study area, the Thamirabarani river drains into the Arabian Sea, forming an estuarine ecosystem where wetlands can be spotted. The Pazhayar river flows from the Mahendragiri Hills and produces a range of wetlands in the Manakudi estuary area, including mud flats, salt marshes, tidal flats, and creeks. Lakes, ponds, saltwater marshes, and brackish water are all examples of waterlogged areas.

4.4 Aeolian formation of coastal landforms:

The coastal region of the Kanyakumari district is composed of several types of aeolian landforms such as sand dunes, barrier dunes, and Terisand dunes formed by erosive and constructive processes of the wind (Jayangondaperumal *et al.*, 2012; Kaliraj, 2016). Aeolian sediment movement and dune growth

play a significant role in the sediment budgets of many coastal settings. Numerous factors influence aeolian sediment transport rates and adjacent dune growth rates (Van Dijk, Arens and Van Boxel, 1999). The essential factors are wind climate, beach slope, sediment grain size, vegetation features, and sediment moisture content. Controls derived from sediment features and beach geometry frequently fluctuate systematically with a beach's morphodynamical state (Sherman and Lyons, 1994).

4.4.1 Coastal Sand Dunes:

Coastal dunes are distributed along most of the world's coastlines and are common wherever an ample supply of sediments is available to the beach (Nickling and Davidson-Arnott, 1990). The coastal sand dune areas have far more similarity to arid dune types during their early phases of creation or when the plant cover is disrupted (Ritchie, 1972). In the study area, sand dune complexes are spread over the coastal sections of Puthenthurai to Periyakadu (figure 17) and Manavazhakurichi to Mandaikadu, with dune crests ranging in height from 2 to 7m due to wind-transported sediments being dumped from blowouts or open beaches. Also, some patches of the dune formations can be found near at Vattakottai(Namboothri *et al.*, 2008). Additionally, the artificial dunes around the Manavalakurichi and Chinnathurai Coastal areas are generated by dumping mining wastes.

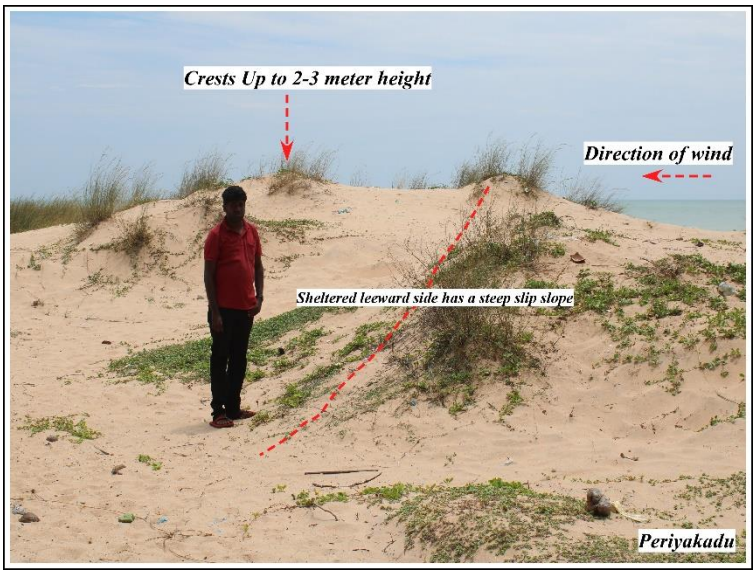

Figure 17 Coastal dune in Periyakadu

4.4.2 Foredunes:

Foredunes are beach parallel dune ridges developed on the top of the backshore due to aeolian sand deposition and vegetation (Hesp, 2002). The foredune formations found along Shotavillai to Sanguthurai and Alanchi to Midalm's coastlines stretch across the study area. The dunes form along the coastal stretch between Sothavillai and Sanguthurai as a process of swashing of sands by low-intensity waves that propel longshore sediments parallel to the beach (Figure). The foredunes develop along the coastal region from Alanchi to Midalam due to sediment accumulation induced by monsoonal winds. The coastal anthropogenic structures have harmed the stability of foredunes by restricting sediment feed to the coast on the down-drift side (Jayappa, Vijaya and Subrahmanya, 2003).

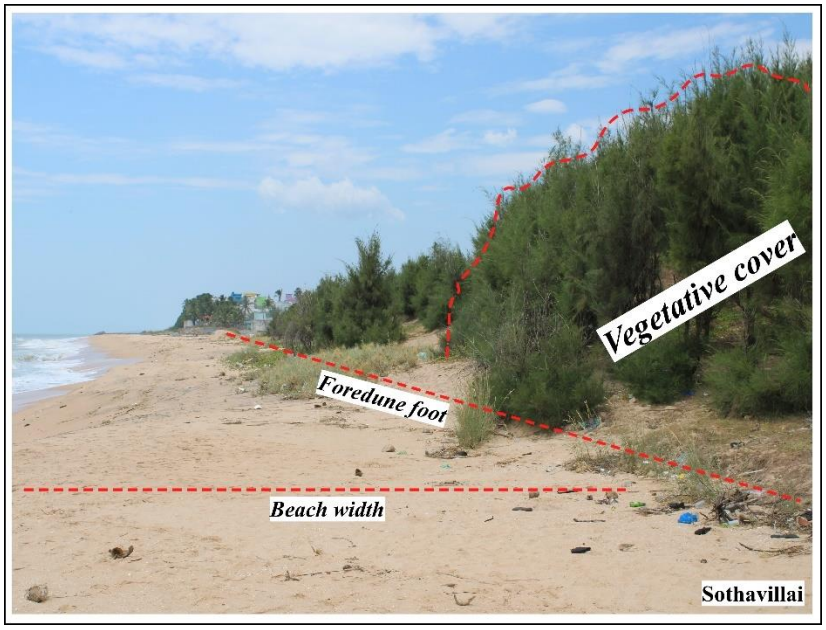

Figure 18 shows Foredune with vegetative cover in Sothavillai

4.4.3 Teri sand dunes:

Teri sand dunes are found along coastal belts, most commonly in low- to mid-latitude regions (Singhvi, Deraniyagala and Sengupta, 1986; Zheng and Wei, 1998). Teri sands of the coastal dunes directly overlie the underlying sandstone formation. These Teri sands in the Kanyakumari coast have been an abundant source of heavy minerals like ilmenite, rutile, zircon, monazite, and sillimanite (Chandrasekharan, 2001). These dunes are distributed as scattered patches and parallel to the current coast in the study area. The dunes are yellowish red in tint and range in thickness from 4–6 metres. The most isolated occurrence of these dunes in the study area is about 5 kilometres from the current coast. Teri dunes are developed in the Kanyakumari-Kovalam coastal region at an elevation of 110-135m above sea level due to the aggregation of red and marine sediments by the NE monsoon's wind direction (Kaliraj, 2016). Also, Teri dune patches are found in the study area's highlands near the Muttom, Enyamputhenthurai, and Alanchi areas (Figure 19).

Figure 19 Shows Teri sand in Muttom

5. Conclusion :

Between Nerrodi and Arokiyapuram(Kanyakumari district), the study area is defined by various geomorphic features. The coastal geomorphic features of this study area clearly demonstrated the sea-level fluctuations and variations in climatic circumstances. Geomorphological field studies like this can

enrich the geographical context of geomorphological research and also contribute to classification and quantitative analysis.

References:

1. Ahmad, E. (1972) 'Coastal geomorphology of India.', *Coastal geomorphology of India.*
2. Ahnert, F. (1998) 'Introduction to Geomorphology'. Arnold Publisher London.
3. Al-Jabri, M. (2016) 'Soil properties of the Alluvial plain and its potential use for agriculture in Donggala Region, Central Sulawesi', *Indonesian Journal of Agricultural Science*, 8(2), pp. 67–74.
4. de Alegria-Arzaburu, A. R. *et al.* (2013) 'Post-nourishment beach scarp morphodynamics', *Journal of Coastal Research*, (65), pp. 576–581.
5. Allen, J. R. L. and Pye, K. (1992) *Saltmarshes: morphodynamics, conservation and engineering significance*. Cambridge University Press.
6. Anbarasu, K. (1994) 'Geomorphology of the northern Tamilnadu Coast using remote sensing techniques', *Unpublished Ph. D. thesis, Bharathidasan University, Tiruchirapalli*, 184.
7. Anitha, G. and Kumar, S. P. (2013) 'Seasonal variations in physico-chemical parameters of Thengapattanam estuary, South west coastal zone, Tamilnadu, India', *International journal of environmental sciences*, 3(4), p. 1253.
8. Balasubramanian, A. (2011) 'Coastal Processes and Landforms'. DOI.
9. van Bemmelen, C. W. T. *et al.* (2020) 'Beach scarp dynamics at nourished beaches', *Coastal Engineering*, 160, p. 103725.
10. Benac, Č., Juračić, M. and Bakran-Petricioli, T. (2004) 'Submerged tidal notches in the Rijeka Bay NE Adriatic Sea: indicators of relative sea-level change and of recent tectonic movements', *Marine Geology*, 212(1–4), pp. 21–33.
11. Bird, E. C. F. (2011) *Coastal geomorphology: an introduction*. John Wiley & Sons.
12. Boorman, L. A. (1999) 'Salt marshes–present functioning and future change', *Mangroves and Salt Marshes*, 3(4), pp. 227–241.
13. Chandrasekar, N. *et al.* (2012) 'Correlation between coastal geomorphology and tsunami inundation along the coast of Kanyakumari, India', *Journal of Ocean University of China*, 11(1), pp. 1–6.
14. Chandrasekharan, S. (2001) 'Heavy minerals in the beach and coastal red sands (Teris) of Tamil Nadu', *Explor. Research Atomic Minerals*, 13, pp. 87–109.
15. Curray, J. R., Emmel, F. J. and Crampton, P. J. S. (1967) 'Holocene history of a strand plain, lagoonal coast', in *Nayarit, Mexico: Coastal lagoons, a symposium: Mexico*, pp. 63–110.
16. Van Dijk, P. M., Arens, S. M. and Van Boxel, J. H. (1999) 'Aeolian processes across transverse dunes. II: Modelling the sediment transport and profile development', *Earth Surface Processes and Landforms: The Journal of the British Geomorphological Research Group*, 24(4), pp. 319–333.
17. Dubois, R. N. (1981) 'Foreshore topography, tides, and beach cusps, Delaware', *Geological Society of America Bulletin*, 92(3), pp. 132–138.
18. Dyer, K. R. (1998) 'The typology of intertidal mudflats', *Geological Society, London, Special Publications*, 139(1), pp. 11–24.
19. Evans, O. F. (1938) 'The classification and origin of beach cusps', *The Journal of Geology*, 46(4), pp. 615–627.
20. EVERTS, C. (1979) 'BEACH BEHAVIOR IN THE VICINITY OF GROINS. TWO NEW JERSEY FIELD EXAMPLES'.
21. Flemming, N. C. (1964) 'Tank experiments on the sorting of beach material during cusp formation', *Journal of Sedimentary Research*, 34(1), pp. 112–122.

22. Gallagher, E. L., Elgar, S. and Guza, R. T. (1998) 'Observations of sand bar evolution on a natural beach', *Journal of Geophysical Research: Oceans*, 103(C2), pp. 3203–3215.
23. Goudie, A. G. (2004) *Encyclopedia of geomorphology*. Psychology Press.
24. Gushing Woods, A. J. and Leahy, L. P. (1983) 'Beach ridges and paleogeography, Central Baja California, Mexico', *Physical Geography*, 4(2), pp. 167–181.
25. Hanslow, D. J. *et al.* (2000) 'Berm height at coastal lagoon entrances in NSW', in *Proc. 10th ann. NSW coast. conf., Yamba*.
26. Hentry, C. *et al.* (2010) 'Influence of geomorphology and bathymetry on the effects of the 2004 tsunami at Colachel, South India', *Bulletin of engineering geology and the environment*, 69(3), pp. 431–442.
27. Hentry, C. (2013) 'Spatial characterisation and coastal change assessment between kanyakumari and thengapattanam coast K k dist tn through remote sensing and geographic information system gis'.
28. Hentry, C. *et al.* (2017) 'Post - Tsunami Damages Assessment, Relief and Rehabilitation Measures in the Kanyakumari District, Tamil Nadu, South India', *Energy and Environment Research*. doi: 10.5539/eer.v7n1p48.
29. Hentry, C., Chandrasekar, N. and Saravanan, S. (2013) 'Beach dynamics of Colachel open coast, Kanyakumari district (SW India)', *Zeitschrift für Geomorphologie*, 57(1), pp. 75–95.
30. Hesp, P. (2002) 'Foredunes and blowouts: initiation, geomorphology and dynamics', *Geomorphology*, 48(1–3), pp. 245–268.
31. Jayangondaperumal, R. *et al.* (2012) 'Luminescence dating of fluvial and coastal red sediments in the SE coast, India, and implications for paleoenvironmental changes and dune reddening', *Quaternary Research*, 77(3), pp. 468–481.
32. Jayappa, K. S., Vijaya, K. G. T. and Subrahmanya, K. R. (2003) 'Influence of coastal structures on beach morphology and shoreline in southern Karnataka, India'.
33. Johnson, D. W. (1920) 'Shore Processes and Shoreline Development', *Geologiska Föreningen i Stockholm Förhandlingar*, 42(2), p. 87.
34. Johnson, M. E. and Webb, G. E. (2007) 'Outer rocky shores of the mowanbini archipelago, devonian reef complex, canning basin, western Australia', *The Journal of Geology*, 115(5), pp. 583–600.
35. Kaliraj, S. (2016) 'Geospatial analysis on coastal geomorphological vulnerability on south west coast of kanyakumari using remote sensing technology'.
36. Kaliraj, S. and Ch, N. (2012) 'Spectral recognition techniques and MLC of IRS P6 LISS III image for coastal landforms extraction along South West Coast of Tamilnadu, India', *Bonfring International Journal of Advances in Image Processing*, 2(3), pp. 1–7.
37. KALIRAJ, S. and CHANDRASEKAR, N. (no date) 'Geo-processing Model on Coastal Vulnerability Index to Explore'.
38. Kaliraj, S., Chandrasekar, N. and Magesh, N. S. (2014) 'Impacts of wave energy and littoral currents on shoreline erosion/accretion along the south-west coast of Kanyakumari, Tamil Nadu using DSAS and geospatial technology', *Environmental Earth Sciences*, 71(10), pp. 4523–4542.
39. Kaliraj, S., Chandrasekar, N. and Ramachandran, K. K. (2017) 'Mapping of coastal landforms and volumetric change analysis in the south west coast of Kanyakumari, South India using remote sensing and GIS techniques', *The Egyptian Journal of Remote Sensing and Space Science*, 20(2), pp. 265–282.
40. Keddy, P. A. (2010) *Wetland ecology: principles and conservation*. Cambridge university press.
41. Krishnaraj, S. *et al.* (2014) 'Evaluation of estuarine impact on groundwater salinisation in

Pondicherry coastal aquifers using electrical resistivity imagine techniques. J Coast Sci', *J Coast Sci*.

42. Kumar, M. G., Agarwal, A. K. and Bali, R. (2008) 'Delineation of potential sites for water harvesting structures using remote sensing and GIS', *Journal of the Indian Society of Remote Sensing*, 36(4), pp. 323–334.
43. Kurian, N. P. *et al.* (2006) 'Inundation characteristics and geomorphological impacts of December 2004 tsunami on Kerala coast', *Current Science*, pp. 240–249.
44. Lawson, A. C. and TOLMAN JR, C. F. (1915) 'Epigene profiles of the desert'.
45. Leatherman, S. P., Davison, A. T. and Nicholls, R. J. (1994) 'Coastal geomorphology', *Environmental Science in the Coastal Zone: Issues for Further Research*, pp. 44–48.
46. Loveson, V. J., Rajamanickam, G. V and Anbarasu, K. (1990) 'Remote sensing application in the study of sea-level variation along the Tamilnadu coast, India', *Sealevel Variation and Its Impact on Coastal Environment. Tanjavore, India: Tamil University*, pp. 179–197.
47. Mason, O. K. (1990) 'Beach ridge geomorphology of Kotzebue Sound: Implications for paleoclimatology and archaeology'. University of Alaska Fairbanks.
48. McLachlan, A. (1983) 'Sandy beach ecology—a review', *Sandy beaches as ecosystems*, pp. 321–380.
49. Melito, L. *et al.* (2020) 'Sandbar dynamics in microtidal environments: Migration patterns in unprotected and bounded beaches', *Coastal Engineering*, 161, p. 103768.
50. Mitsch, W. J. and Gosselink, J. G. (2000) 'The value of wetlands: importance of scale and landscape setting', *Ecological economics*, 35(1), pp. 25–33.
51. Murty, T. S. and Flather, R. A. (1994) 'Impact of storm surges in the Bay of Bengal', *Journal of Coastal Research*, pp. 149–161.
52. Namboothri, N. *et al.* (2008) 'Beyond the Tsunami: coastal sand dunes of Tamil Nadu, India-an overview', *UNDP/UNTRS, Chennai and ATREE, Bangalore, India*.
53. Nanson, G. C. and Croke, J. C. (1992) 'A genetic classification of floodplains', *Geomorphology*, 4(6), pp. 459–486.
54. Natesan, U. and Subramanian, S. P. (1994) 'Identification of Erosion-Accretion regimes along the Tamilnadu coast, India', *Journal of Coastal Research*, pp. 203–205.
55. Nickling, W. G. and Davidson-Arnott, R. G. (1990) 'Beaches and coastal sand dunes', in *Proceedings Canadian Symposium on Coastal Sand Dunes*, p. 1.
56. Nixon, S. W. (1982) *The ecology of New England high salt marshes: a community profile*. Fish and Wildlife Service, US Department of the Interior.
57. Otvos, E. G. (2000) 'Beach ridges—definitions and significance', *Geomorphology*, 32(1–2), pp. 83–108.
58. Parthasarathy, A. and Natesan, U. (2015) 'Coastal vulnerability assessment: a case study on erosion and coastal change along Tuticorin, Gulf of Mannar', *Natural Hazards*, 75(2), pp. 1713–1729.
59. Paul, A. K. (2002) 'Coastal Geomorphology And Environment acb publication Kolkata', *acb publication Kolkata*, p. 757.
60. Pritchard, D. W. (1967) 'What is an estuary: physical viewpoint', in. American Association for the Advancement of Science.
61. Reddy, B. S. R., Sarma, K. G. S. and Kumar, K. H. (1984) 'Beach changes during normal and cyclonic periods along Visakhapatnam coast'.
62. Redfield, A. C. (1972) 'Development of a New England salt marsh', *Ecological monographs*, 42(2), pp. 201–237.
63. Redman, J. B. (1864) 'THE EAST COAST BETWEEN THE THAMES AND THE WASH ESTUARIES (INCLUDING PLATE).', in *Minutes of the Proceedings of the Institution of Civil*

Engineers. Thomas Telford-ICE Virtual Library, pp. 186–224.
64. Revathy, G. (2002) 'Coastal landforms in between Nagapattinam and PortoNovo, Tamil Nadu, east coast of India', *Indian J. Geomorphology*, 7(1), pp. 119–133.
65. Richards, K. S. (1982) *Rivers: form and process in alluvial channels*. Methuen London.
66. Ritchie, W. (1972) 'The evolution of coastal sand dunes', *Scottish Geographical Magazine*, 88(1), pp. 19–35.
67. Ruessink, B. G. and Terwindt, J. H. J. (2000) 'The behaviour of nearshore bars on the time scale of years: a conceptual model', *Marine Geology*, 163(1–4), pp. 289–302.
68. Russell, R. J. and McINTIRE, W. G. (1965) 'Beach cusps', *Geological Society of America Bulletin*, 76(3), pp. 307–320.
69. Sanjeevi, S. (1996) 'Morphology of dunes of the Coromandel coast of Tamil Nadu: A satellite data based approach for coastal landuse planning', *Landscape and Urban Planning*, 34(3–4), pp. 189–195.
70. Sathish, S. and Elango, L. (2011) 'Groundwater Quality and Vulnerability Mapping of an Unconfined Coastal Aquifer.', *Journal of Spatial Hydrology*, 11(1).
71. Schumm, S. A. (1977) 'The fluvial system'.
72. Sheik, M. and others (2011) 'A shoreline change analysis along the coast between Kanyakumari and Tuticorin, India, using digital shoreline analysis system', *Geo-spatial information Science*, 14(4), pp. 282–293.
73. Sherman, D. J. and Lyons, W. (1994) 'Beach-state controls on aeolian sand delivery to coastal dunes', *Physical Geography*, 15(4), pp. 381–395.
74. Short, A. D. and Wright, L. D. (1983) 'Physical variability of sandy beaches', in *Sandy beaches as ecosystems*. Springer, pp. 133–144.
75. Singhvi, A. K., Deraniyagala, S. U. and Sengupta, D. (1986) 'Thermoluminescence dating of Quaternary red-sand beds: a case study of coastal dunes in Sri Lanka', *Earth and Planetary Science Letters*, 80(1–2), pp. 139–144.
76. Siple, G. E. (1967) *Geology and ground water of the Savannah River Plant and vicinity, South Carolina*. US Government Printing Office.
77. Soulsby, R. (1997) *Dynamics of marine sands: a manual for practical applications*. Thomas Telford.
78. Stapor, F. W. and FW, S. (1975) 'Holocene beach ridge plain development, northwest Florida.'
79. Taylor, M. and Stone, G. W. (1996) 'Beach-ridges: a review', *Journal of Coastal Research*, pp. 612–621.
80. Thamarai, S. B. P. P. (2008) 'Lithological Studies and Types of Soils Along Coastal Area of Kanyakumari to Colachel Coastal Belt, South Tamil Nadu, India', *Nature Environment and Pollution Technology*, 7.
81. Walsh, S. J. *et al.* (2017) 'A beach vulnerability framework for the galapagos islands: Fusion of worldview 2 imagery, 3-d laser scanner data, and unmanned aerial vehicles, Comprehensive Remote Sensing'. Elsevier. https://doi. org/10.1016/B978-0-12-409548-9.10438-5.
82. Woltemade, C. J. (1994) 'Form and Process: Fluvial Geomorphology and Flood-Flow Interaction, Grant River, Wisconsin', *Annals of the Association of American Geographers*, 84(3), pp. 462–479.
83. Wood, N. and Hine, A. C. (2007) 'Spatial trends in marsh sediment deposition within a microtidal creek system, Waccasassa Bay, Florida', *Journal of Coastal Research*, 23(4 (234)), pp. 823–833.
84. Wziatek, D., Vousdoukas, M. V and Terefenko, P. (2011) 'Wave-cut notches along the Algarve coast, S. Portugal: Characteristics and formation mechanisms', *Journal of Coastal Research*, pp. 855–859.

85. Yapp, R. H., Johns, D. and Jones, O. T. (1917) 'The salt marshes of the Dovey Estuary', *The Journal of Ecology*, pp. 65–103.
86. Zheng, W. and Wei, W. (1998) 'Formation of "old red sands" and paleogeographic environment on South China coasts', *Science in China Series D: Earth Sciences*, 41(3), pp. 306–313.