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& KIZHUR KANDATHIL RAMACHANDRAN [1]

COASTAL HABITAT VULNERABILITY OF SOUTHERN INDIA: A MULTIPLE PARAMETRIC APPROACH OF GIS BASED HVI (*HABITAT VULNERABILITY INDEX*) MODEL

ABSTRACT: KALIRAJ S., CHANDRASEKAR N. & RAMACHANDRAN K.K., *Coastal habitat vulnerability of Southern India: a multiple parametric approach of GIS based HVI (Habitat Vulnerability Index) model.* (IT ISSN 0391-9838, 2019).

The southern-most coast of India gently sloped southwards, which comprises the landforms like sandy beaches, dunes, estuaries, and other fluvio-marine landforms. During the past two decades, the rapid growth of population leads to serious environmental problems of the coast such as erosion, deformation of coastal landforms, aquifer contamination causing damages to habitat. We perform the Habitat Vulnerability Index (HVI) for demarcating vulnerable zone to habitat impairment by analyzing multiple physical, environmental and social variables. The algorithm in this model uses weighted vulnerability score of feature classes of each variable and combination of variables to facilitate computation of thresholds to calculate pixel-based vulnerability rate by averaging the weighted values using ArcGIS software. The result of the HVI model has estimated index values between 8 and 52 with a mean vulnerability index value of 30. Based on the range of HVI values, we categorize the coastal zones into five classes such as very low or protected zone, low vulnerable, moderately vulnerable, high vulnerable and very high vulnerable zones. Out of the total area, 9% of the coastal areas fall into the category of very high vulnerability conditions. It distributes the coastal habitats such as salt marshes, sand dunes, estuaries, brackish water, and cliffs within the area. Estuaries and its associated landforms are active shelters for numerous species in the coastal and marine habitats. Human settlements along the low-lying areas (elevation less than 10 m) of the Inayamputhenthurai, Mandaikadu, Pallam, and Puthenthurai coastal zones are highly vulnerable to erosion and land submergence resulting from high-energy waves, tidal actions, and other extreme events. Overall observation reveals that changes in physical and environmental factors directly influence the growth and productivity of coastal habitats in the wetlands, lagoons, estuaries, sea-grass beds, coral reefs, mangroves, and dunes vegetative cover. Anthropogenic influence seriously deteriorates the life cycle of the marine and coastal ecosystem in the nearshore environment producing adverse impacts on a long-term scale. Mapping of coastal habitat vulnerability using GIS based HVI model provides crucial information for long-term sustainable coastal habitat management.

KEY WORDS: Habitat Vulnerability Index, GIS analysis, Coastal environment, Coastal erosion, Geomorphological hazard, India.

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INTRODUCTION

The coast is a transition zone of land and water, which supports a variety of habitats such as human settlements, beaches, dunes, salt marshes, tidal flats, cliffs, rock pools, estuaries and mangroves (Anon, 2000). Coastal habitats are highly vulnerable as they are impacted by natural and anthropogenic hazards such as erosion, subsidence, flooding, seawater inundation, cyclones, storm surges, *tsunamis* and other human encroachments (Loveson, 1993; Kaliraj, 2016). Along the Indian coastline with the length of 7500 km, the various coastal habitats expose directly to a variety of natural and anthropogenic hazards because of extreme events such as beach erosion, cyclone, storms surges, tsunami and other human induced impacts. Sea level rise is one of the major threatening issues causing the destruction of coastal habitats. Along the south coast of Tamil Nadu, coastal habitats are characterized by enriched biodiversity, which is being threatened for erosion, landform deformation, inundation, and wave run-up processes (Chandrasekar, 2005; Hentry, 2013). IPCC (2007) reports predict sea level rise for almost all parts of the world's coastline. Sea level rise along the Indian coastline, though differ at various locations, are likely to damage the coastal ecosystems and human settlements in the low-lying coastal regions (Brown, 1999; Unnikrishnan & *alii*, 2006; Kaliraj & *alii*, 2014). Various hotspots of coastal habitats along the southern coast of India are prone to degradation due to beach erosion, flooding, storm surge and human encroachments (Chandrasekar & *alii*, 2006; Kaliraj & *alii*, 2013). The coastal hydrodynamic forces undergo significant changes with time and with changing-morphology of landforms the coastal habitats in various parts of the southern Tamil Nadu coast get affected (Loveson, 1993; Chandrasekar & *alii*, 1996; Hentry, 2013). Indian Ocean tsunami on December 26, 2004, has adversely brought considerable changes in coastal habitats irrespective of their landform settings (Chandrasekar, 2005; Murthy & *alii*, 2006; Kaliraj & *alii*, 2013). During the past two decades, many parts of Kanyakumari coast are experiencing higher density of population that causing to serious environmental degradation such as erosion, deformation of coastal landforms, aquifer contamination affecting the coastal habitats (Kaliraj & Chandrasekar, 2012). The coastal landforms are resourceful for coastal and marine habitats sustenance (Ahnert, 1998; Kaliraj & *alii*, 2017). Major coastal cities experience rapid growth of population within the coastal stretch of 500 m to 1 km from shoreline favored by the availability of resources and infrastructure. Urbanization is a major threat damaging physical and environmental properties of the coastal region compared to their counterpart in the inland areas. Impact of urbanization and industrial development severely affects the coastal habitats, mangroves, and coral reefs for unplanned development and also because of poverty forcing the unaffordable poor to occupy wetlands (mangrove) areas for dwelling (Paul, 2002; Ramesh & Elango, 2008; Salaj & *alii*, 2018). Long-term coastal erosion produces adverse impacts on morphological and sedimentological properties leading to degradation of coastal habitats by upsetting nutrient supply to different ecosystems (Alam & *alii*, 2002; Saxena & *alii*, 2013; Barman & *alii*, 2016). UNEP (2003) has reported that anthropogenic activities have significantly increased coastal habitat vulnerability through alteration of hydrodynamic regimes, water trophic conditions that change in biological communities and marine species. An adverse change in coastal landforms due to waves, currents, sped up sea-level rise and human activities produce critical impacts on coastal and marine ecosystems (Paul, 2002; Baskar & Sridhar, 2013). The southern Tamil Nadu coastal area is highly prone to physical, environmental and habitat vulnerability due to natural and anthropogenic activities (Kaliraj & *alii*, 2017). Impacts of anthropogenic factors lead degradation of coastal ecosystems along the south-west coast of Kanyakumari district by intervening the coastal processes for long-term scale (Baskaran, 2004; Kaliraj & Chandrasekar, 2012a). Along the southern Tamil Nadu coastal area, the many coastal zones are highly threatening to coastal hazards like erosion, subsidence, flooding, pollution, storm surges and extreme events that causing loss of human life and properties, damages of coastal and marine habitats (Hentry, 2013; Kaliraj & *alii*, 2016). Coastal vulnerability studies encompass vulnerability assessment and adaptation strategies of the coastal communities to manage and to withstand a hazard leading to disaster (Pal, 2001; Patnaik & Narayanan, 2009). It defines habitat vulnerability as a measure of the degree of magnitude to which coastal habitats cannot cope with adverse effects, risk, damages or degradation from coastal hazards induced by natural or anthropogenic activities (Saxena & *alii*, 2013). The habitats of marine and coastal ecosystems show enriched biodiversity within the tidal zones, including salt marshes, sand dunes, estuaries, brackish water, and cliffs along the southern Tamil Nadu coast (Chandrasekar & *alii*, 2006; Kaliraj & *alii*, 2016). South coast is highly dynamic due to changes in physical and environmental characteristics. One-third of coastal habitats are under the threat to natural and anthropogenic hazards like erosion, subsidence, flooding, pollution, storm surges and extreme events (Sreekala & *alii*, 1998; Kaliraj & Chandrasekar, 2012a). The coastal zones exposed to human intervention adversely affect habitats of flora and fauna within the beaches, estuaries, headlands, and shallow marshes (Nayak 2002; Cherian & *alii*, 2012; Selvakumar & *alii*, 2016).

The sustenance of habitats of marine and coastal ecosystems is directly proportional to the sensitivity of multiple environmental factors and inversely proportional to the degree of resilience to the impacts of those factors. Changes in coastal processes severely distract coastal habitats that result in decreasing the productivity, growth rate and loss of lives of living things in the coastal region (Adger & *alii*, 2005; Vittal & *alii*, 2007; Sowmya & Jayappa, 2016). IPCC (2007) published a trend analysis of worldwide coastal habitat points to the increased vulnerability to over four times from 1975 to 2011. The Indian coastline experiences high vulnerability of marine and coastal habitats mainly along the east coast of Odisha, Andhra Pradesh and southern coast of Tamil Nadu to the reason being the tropical cyclones and storm surges (Srinivasa Kumar & *alii*, 2010). The present study is a first attempt to investigate coastal habitat vulnerability along the Southern coast of India using GIS based habitat vulnerability index (HVI) model, the result of site-specific geo-database of habitat vulnerability can be used for sustainable coastal management to decision makers and planners.

STUDY AREA

The southern coast of Tamil Nadu, India is located within the geographical extent from 77° 09′ 49″ to 77° 34′ 14″ longitude E and 8° 06′ 32″ to 8° 14′ 15″ N latitude N, which covers a 58 km length of coastline from Kanyakumari to Thengapattinam (fig. 1). The coast gently slopes southwards which comprises landforms such as sandy beaches, dunes, estuaries and other fluvio-marine landforms (Loveson, 1993; Kaliraj & *alii*, 2016). The coastal uplands mainly associated with the rocky shore in Kanyakumari and Muttam are acting a natural barrier to wave action and storm surges. It composes the hinterland of backshore of thick-layered Late Quaternary deposits and sandy materials sloping seaward are composed of settlements, salt marshes, tidal flats, estuaries, saltwater

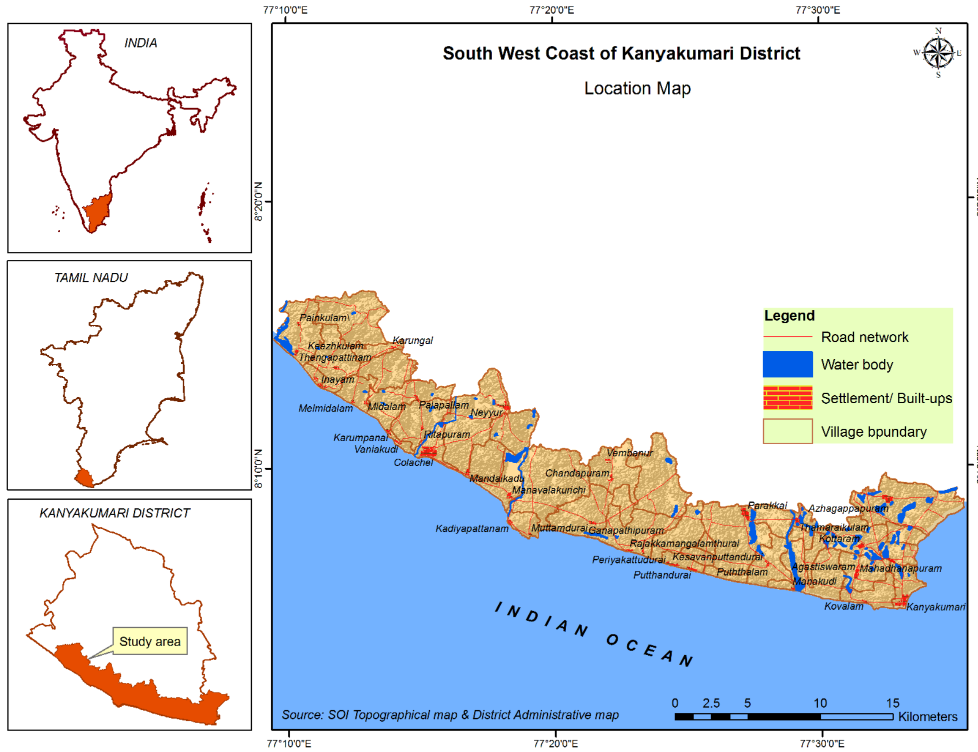

FIG. 1 - Geographical location of the study area.

bodies, backwater and creeks (Loveson & Rajamanickam, 1998; Chandrasekar & *alii*, 2006). Along the backshore tract, the isolated dune stretches are located roughly parallel to the shoreline that is being used for coastal habitats. It identifies many batches of rocky outcrops and sea cliffs along Muttam, Kanyakumari and Cape Comorin coastal zones (Loveson, 1993; Chandrasekar & *alii*, 2012). The three major drainage networks such as Pazhayar, Valliyar and Thamirabarani, and their tributaries flow southerly from the Western Ghats to join the sea. It distributes coastal habitats consisting of salt marshes, tidal flats, and estuaries in the river mouth of Thamirabarani and Pazhayar (Kaliraj, 2016). Sub-tropical climatic conditions prevail in the study area with normal annual rainfall varying from 826 mm to 1456 mm and the annual range of temperatures fluctuating between 23.78 °C to 33.95 °C. The study area has been divided into four major sectors such as (i) Kanyakumari; (ii) Rajakkamangalam; (iii) Muttam and (iv) Thengapattinam comprising 20 villages based on administrative boundary for ease of measurement of coastal habitat vulnerability characteristics.

MATERIALS AND METHODS

Mapping of coastal habitat vulnerability along the southern coast of India is the first attempt that has been performed by analyzing multiple geo-environmental parameters using GIS based HVI model. This is an index based model that is used to estimate the degree of magnitude to which coastal habitats cannot cope with adverse effects, risk, damages or degradation from the coastal hazards induced by natural or anthropogenic activities (Pethick & Crooks, 2000; UNEP, 2007; Saxena & *alii*, 2013). The algorithm of HVI model computing the weighted HVI parameters to the pixel-based vulnerability of habitat damage using remote sensing derived data and geo-processing techniques. The method adopts to analyze various primary and secondary data sources on themes of site-specific coastal habitat to assess vulnerability characteristics. It uses the geo-environmental parameters to quantifying the coastal dynamic processes including shoreline change, erosion of geomorphic landforms, and changes of landuse and land cover features, etc. The multiple thematic layers are prepared using spatial data sources such as Survey of India topographical map (scale 1:50,000), Landsat TM and ETM+ images (30 m), GPS field surveyed data, wave heights, tidal fluctuation and ASTER DEM (30 m) using ArcGIS 10.3 software. Coastal topographical features such as elevation (relief), spot heights, benchmarks, high water line (HWL), and other natural and man-made landmarks are extracted from the topographical maps; similarly, the ASTER DEM (30 m) data is used for demarcating low-lying landforms associated water bodies and estuaries, we execute GPS field survey (Garmin GPS ETREX 30) for high tide line demarcation and shoreline erosion measurements. We collected wave height and hydrodynamic data from buoy observed data published by INCOIS, NIOT, and NIO. It derives sea level rise data collected from USACE-Wave Information Study Atlas and Permanent Service for Mean Sea Level (PSMSL) from Census report 2011 to estimate population growth and density at the village level. We apply GIS techniques for systematic processing of data sources for preparing geo-database of each thematic layer with UTM-WGS84 projection and coordinate system. The feature classes of all the multiple parameters are assigned to weights and rating for representing potentiality to habitat damage at site-specific scale.

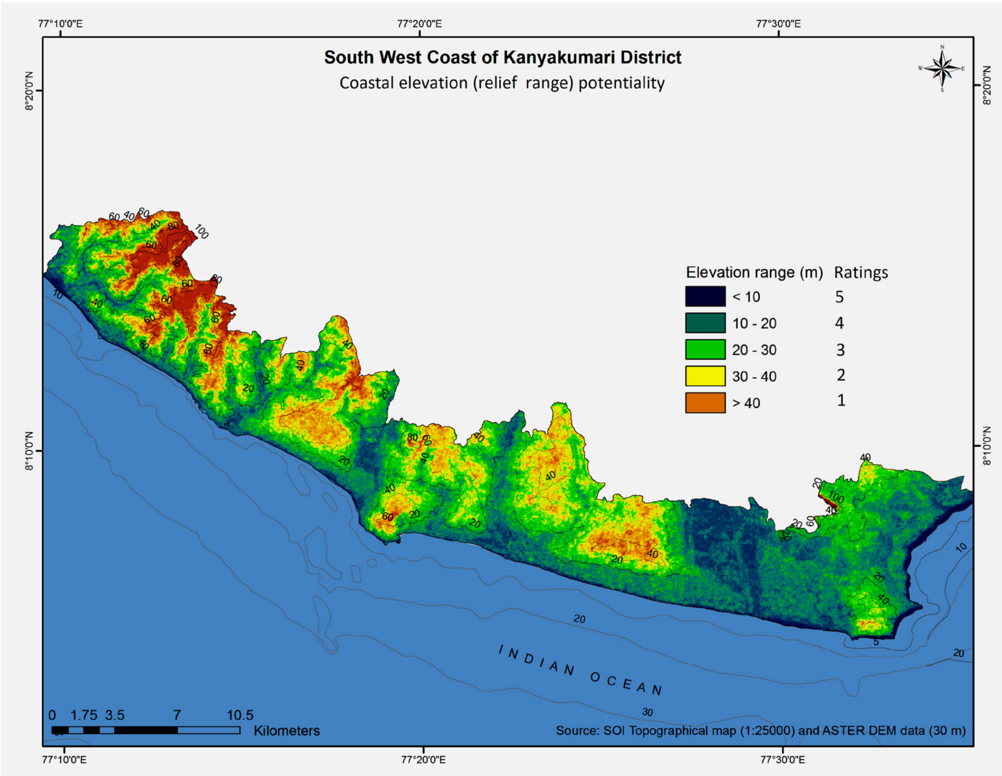

FIG. 2 - The coastal elevation (relief range) overlay with contour lines shows habitat damage potentiality and assigned ratings.

Habitat vulnerability index (hvi) modeling

GIS based habitat vulnerability index (HVI) model is incorporated multiple parameters to analyze various physical, environmental and social variables such as (i) coastal elevation level (above MSL), (ii) flood or inundation potential zone, (iii) erosion potential distance, (iv) settlement distance from the shoreline, (v) coastal habitat over-washing rate, (vi) salt marsh and swamp change rate, (vii) change rate of mud flats (or) tidal flats, (viii) groundwater contamination vulnerability (DRASTIC model) and (ix) population density rate. It executes multiple parametric analysis on various spatial datasets using systematic geoprocessing tools and functions in ArcGIS 10.3 software; we use i.e. spatio-temporal Landsat TM and ETM images to estimate erosion rate, settlement distance from the shoreline and site-specific over-washing rate, etc. It considers these parameters being the indicators of geo-environmental characteristics in the coastal stretches that are directly influencing the growth and productivity of coastal habitats. We, therefore, use the HVI model for computing the cumulative weights of a vulnerability index for identifying the degree of vulnerability to habitat damage at each grid in the coastal zone (Kaliraj, 2016). It derives a quantitative estimation of sediment loss or gain (over washing sediment rate) from the coastal landforms using SRTM and ASTER DEM datasets using GIS-based geomorphic change detection (GCD) analysis (Kaliraj *et alii*, 2017). Slope gradient (coastal relief or topography) between near offshore and beach is spatially drawn using integrated contour line (interval of 10 m) of bathymetry and the topographical map and it used to characterize the potential distance to flooding or seawater inundation by overlaying the projected sea level rise derived from tide gauges and buoy data. The HVI model is the semi-empirical algorithm that incorporating multiple weighted parameters to assess the potential vulnerability rate at the site-specific level and us expresses it as,

$$V_{hvi}=j=1nXj \text{ x } Wj/j=1nWj \quad (1)$$

where V_{hvi} refers to the rate of vulnerability to habitat damage; X_j is the rank value of the feature class within a variable *j*; W_j is assigned a weight value of the variable *J*; *n* is a total number of variables. It assigns the feature classes of each variable to vulnerability weights from 1 to 5 based on the degree of magnitude to habitat damage. It is described that the feature classes having ability to resist and (or) recover the coastal habitats from natural or anthropogenic hazards are assigned lower weighted value of 1; while we assign the feature classes of higher weighted value of 5. Likewise, many of the feature classes are assigned rank values according to the degree to which the respective parameter can cause habitat damage. Tab. 1 shows the detailed conversion of the weighted value assigned to multiple parameters contributing coastal habitat vulnerability. The algorithm of this model computes the cumulative weighted vulnerability index for feature classes of each variable to estimate habitat vulnerability rate at each pixel level (Patnaik & Narayanan, 2009) and weighted variables determine thresholds to calculate vulnerability using raster calculator module in ArcGIS (Kaliraj & Chandrasekar, 2012a). Thus, the resultant map shows the rate of vulnerability to habitat damage with varied ranges for the study area.

RESULTS AND DISCUSSION

The result of the HVI model shows the potential vulnerability rate in various parts of the coastal stretch. The geo-environmental parameters are assigned to appropriate weights and ratings based on their potential magnitude for contributing to coastal habitat vulnerability to physical damage and environmental degradation and they are described as follows,

Assigning weights and rating of HVI parameters

HVI modeling is performed to assess habitat vulnerability using nine parameters, which are highly sensitive to habitat damages. The model computes the habitat vulnerability rate from the physical and environmental variables based on the degree of vulnerability (Saxena & *alii*, 2013; Kaliraj, 2016). The weighted score indicates a change in variables responsible for damaging the coastal habitats in a particular area. It assigned the weighted values ranging from 1 to 5 for variables based on their potential magnitude to influence the habitat vulnerability. For example, a variable consisting of several feature classes is categorized into lower vulnerability it assigns to habitat damage with a lower weighted value of 1; whereas, the feature class that can be likely to bring very vulnerability is assigned a higher weighted value of 5. The variables and feature classes are assigned weights appropriately based on their sensitivity to habitat vulnerability. It shows HVI parameters with their feature classes and assigned weighted values in tab. 1.

Coastal elevation (relief range) potentiality

Fig. 2 shows the coastal elevation range that overlay with contour lines. It assimilates the coastal elevation range using contours (10 m interval) generated from the ASTER DEM (30 m) with the reference of Survey of India (SOI) topographic maps. Coastal habitats are distributed in landforms of their choice with varying relief and elevation ranging from low-lying to the upland area of the coastal region (Hentry, 2013). It incorporated coastal relief characteristics with geomorphology and LULC features to discriminate the potential impacts to the spatial distribution of coastal habitats and human settlements. Topographically, the coastal stretch comprises steep sloping surface is workable for erosion and beach subsidence along the sandy beaches and cliffs, respectively. The low-lying coastal landforms (altitude < 10 m MSL) include estuaries, shallow marshes, backwater creeks, and saltpans that are potentially vulnerable to habitat damage are assigned with higher vulnerability weighted value of 5. The human settlements and coastal habitats distributed within the elevation range of 10-20 m are potentially vulnerable during a storm surge, cyclone, and tsunami run-up and they are assigned with vulnerability weighted value of 4. The coastal uplands and terisand dunes within higher elevation (> 40 m above MSL) are considered as lower vulnerable zone and they are assigned to the weighted values of 1 and 2. The coastal habitats show higher diversity in various parts of the coastal area wherein they can re-establish or balance their growth and distribution in the diverse pattern regarding locations of habitat in the study area.

Coastal flooding (or) seawater inundation potentiality

The parameters analyzes the long-term characteristics of sea level rise to project the potential impacts zones that can be inundated coastal habitats existing along the low-lying areas. It identifies the coastal zones having a potential vulnerability to flooding or seawater inundation from sea level rise datasets derived from tide gauges and buoys for the periods of 2000-2016. Coastal habitats are

TABLE 1 - The HVI parameters and assigned vulnerability ratings

Sl.No.	HVI parameters	Very low	Low	Moderate	High	Very high
		1	2	3	4	5
1	Coastal elevation (relief range) potentiality (m)	> 40	30 - 40	30 - 20	10 - 20	< 10
2	Coastal flooding (or) seawater inundation potentiality (km)	< 0.5	0.5 - 1.0	1.0 - 1.5	1.5 - 2.0	> 2.0
3	Coastal erosion (shoreline change) potentiality (m)	< 250	250 - 500	500 - 750	750 - 1000	> 1000
4	Impacts of settlements and shoreline extends (km)	> 2.0	1.5 – 2.0	1.0 – 1.5	0.5 – 1.0	< 0.5
5	Coastal habitats overwashing potentiality (m^3/km)	> 100	100 - 200	200 - 300	300 - 400	> 400
6	Salt marsh (or) swamp change potentiality (m^3/km)	> 500 (accretion)	250 and 500 (accretion)	250 and -250 (accretion/ erosion)	-250 and -500 (erosion)	< -500 (erosion)
7	Mud flat (or) tidal flat change potentiality (m^3/km)	> 600 (accretion)	300 and 600 (accretion)	300 and -300 (accretion/ erosion)	-300 and -600 (erosion)	< -600 (erosion)
8	Impact of coastal groundwater vulnerability (DRASTIC score)	< 85	85 - 117	117 - 149	149 - 181	> 181
9	Impacts of population growth and density (persons/km^2)	< 615	616 - 1063	1064 - 1745	1746 - 5033	> 5034

Note: negative value (-) refers to erosion and positive value (+) refers to accretion.

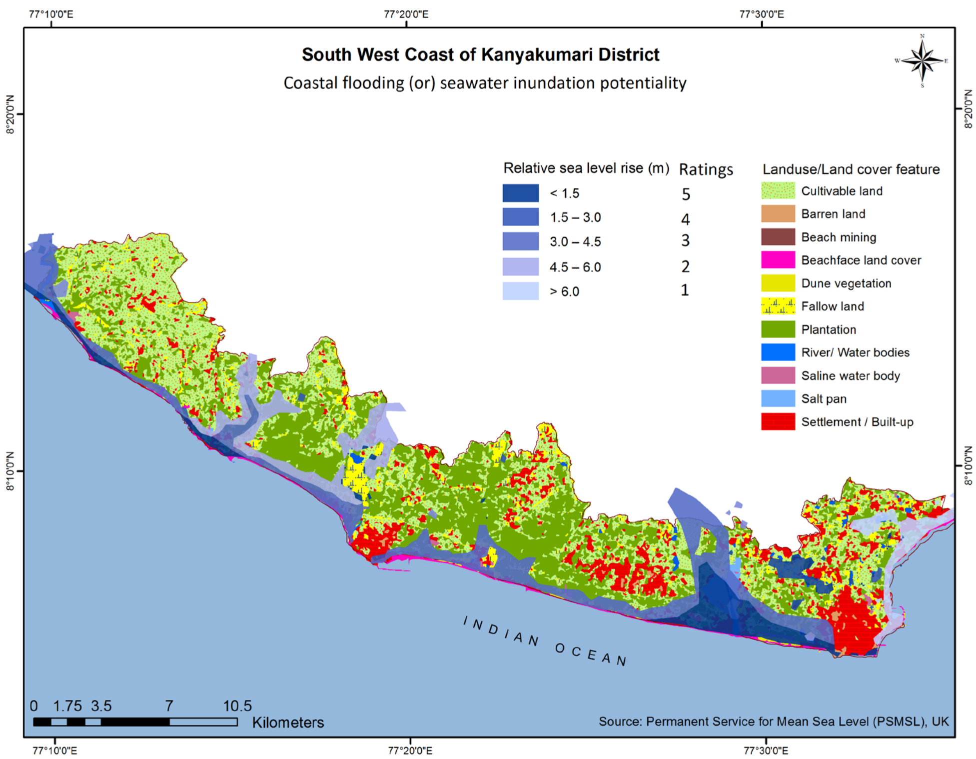

FIG. 3 - The potential impacts of sea level rise causes inundation vulnerability to the variety of landforms in the study area.

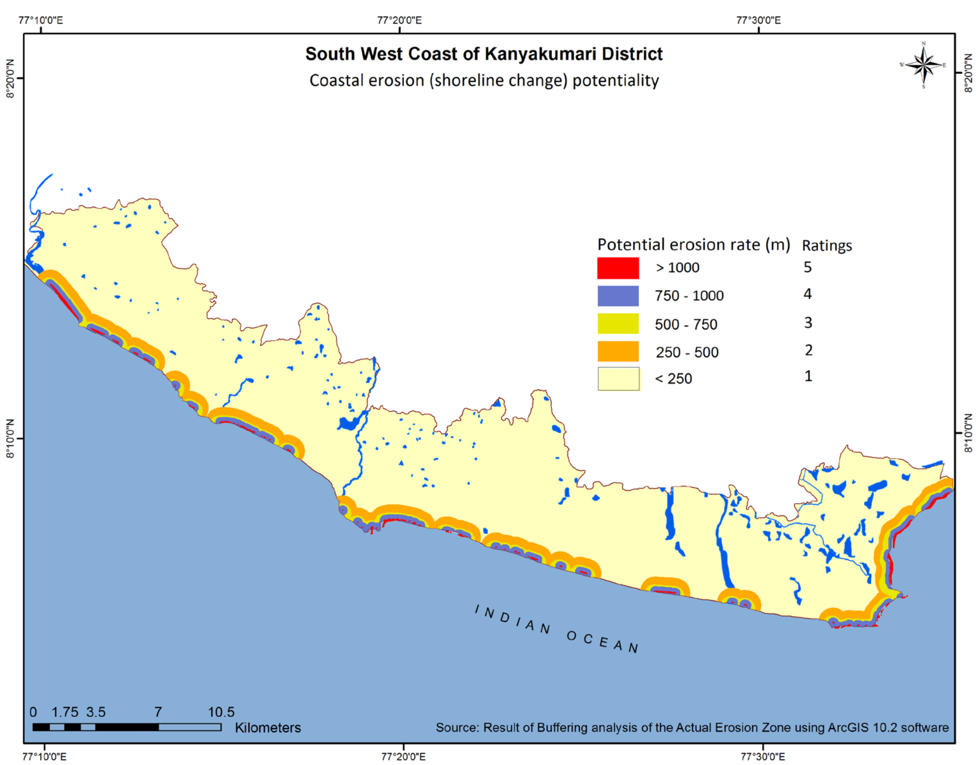

FIG. 4 - The potential zones of (shoreline change) of erosion/accretion and its assigned ratings.

extensively affected through floods and seawater inundation because of sea level rise, storm surge, tsunami and wave run-up along the coastal area (Vittal & *alii*, 2007; Mahendra & *alii*, 2011; Baskar & Sridhar, 2013). Fig. 3 shows the inundation zones with a variety of landforms; where, the coastal habitats such as salt marshes, tidal flats, backwater creeks, and estuaries exists in the low-lying areas along with human settlements - spread within a shoreline distance of 2 km are highly vulnerable to habitat damage because of wave height crossing 1.0 m above MSL. These areas are potentially vulnerable to flooding and seawater inundation while the rise of seawater up to 1.5 m compared to other zones. Habitats associated with estuarine and shallow sub-tidal water zones (~2 m depth) are highly vulnerable to flooding and seawater inundation (Kaliraj, 2016; Tanh & Furukawa, 2007; Mahendra & *alii*, 2011) for human encroachment activities that restricting drainage outflow followed by flooding and are assigned with higher vulnerability weighted value of 5. Coastal communities found within a distance of 1.5-2.0 km within the tidal wetlands, dune vegetative covers, and sandy beaches that are affected by flooding and seawater inundation during storm surges, cyclone and extreme events have been assigned with a weighted value of 4. Coastal estuaries and associated swampy areas near Thengapattinam and Manakudi area are likely to experience strong wave run-up (> 4.5 m) that are seasonal affects marine and coastal habitats in the salt marshes and tidal flats because of high energy wave set-up, tidal currents, river flooding, and surface runoff and hence, they are assigned with moderate weighted values of 2 and 3. Along the backshore areas, the range of uplands and teridunes are assigned with a lower weighted value of 1 and these areas are having no significant impacts for flooding and seawater inundation except the impacts of extreme events.

Coastal erosion (shoreline change) potentiality

Coastal eroded landforms are consequently experienced changes in their distribution because of the removal of sediments (Kaliraj & *alii*, 2013). It computes the long-term erosion rate for each grid using multi-temporal Landsat TM and ETM+ images for the years 1999 to 2011. The potential distance of erosion along the coast has been demarcated which is shown in fig. 4. Potential high erosion-prone areas with a distance of shoreline displacement measuring > 1000 m are located around the headlands of Cape Comorin and Kovalam and the sandy beaches of Manavalakurichi, Mandaikadu and Inayamputhenthurai coastal areas where the action of high-energy waves and divergence of littoral currents removing larger amount of sediments through backwash from the beach (Kaliraj & *alii*, 2014). It depletes sandy beaches in the Manavalakurichi-Mandaikadu zones in sediment for unregulated placer mining causes potential damage to coastal habitats. Coastal structures such as groins and revetments eroding on the down-drift side continuously affect coastal habitats and human settlements and therefore assigned a higher vulnerability weighted value of 5. The narrow coastal stretches of Kovalam–Manakudi and Colachel–Midalam, where the shoreline erosion distance estimated range from 750 to 1000 m causes shifting or loss of coastal and marine habitats. The estuarine habitats in the Thengapattinam and Manakudi coastal zones undergone changes in their growth and distribution during monsoons for river discharge are assigned a vulnerability weighted value of 4. In the Rajakkamangalam-Pillaithoppu coastal tracts, habitats in sandy beaches and dunes alter seasonally in terms of their productivity and distributions because of fluctuation in sedimentation rate (Kaliraj, 2016). Variation in the coastal processes during summer removes a larger amount of sediments from the down-drift side, causing adverse impacts on habitats and hence these areas are assigned a moderately weighted value of 2 and 3. The coastal zones, namely Sanguthurai, Chothavilai, Ganapathipuram, Pillaithoppu, and eastern part of Muttam register low erosion (distance < 250 m) due to prevailing low energy condition favor availability of nutrients to marine and coastal habitats and hence are assigned with lower vulnerability weighted value of 1.

Impacts of settlements and shoreline extends

Impact of occupying land for human settlements within a proxy of coastal hotspots is gradually increasing the vulnerability to physical damage of habitats and it leads adverse impacts on their productivity and spatial distributions. In the study area, human encroachments for developing settlements and inhabitant is acting as one of the primary barrier for changing natural dynamic processes and also reducing food or nutrient supply by polluting land and water sources (UNEP, 2007). Presently, the study area experiences larger scale of encroachment for constructing human settlements and built-ups that occupies the area of 17.54 km^2 (6.01%) in 2000 that was increased to 39.22 km^2 (13.43%) in 2011. The land encroached for settlements and built-up up to the area of 7.42% within a proxy of nearshore and backshore that results from encroaching on the headlands, sand dune complexes and other natural land cover features (Kaliraj & Chandrasekar, 2012a). It is demarcated that the changes of coastal areas due to development of settlements and built-ups using change detection analysis of Landsat TM and ETM+ images, ASTER DEM (30 m), topographical maps (scale 1:50,000). Fig. 5 shows the potentially vulnerable zones to damage of coastal habitat based on the encroachment of land for settlements and built-ups. Larger area of settlements and built-ups within the shoreline distance of 0.5 km of low-lying area (elevation < 10 m) are noted with severe pressure from both manmade and natural events and this condition prevails in the Inayamputhenthurai, Mandaikadu, Pallam, and Puthenthurai coastal zones and hence these areas are assigned to the higher vulnerability weighted value of 5. The areas consist of settlements and built-ups within a distance of 0.5-1.0 km in Midalam, Simonkudiyiruppu, Manavalakurichi, Periyakadu, and Manakudi are facing severe erosion during high wave run-up and hence these areas are categorized as high vulnerable zone to vulnerable to habitat damage (Hentry, 2013) and they are assigned to vulnerability

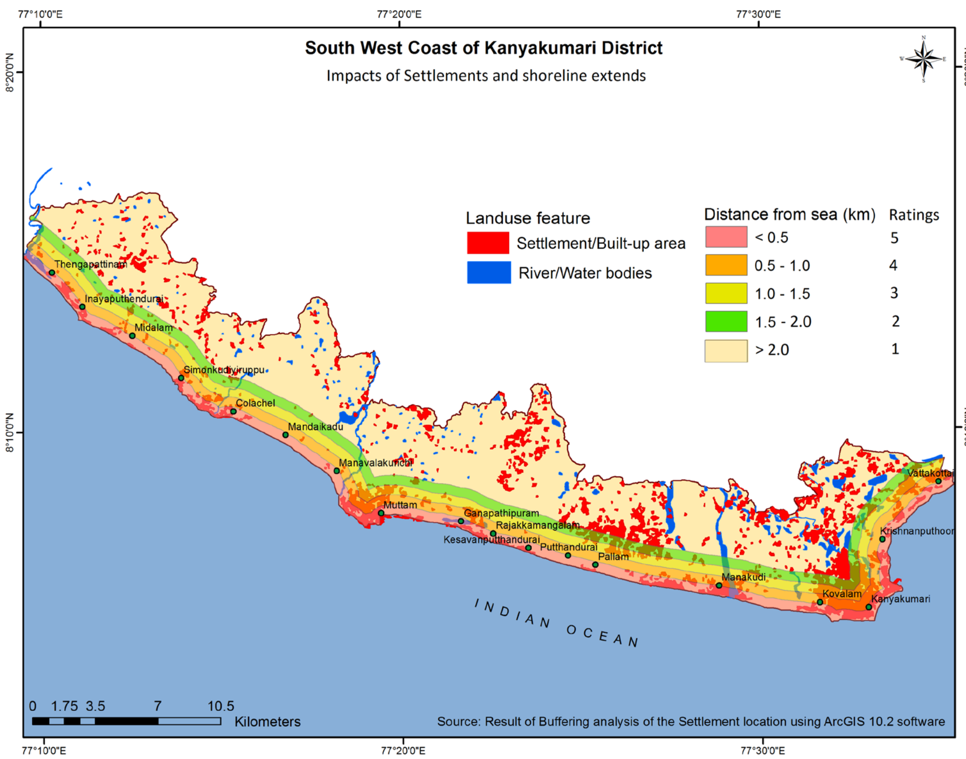

FIG. 5 - Impact of human settlements within a proxy of shoreline extends and its assigned ratings.

weighted value of 4. The settlement areas of Ganapathipuram, Rajakkamangalam, Pillaithoppu, and South Thamaraikulam are located within a distance of 1.0-1.5 km that are seasonally experienced significant changes in beach landforms because of lack of sediment flow while changing wave direction and littoral currents and these areas are assigned with moderate weighted values of 2 and 3. Upland areas (> 20 m above MSL) mainly in backshore comprise larger settlements in Kanyakumari, Muttam and Colachel, whereas, the various habitats may be protected from subsequent impacts of coastal erosion and other extreme events and hence these areas are assigned with lower vulnerability weighted value of 1. It exhibits the habitats existing within proximity of the shoreline are highly vulnerable to physical damage due to coastal and marine waves events and human impacts that causing an adverse impact on growth and distribution of coastal habitats.

Coastal habitats overwashing (sediment removal) rate

Overwashing of coastal habitats occurs because of removal and transportation of sediments by waves, tides, storm surges, tropical cyclones resulting in degradation of habitats on a long-term scale (Magesh & *alii*, 2014). Coastal habitats of sandy beaches, tidal flats, shallow marshes, dune vegetative covers, and estuaries are seriously affected by surging water that spills out onto the landward side of the barriers (Saxena & *alii*, 2013). The higher overwashing of sediment is estimated (> 400 m^3/km) for coastal landforms of Manakudi, Murungavilai, Periyakadu, Manavalakurichi, Mandaikadu, and Inayamputhenthurai and they significantly undergo changes in shape and size producing adverse effects on coastal habitats (Kaliraj & *alii*, 2013), and therefore, they are assigned a higher vulnerability weighted value of 5. The long-term overwashing (300-400 m^3/km) from low-lying landforms along the Periyakadu, Murungavilai, and Pallamthurai coastal zones severely damage coastal habitats, human settlements, and infrastructures which are assigned with higher vulnerability weighted value of 4. The beach slopes experience overwashing of sediments (300-400 m^3/km) from the beach face due to wave run-up causing damage to coastal settlements and infrastructures in the Pallamthurai, Murungavilai, and Mandaikadu coastal zones. The low-lying areas along the Puthenthurai, Rajakkamangalam, Midalam and Inayamputhenthurai seasonally influence the productivity of coastal habitats due to overwashing of sediments having a rate of 200-300 m^3/km during the monsoons (Chandrasekar & *alii*, 2012; Sowmya & Jayappa, 2016), and are assigned a moderately vulnerable weighted value of 3. Coastal habitats in the Sanguthurai, Pillaithoppu and Mel Midalam coastal zones are protected from overwashing actions due to foredune stretches providing active shelter. Therefore, these areas are assigned with lower vulnerability weighted values of 1 and 2. The overwashing of sediments from the beaches and sand dunes significantly determine the growth and distribution of coastal habitats in various parts of the study area.

Salt marshy change potentiality

Changing the rate of salt marshes (or) swampy in the coastal low-lying areas indicates the direct impacts of coastal habitats. Landforms along the low-lying coast such as salt marshes and swamps have the enrichment of flora and fauna of marine and coastal ecosystems (Chandrasekar & *alii*, 2006; Kaliraj & *alii*, 2016). Salt marshes distributed around estuaries, brackish and backwaters are nursery grounds for a rage of habitats of marine and coastal ecosystems (Vittal & *alii*, 2007; Saxena & *alii*, 2013). The low-lying landforms of salt marshes and swamps found in the estuarine parts of Thengapattinam and Manakudi get strongly degraded (> 500 m^3/km) due to higher wave run-up at the height of 3.0 to 4.0 m frequently affecting the growth and productivity of coastal habitats (Kaliraj & *alii*, 2013) which have been assigned with higher vulnerability weighted value of 5. Coastal habitats around saltpans, saltwater bodies, and backwater creeks in Manakudi, Kovalam, and Colachel area are extensively affected through erosion and human encroachment (Hentry, 2013) that are causing flooding or seawater inundation and hence are assigned with a weighted value of 4. Seasonal changes in hydrodynamic forcing influence the shape and size of salt marshes and swamps in the Puthenthurai, Periyakadu, and Midalam area accounting for erosion and deposition of sediments (250 m^3/km and -250 m^3/km) locally affecting biomechanical processes of coastal habitats, hence are assigned a moderately weighted value of 3. The coastal habitats occurring in salt marshes and wetlands of Sanguthurai, Chothavilai, Simonkudiyiruppu, and Mel Midalam area significantly get stabilized over the years due to a constant supply of nutrients and minerals (Kaliraj, 2016) and are assigned to lower vulnerability weighted values of 1 and 2. Cyclic coastal processes resulting from waves, tide, and currents control the growth and distribution of coastal habitats; upon which human activities significantly affect them as clear from various parts of the study area.

Mudflat (or) tidal flat change potentiality

The mud flats or tidal flats are mainly associated low-lying areas, estuaries and river mouth of Thamirabarani, Valliyar and Pazhayar and their tributaries with area coverage of 1.31 km^2. The extent of these landscapes are decreasing (> -600 m^3/km) due to flooding, runoff and soil erosion resulting in rapid changes in landuse and land cover, removal of dune vegetation and other anthropogenic activities, and are assigned a higher vulnerability weighted value of 5. In certain parts of the tidal flats, habitats are fragmented limiting their natural mobility due to sedimentation (-300 to 600 m^3/km) brought in by high-energy waves and tidal currents affecting their productivity (Chandrasekar & *alii*, 2006; Kaliraj, 2016). Mudflats in the shallow wetlands and backwater creeks within the middle-eastern parts seasonally are influenced in terms of sedimentation rate (300 m^3/km and -300 m^3/km). Further, the habitats of the mud flats or tidal flats get severely affected due to discharge from agricultural land, placer mining and urban sewage declining productivity of the coastal ecosystems (Mujabar & Chandrasekar, 2011). It assigns them with vulnerability weighted value of 4. Coastal habitats around the low-lying tidal flats denied nutrients and minerals due to seasonal change in river discharge affecting the growth and productivity of species. It assigns a moderately weighted value of 3 to them. In certain parts of the intertidal zones, estuaries, mud flats and tidal flats larger amount of sediments (> 300 m^3/km) get deposited from river discharge and tidal currents (Santhiya & *alii*, 2010), providing active shelter for various marine and coastal habitats. Therefore, these areas are assigned with lower vulnerability weighted values of 1 and 2. Change in mud flats and tidal flats determine the availability of nutrients influencing coastal habitats growth, productivity, and distribution in the coastal region.

Impact of coastal groundwater vulnerability (DRASTIC score)

Groundwater contamination due to the mixing of pollutants from point and non-point sources hurts coastal ecosystems by controlling the availability of nutrients and minerals in groundwater (Baalousha, 2006; Sathish & Elango, 2011). GIS based DRASTIC model analyzes multiple parameters to demarcate groundwater vulnerability that would affect coastal habitats (fig. 6). We estimate the DRASTIC vulnerability index value of the total coastal track between 85-213. An area of 34.7 km^2 (12.2%) fall under high vulnerability (DRASTIC score > 181) in deltaic plains near Nagercoil urban settlements and coastal plains around South Thamaraikulam and Manakudi (Kaliraj & *alii*, 2015) mainly due to discharge from sewage and urban wastewater. Sandy aquifers underlying Manavalakurichi - Mandaikadu coastal tracts get frequently contaminated due to unregulated beach placer mining resulting in degradation of coastal and marine ecosystems (Kaliraj & Chandrasekar, 2012a), and those areas are assigned a higher vulnerability weighted value of 5. Estuaries in the Thengapattinam and Manakudi area experience high vulnerability (DRASTIC score 149-181) due to saltwater intrusion and are assigned a high vulnerability value of 4. Major parts (125.8 km^2) of the floodplains and terisand deposits in the area are found to have a moderate vulnerability to coastal habitats (DRASTIC score 117-149), where pollutants from point sources are dispersed into shallow water bodies. Certain parts of the eroded coast with sandy aquifers on the hinterland are seasonally affected in terms of groundwater quality due to the sub-surface discharge of saltwater from the sea, salt marshes and saltpans (Hentry, 2013). It assigns them with a moderately weighted value of 3. Whereas, in various parts along the depositional coast, groundwater table within the thick sediment layer protects freshwater heads from infiltration of pollutants and seawater (Kaliraj & *alii*, 2013). Confined aquifers underlying hinterland have well protected freshwater and they are the least vulnerable zone (DRASTIC score > 117) thus assigned with lower vulnerability weighted values of 1 and 2. The change in the groundwater quality is likely to affect the availability of minerals and nutrients to the habitats of coastal ecosystems indirectly controlling growth and distribution of coastal habitats discretely.

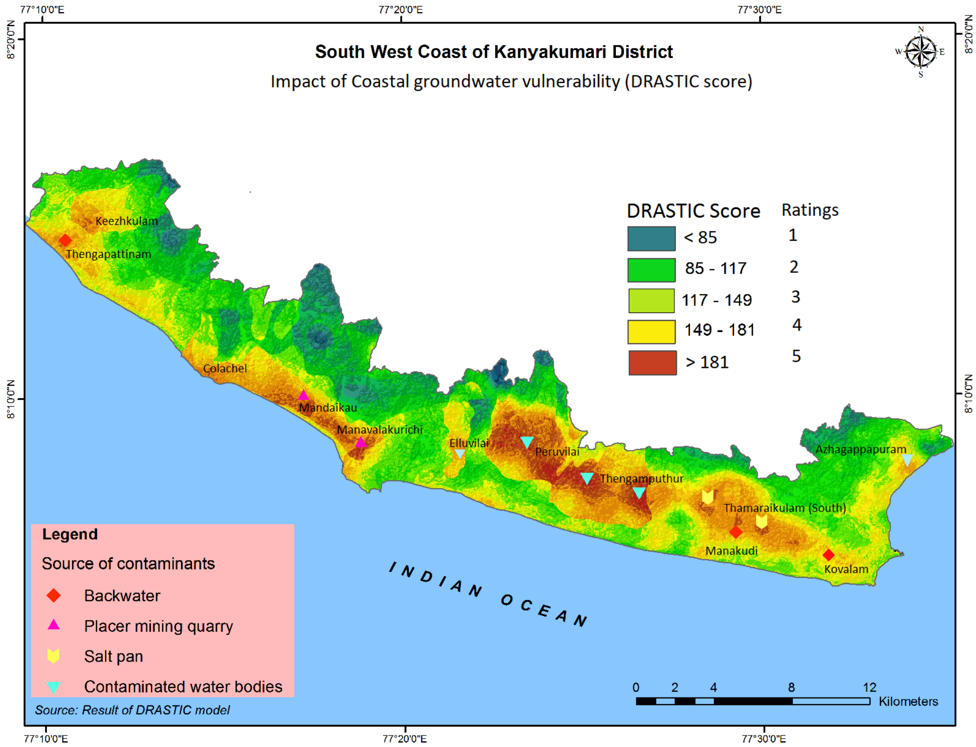

FIG. 6 - Impact of coastal groundwater vulnerability (based on the DRASTIC score) and its assigned ratings.

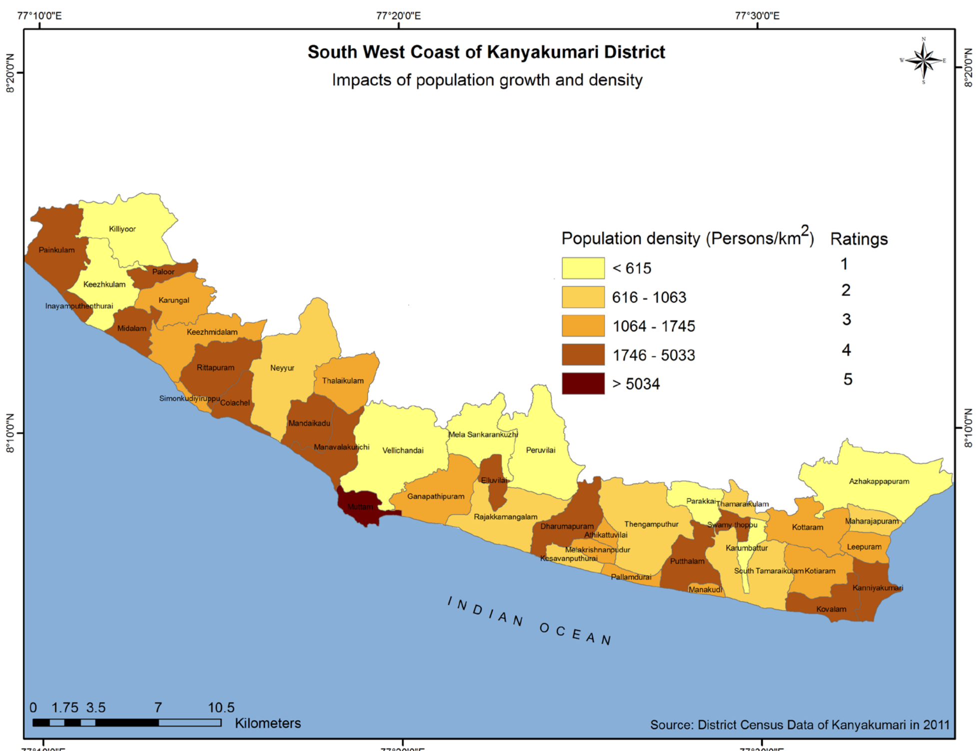

FIG. 7 - Impact of population growth and density within a proxy of coastal stretch and its assigned ratings.

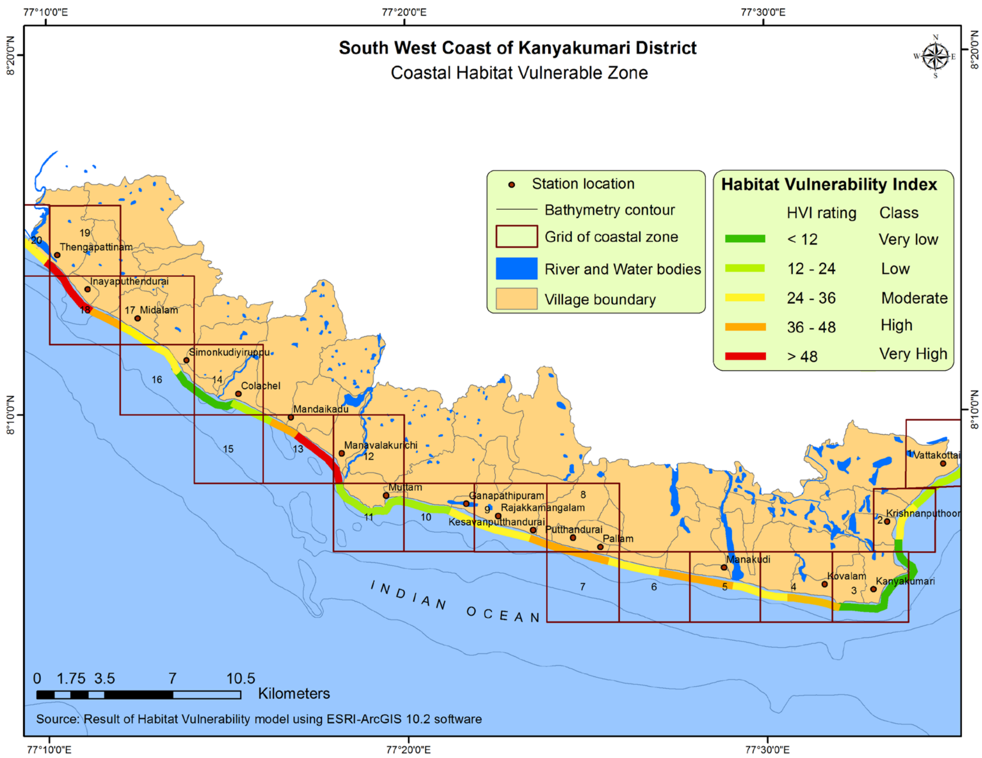

FIG. 8 - The potentially vulnerable zone to habitat damage and degradation in the study area.

Impacts of population growth and density

Estimation of population density is the result of number of persons occupied the area per km^2 that mainly concerned with the growth rate and land areas occupied for settlements and built-ups. Impact of population growth rate has been categorized at site-specific characteristics for estimating pixel-by-pixel level vulnerability to coastal habitat damage. The settlements with higher population density occur in various parts are causing severe impacts on coastal habitats through encroaching land area and polluting surface and groundwater sources; therefore, there is no contradiction of this parameters involving into calculation of coastal habitat vulnerability. The various parts of the coastal stretch especially across the nearshore experience potential impacts on coastal habitat damage due to increasing of population density that leading to encroachment of landforms and sensitive hotspots. Fig. 7 shows the impacts of population growth and density within a proxy of coastal stretch at the village level and its assigned ratings. Settlements and built-up area have registered an increase from 17.54 km^2 in 2000 to 39.22 km^2 in 2011 in the coastal stretches of Kanyakumari, Muttam, Manavalakurichi, Colachel, Midalam, Inayamputhenthurai and Painkulam where the population density increased to a whopping figure of 5034 persons/km^2 (Hentry, 2013), and hence those areas are assigned a higher vulnerability weighted value of 5. The coastal habitats of the region underwent adverse impacts due to erosion; landuse and land cover change. The coastal zones of Pallam, Puthenthurai, Murungavilai, Rajakkamangalamthurai, and Midalam have a significant increase in population density ranging from 1746 to 5033 persons/km^2. Because of the encroachment of coastal landforms for settlements and built-ups, the coastal habitats along embryo dunes, foreshore dunes, and backshore dunes in the area have been affected seriously (Kaliraj, 2016). Along the Manavalakurichi-Mandaikadu coastal stretches, dunes vegetation cover has been removed for placer mining activities and an area of 0.32 km^2 has been transformed to saltwater bodies (Kaliraj & *alii*, 2014) designating them to a high vulnerability weighted value of 4. Population density rate has increased from 1064 to 1745 persons/km^2 in the Kanyakumari, Rajakkamangalamthurai, Muttam, and Colachel areas, wherein one-third of fallow and barren lands (15.32 km^2) have been converted to settlements and built-ups. These areas are categorized as moderately vulnerable with a weighted value of 3. In the middle-eastern part, some coastal settlements have the lower population density (less than 1063 persons/km^2) where the coastal habitats are sparsely distributed along the beaches, dunes, shallow marshes and cultivable lands (Kaliraj & Chandrasekar, 2012a), contributing to a low vulnerability classes having weighted values of 1 and 2. Many densely populated zones have a direct impact on beach erosion, groundwater contamination and seawater intrusion ultimately causing degradation of coastal and marine habitats.

Mapping and assessment of coastal habitat vulnerability

Coastal zones are under threat from adverse changes of natural and anthropogenic factors resulting in an impact to coastal habitats. The coastal habitats along the southern coast of India remaining threatened due to various reasons like erosion, subsidence, flooding, pollution,

TABLE 2 - Location specific habitat vulnerability ratings and characteristics

Coastal Sector	Grid No.	Coastal zone	HVI vulnerability		Coastal zone vulnerability to habitat damage or degradation
			rating	class	
Kanyakumari	1	Kanyakumari North East	18	Low	Safe zone
	2	Kanyakumari East	30	Moderate	Moderately vulnerable
	3	Kanyakumari	12	Very low	Highly vulnerable
	4	Kovalam	38	High	Highly vulnerable
	5	Manakudi	26	Moderate	Moderately vulnerable
Rajakkamangalam	6	Pallam	44	High	Highly vulnerable
	7	Puthenthurai	36	Moderate	Low vulnerable
	8	Kesavanputhenthurai	38	High	Low vulnerable
	9	Rajakkamangalam	32	Moderate	Safe zone
Muttam	10	Ganapathipuram	24	Low	Safe zone
	11	Muttam	8	Very low	Low vulnerable
	12	Manavalakurichi	52	Very high	Highly vulnerable
	13	Mandaikadu	32	High	Highly vulnerable
Colachel	14	Colachel	16	Low	Low vulnerable
	15	Simonkudiyiruppu	32	Moderate	Low vulnerable
	16	Midalam	34	High	Low vulnerable
Thengapattinam	17	Mel Midalam	42	High	Moderately vulnerable
	18	Inayamputhenthurai	50	Very high	Highly vulnerable
	19 & 20	Thengapattinam	24	Moderate	Moderately vulnerable

storm surges and extreme events (Murthy & *alii*, 2006; Hentry, 2013; Sowmya & Jayappa, 2016). Fig. 8 shows the potentially vulnerable zone to habitat damage and degradation in the coastal stretch. The result of the HVI model indicates that the habitat vulnerability rate is likely to damage coastal habitats. This reveals site-specific vulnerability based on the analysis of multiple physical and environmental parameters collated and composed on a GIS platform. Tab. 2 enumerates location specific vulnerability rate and potentiality in the villages of the study area. In the study area, we estimate the cumulative habitat vulnerability index value with the range from 08 to 52 and the mean vulnerability index value of 30. The HVI vulnerability index values dictates five categories of habitat vulnerability in the coastal zones such as very low or protected zone (area suitable for habitats growth and productivity and protected from adverse impacts), low vulnerable zone (area potentially adopting vulnerability due to physical and environmental changes), moderately vulnerable zone (seasonal changes of coastal and marine processes causing impacts of habitats growth and spatial distribution), high vulnerable zone and very high vulnerable zone (areas not adopting changes of physical and environmental factors that damaging the coastal habitats). Of the total area, it categorizes 9 % of the coastal areas into very high vulnerability conditions. Coastal zones of Thengapattinam, Inayamputhenthurai, Manavalakurichi, and Kovalam are facing the threat to their marine and coastal habitats for which the corresponding estimated HVI value is greater than 48. Coastal habitats such as salt marshes, sand dunes, estuaries, brackish water, and cliffs distributed very close to the shore and intertidal zones fall into this category. Landforms associated with estuaries active sheltering places for numerous species of coastal and marine habitats; in these areas, it maintains the optimum coastal water salinity due to mixing of tidal water with freshwater providing a favorable breeding zone for a variety of species in marine and fluvio-marine ecosystems (Saxena & *alii*, 2013; Kaliraj & *alii*, 2016). Human settlements are frequently affected by erosion and subsidence of beaches due to flooding and seawater inundation during storm surges, cyclone and other extreme events (Chandrasekar & *alii*, 2013). Seagrass meadows along the continental shelf provide important habitat for macro and microfauna of marine habitats, but they often get affected by shoaling actions of waves and longshore currents. An area of 18% of the total study area falls under high vulnerability conditions with a corresponding HVI score between 36 and 48. Habitats in the Thengapattinam and Manakudi estuaries fall under the high vulnerability conditions due to overwashing of sediments along with nutrients and minerals (Mujabar & Chandrasekar, 2011). Further, coastal habitats associated with shallow sub-tidal zones (depth of ~2 m) are also highly vulnerable to anthropogenic activities and natural hazards. Change of morphological structures in the salt marshes, tidal flats, creeks, and estuaries amplifies the magnitude of habitat vulnerability due to the poor availability of nutrients during flooding and runoff (Santhiya & *alii*, 2010; Sowmya & Jayappa, 2016). Erosion and land subsidence resulting from high-energy waves, tidal actions, and other extreme events induce high vulnerability to the human settlements in the low-lying areas (altitude < 10 m) of Inayamputhenthurai, Mandaikadu, Pallam and Puthenthurai (Kaliraj *et alii*, 2014). High-energy wave action triggers overwashing of sediments (> 400 m^3/km) from beaches, cliffs and foredunes that resulting into morphological changes causing damage to coastal habitats, human settlements, and infrastructures (Kaliraj & *alii*, 2013). Unregulated placer mining activities along the Manavalakurichi-Mandaikadu coastal tracts poses the threat to the sustenance of coastal habitats and settlements. Population growth in both urban and rural settings and the resultant encroachment of dunes vegetative cover, shallow marshes and water bodies have severely affected the productivity and spatial distribution of coastal and marine habitats (Kaliraj, 2016). Construction of coastal structures like groins, seawalls, and revetments along the coast has affected the sediment supply to the down-drift side causing the paucity of nutrients adsorbed with the sediments to the marine and coastal organisms leading to degradation of coastal ecosystems (Mujabar & Chandrasekar, 2011; Kaliraj & *alii*, 2013). The coastal zones having a range of HVI values 24-36 are categorized as moderately vulnerable typically seen along the Midalam, Rajakkamangalam, Chothavilai, and South Thamaraikulam, area. Here, the coastal landforms undergo seasonal changes affecting the productivity and distribution of coastal habitats. The coastal habitats along the intertidal zone and coastal plains in the middle-eastern part are protected from the erosion and flooding during normal conditions, however, they are vulnerable during high-energy wave set-up, storm surge, tsunami and other extreme events (Kaliraj & *alii*, 2014). The landward shifting of the shoreline along the Periyakadu-Pillaithoppu and Manavalakurichi-Mandaikadu coastal tracts facing physical damage to vulnerability to built-up and infrastructures due to erosion and beach subsidence triggered by extreme events. Seasonal changes in the hydrodynamics alter sediment replenishment declining habitat productivity in salt marshes, tidal flats, and estuaries (Kaliraj & *alii*, 2015).

Areas of 39 % of the total coastal tract result in lower vulnerability (HVI value is < 24) due to the positive response of waves and currents. Sandy beaches associated with estuaries, where the influence of tidal action control the distribution of habitats provide active shelters and feeding grounds for many organisms, including fish, macro and microinvertebrates, and other microbial organisms. Along with certain sandy beaches, coastal habitats having the ability to endure the local hydrodynamics of waves, tides, and currents sustain their growth and productivity (Chandrasekar & *alii*, 2006; Hentry, 2013). Coastal uplands and teri-dunes along the Kanyakumari, Muttam, and Colachel areas show a greater diversity of species among the coastal habitats by harmonizing their growth and productivity to the *in situ* physical and environmental conditions. Coastal habitats maintain their growth and productivity in mudflats, tidal flats, salt marshes and wetlands near Sanguthurai, Chothavilai, Simonkudiyiruppu and Mel Midalam owing to the low-energy waves and tidal currents with a constant input of nutrients and minerals (Kaliraj, 2016). Within the estuarine regions of Thengapattinam and Manakudi zones, the intertidal zones and mud flats active shelter marine and coastal species due to uninterrupted deposition of sediments along with nutrients and minerals through river discharge. However, adverse changes in physical and environmental factors in the area would directly impact the coastal habitats in the wetlands, lagoons, estuaries, sea-grass beds, coral reefs, mangroves, and dunes vegetative cover. About 13% of the total area is under extreme vulnerability category where coastal and marine habitats can get affected by both natural and anthropogenic activities. Beaches and dunes are experiencing severe erosion causing the degradation of marine and coastal ecosystem near to the shore (Vittal & *alii*, 2007; Kaliraj & Chandrasekar, 2012a). The decreasing rate of sediment load in the shallow landforms produces negative impacts on coastal environments like displacement of habitats in wetlands, lagoons, estuaries, sea-grass beds, coral reefs, mangroves, and dunes vegetative cover (Kaliraj & *alii*, 2014). Human settlements in the low-lying areas (altitude < 10 m) of Inayamputhenthurai, Mandaikadu, Pallam, and Puthenthurai coast are highly vulnerable to erosion and land subsidence due to high-energy waves, tidal actions, and other extreme events. The overwashing of sediments (> 400 m^3/km) from the steeply sloped beaches and foredunes produce large-scale morphological changes causing imminent damages to coastal habitats, human settlements and infrastructures (Vittal & *alii*, 2007; Santhiya & *alii*, 2010; Kaliraj & *alii*, 2016). Coastal habitats of the floodplains fall under high vulnerability where the morphological structures have been extensively altered due to flooding and runoff. However, the coastal uplands and teri-dunes along the Kanyakumari, Muttam, and Colachel areas sustain habitats preserving greater diversity by maintaining growth and productivity. Overall observations reveal that the low-lying areas are highly vulnerable leading to habitat destruction. Adverse changes in physical and environmental factors directly influence the growth and productivity of coastal habitats in wetlands, lagoons, estuaries, sea-grass beds, coral reefs, mangroves, and dune vegetative cover. Anthropogenic impacts will seriously degrade the life cycle of marine and coastal habitats along the coastal area on a long-term scale.

CONCLUSION

Assessment of habitat vulnerability is an important process for sustainable coastal habitat management programme. The low-lying landforms such as estuaries, backwater creeks, mudflats, swamps, and saltpans are the most vulnerable locations to impairment of habitats owing to high energy wave run-up and the impending threat of sea level rise. The coastal zones having consistent accretion tendencies register rich and diverse marine and coastal habitats. The coastal uplands located along Colachel and Muttam coastal zones have well protected coastal habitats devoid of any threat from flooding and inundation due to sea level rise even up to 2 meters. The coastal erosion is a major factor affecting the sedimentation along the coasts leading to adverse impacts on the coastal environment and ecosystems. Coastal habitats in salt marshes, wetlands and estuaries are highly vulnerable to flooding and inundation during the cyclone, storm surge, and wave run-up heights to4.5 m. Human habitats along the low-lying areas (altitude < 10 m) in Inayamputhenthurai, Mandaikadu, Pallam, and Puthenthurai are highly vulnerable due to erosion and land subsidence. The landward shift of shoreline along the Periyakadu-Pillaithoppu and Manavalakurichi-Mandaikadu coastal tracts pose a serious threat to built-ups and infrastructures. The coastal habitats in the Sanguthurai, Chothavilai, Ganapathipuram, Rajakkamangalam Simonkudiyiruppu and Mel Midalam coastal areas have attained sustained growth and productivity in terms of their habitats. The present study substantiates the usefulness of remote sensing and GIS for coastal habitat vulnerability studies wherein the information can be used as primary indicators for sustainable planning and management.

REFERENCES

Adger W.N., Hughes T.P., Folke C., Carpenter S.R. & Rockstrom J. (2005) – *Social-ecological resilience to coastal disasters*. Science, 309, 1036-1039.

Ahnert F. (1998) - *Introduction to Geomorphology*. London: Arnold.

Alam S.M.N., Demaine H. & Phillips M.J. (2002) - *Landuse diversity in south western coastal areas of Bangladesh*. The Land, 63, 173-184.

Anon (2000) - *Development of GIS based information system for critical coastal habitats*. Institute for Ocean Management - Annual report (DOD, New Delhi), Anna University, Chennai.

Baalousha H. (2006) - *Vulnerability assessment for the Gaza Strip, Palestine using DRASTIC*. Environmental Geology, 50 (3), 405-414.

Barman N.K., Paul A.K. & Bera G. (2016) - *Assessment of Low-lying Deltaic Coastal Issues around the Subarnarekha Delta Plain at Odisha Coast, India*. Journal of Coastal Sciences, 3 (1), 8-14.

Baskar K. & Sridhar S.G.D. (2013) - *Distribution of Recent Benthic Ostracoda off Rameswaram, Palk Strait, Tamil Nadu, South East Coast of India*. Special Pubb. of the Geological Society of India, 1, 195-212. doi: 10.17491/cgsi/2013/63296

Baskaran R. (2004) - *Coastal erosion*. Current Science, 86, 25-30.

Brown D.G. & Arbogast A.F. (1999) - *Digital Photogrammetric Change Analysis Applied to Active Coastal Dunes in Michigan*. Journal of Photogrammetric Engineering and Remote Sensing, 65, 267-474.

Chandrasekar N. (2005) - *Tsunami of 26th December 2004: Observation on inundation, sedimentation and geomorphology of Kanyakumari Coast, South India*. Proc. 22nd IUGG Int. Tsunami Symp. Chania, Greece, 49-56.

Chandrasekar N., Loveson V.J. & Rajamanickam G.V. (1996) - *Longshore sediment transport along the southern coast, Tamil Nadu*. Indian Geological Congress, 6063.

Chandrasekar N., Saravanan S., Loveson, J., Rajamanickam M., Rajamanickam G.V. (2006) - *Classification of Tsunami Hazard along the Southern coast of India: An initiative to safeguard the Coastal Environment from similar debacle.* Science of Tsunami Hazards, 24 (1), 323.

Chandrasekar N., Saravanan S., Rajamanickam M., Hentry C. & Rajamanickam G.V. (2012) -*Correlation between coastal geomorphology and Tsunami inundation along the coast of Kanyakumari, India.* Journal of Ocean University of China, 11 (1), 16. doi: 10.1007/s11802-01217940.

Cherian A., Chandrasekar N., Gujar A.R. & Rajamanickam G.V. (2012) - *Coastal erosion assessment along the southern Tamil Nadu coast, India*. International Journal of Earth Sciences and Engineering, 5 (2), 352-357.

Hentry C. (2013) - *Spatial characterization and coastal change assessment between Kanyakumari and Thengapattanam coast, K.K. dist, TN through Remote sensing and Geographic Information System (GIS).* Unpublished Ph.D. Thesis, Manonmaniam Sundaranar University, Tirunelveli, 110 pp.

IPCC (2001) - *Climate Change 2001: Impacts, Adaptation and Vulnerability*. IPCC, Geneva.

IPCC (2007) - *Climate Change: Synthesis report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change.* Cambridge University Press, Cambridge, UK.

Kaliraj S. (2016) - *Geospatial analysis of coastal geomorphological vulnerability on South West coast of Kanyakumari using Remote sensing Technology*. Unpublished Ph.D. Thesis, Manonmaniam Sundaranar University, Tirunelveli, 110 pp.

Kaliraj S. & Chandrasekar N. (2012a) - *Geo-processing Model on Coastal Vulnerability Index to Explore Risk Zone along the South West Coast of Tamilnadu, India*. International Journal of Earth Sciences and Engineering, 5 (5), 1138-1147.

Kaliraj S. & Chandrasekar N. (2012b) - *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), 1-7.

Kaliraj S., Chandrasekar N. & 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), 4523-4542. doi: 10.1007/s12665-013-2845-6.

Kaliraj S., Chandrasekar N. & Magesh N.S. (2013) - *Evaluation of coastal erosion and accretion processes along the southwest coast of Kanyakumari, Tamil Nadu using geospatial techniques*. Arabian Journal of Geosciences, 8 (1), 239-253. doi: 10.1007/s12517-013-1216-7.

Kaliraj S., Chandrasekar N. & Ramachandran K.K. (2016). *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), 265-282. doi: 10.1016/j.ejrs.2016.12.006.

Kaliraj S., Chandrasekar N., Ramachandran K.K., Srinivas Y. & Saravanan S. (2017) - *Coastal landuse and land cover change and transformations of Kanyakumari coast, India using remote sensing and GIS.* The Egyptian Journal of Remote Sensing and Space Sciences, 20 (2), 169-185. doi: 10.1016/j.ejrs.2017.04.003.

Kaliraj S., Chandrasekar N., Simon Peter T., Selvakumar S. & Magesh N.S. (2015) - *Mapping of coastal aquifer vulnerable zone in the south west coast of Kanyakumari, South India, using GIS-based DRASTIC model*. Environmental Monitoring and Assessment, 87 (1), 4073. doi: 10.1007/s10661-014-4073-2.

Loveson V.J. (1993) - *Geological and geomorphological investigation related to sealevel variation and heavy mineral accumulation along the southern Tamilnadu beaches, India*. Thesis report, Madurai Kamaraj University, Madurai, 223-230.

Magesh N.S., Chandrasekar N. & Kaliraj S. (2014) - *Mapping the coastal geomorphological landforms through Aster DEM and Landsat data – a case study between Tuticorin Vembar coastal stretch, southeast coast of India*. Journal of Coastal Sciences, 1 (1), 1-5.

Mahendra R.S., Mohanty P.C., Bisoyi H., Srinivasakumar T. & Nayak S.R. (2011) - *Assessment and management of coastal multihazard vulnerability along the Cuddalore–Villupuram, East Coast of India using geospatial techniques*. Ocean & Coastal Management, 54 (4), 302-311.

MUJABAR P.S. & CHANDRASEKAR N. (2011) - *A shoreline change analysis along the coast between Kanyakumari and Tuticorin, India, using Digital Shoreline Analysis System*. Geo-spatial Information Science, 14 (4), 282-293.

MURTHY K.S.R., SUBRAHMANYAM A.S., MURTY G.P.S., SARMA K.V.L.N.S., SUBRAHMANYAM V., RAO K.M., RANI P.S., ANURADHA A., ADILAKSHMI B. & SRI DEVI T. (2006) - *Factors guiding tsunami surge at the Nagapattinam–Cuddalore shelf, Tamil Nadu, East Coast of India*. Current Science, 90 (11), 1535-1538.

NAYAK S. (2002) - *Use of satellite data in coastal mapping*. Indian Cartographer, 22, 147156.

PAL R. (2001) - *Environmental Vulnerability Index: Marshall Islands Data Profile: Summary Trip Report, October 2000*. SOPAC Trip Report, 256-282.

PATNAIK U. & NARAYANAN K. (2009) - *Vulnerability and climate change: an analysis of the Eastern Coastal Districts of India.* MPRA Paper N. 22062. Available online at: http://mpra.ub.uni-muenchen.de/22062/1/MPRA_paper_22062.pdf.

PAUL A.K. (2002) - *Coastal geomorphology and environment*. ACB Publication, Kolkata, 575 pp.

PETHICK J.S. & CROOKS S. (2000) - *Development of a coastal vulnerability index: a geomorphological perspective.* Environmental Conservation, 27, 359-367.

RAMESH K. & ELANGO L. (2014) - *Impact of Groundwater Quality from Industrial East Coastal Town, Southern India*. International Journal of Engineering Research and Application, 4 (1), 346-354.

SALAJ S.S., RAMESH D., SURESH BABU D.S. & KALIRAJ S. (2018) - *Assessment of coastal change impact on seawater intrusion vulnerability in Kozhikode coastal stretch, South India using Geospatial technique*. Journal of Coastal Sciences, 5 (1), 27-41.

SANTHIYA G., LAKSHUMANAN C. & MUTHUKUMAR S. (2010) - *Mapping of landuse/landcover changes of Chennai coast and issues related to coastal environment using remote sensing and GIS*. International Journal of Geomatics Geosciences, 1 (3), 563-576.

SATHISH S. & ELANGO L. (2011) - *Groundwater quality and vulnerability mapping of an unconfined coastal aquifer.* Journal of Spatial Hydrology, 11 (1), 1833.

SAXENA S., GEETHALAKSHMI V. & LAKSHMANAN A. (2013) - *Development of habitation vulnerability assessment framework for coastal hazards: Cuddalore coast in Tamil Nadu, India. A case study*. Weather and Climate Extremes, 2, 48-57.

SELVAKUMAR S., CHANDRASEKAR N., KALIRAJ S. & MAGESH N.S. (2016) - *Salinization of shallow aquifer in the Karamaniyar river basin, Southern India*. Environment, Development and Sustainability, 20 (3), 1255-1273. doi: 10.1007/s10668-017-9937-5

SOWMYA K. & JAYAPPA K.S. (2016) - *Environmental sensitivity mapping of the coast of Karnataka, west coast of India.* Ocean & Coastal Management, 121, 7087.

SREEKALA S.P., BABA M. & MURALIKRISHBNA M. (1998) - *Shoreline changes of Kerala coast using IRS data and aerial photographs*. Indian Journal of Marine Sciences, 27, 144 148.

SRINIVASA KUMAR T., MAHENDRA R.S. NAYAK S., RADHAKRISHNAN K. & SAHU K.C. (2010) - *Coastal Vulnerability Assessment for Orissa State, East Coast of India*. Journal of Coastal Research, 26 (3), 523-534.

TANH P.T.T. & FURUKAWA M. (2007) - *Impact of sea level rise on coastal zone of Vietnam*. Bulletin of the College of Science. University of the Ryukyus, 84, 45-59.

UNEP (2007) - *Physical Alteration and Destruction of Habitats*. www.unep.org

UNNIKRISHNAN A.S., RUP KUMAR K., FERNANDES S.E., MICHAEL G.S. & PATWARDHAN S.K. (2006) - *Sea level changes along the Indian coast: observations and projections.* Current Science 90 (3), 362-368.

VITTAL A., HEGDE REJU V.R. (2007) - *Development of Coastal Vulnerability Index for Mangalore Coast, India*. Journal of Coastal Research, 23 (5), 1106-1111.

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