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The potential impacts of sea level rise along the coastal zone of Kanyakumari District in Tamilnadu, India

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Abstract Climate change associated with sea level rise (SLR) is one of the major environmental concerns of today. This paper presents an assessment of the impacts of sea level rise on the coastal zone of Kanyakumari District in Tamilnadu, India. Digital Elevation Model (DEM) combined with overlay techniques in GIS are used in determining the inundation zones along the coastal region. The analysis evaluated the impact on coastal fishing villages, landuse, tourist spots and sensitive areas under threat. The vulnerability of the coastal areas in Kanyakumari to inundation was quantified, based on the projected sea level rise scenarios of 0.5 and 1 m. Our findings reveal that approximately 13 km^2 of the land area of Kanyakumari would be permanently inundated due to SLR. This would result in loss of land, alteration of the coastal zone and affects coastal ecosystem. From the study, the mitigation measures (engineering measures) and Coastal Zone Management practices that can be taken to protect human life and property from sea level rise are suggested.

Keywords Sea level rise · Digital Elevation Model · Kanyakumari · Tamilnadu · India · GIS

Abbreviations

DEM	Digital Elevation Model
GIS	Geographical Information System
GHG	Greenhouse Gases
IPCC	Intergovernmental Panel on Climate Change
IRS	Indian Remote sensing Satellite
NAPCC	National Action Plan on Climate Change
SLR	Sea level rise

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Introduction

Climate change was projected to impact tropical countries more negatively than the temperate ones. IPCC (2007) stated that anthropogenic global warming is expected to continue to contribute to an increase in global mean sea level during this century and beyond. Sea level rise is a serious threat to the countries with heavy population with wide economic activities. Human induced increases of atmospheric concentrations of greenhouse gases (GHG) such as CO_2, CH_4, N_2O and CFCs may result in unparalleled increases in global temperature (Houghton 1995; Bush 1997). Sea level rise is accounted by an increase in the volume of the ocean with change in mass mainly due to the thermal expansion of ocean water and melting of continental ice (IPCC 2001). The global mean sea level has risen at a rate of 1 to 2 mm per year during last century (Church and White 2006). Analysis of tide-gauge data indicates a rate of global-mean sea level rise during the twentieth century recently updated to 17 cm (±5 cm) by the IPCC (2007). The global atmospheric concentration of CO_2 has increased from 280 ppm to 375 ppm in 2005. Multi-model averages by IPCC show that the temperature increases during 2090–2099, may range from 1.1°C to 6.4°C and sea level rise from 0.18 to 0.59 m. Reductions in the polar ice volume lead to 4–6 m sea level rise (IPCC 2007).

According to the IPCC report (1998) a 30 cm sea level would increase flood damages by 36–58% along the coastal areas. The key natural parameters that influence the sea level rise are: (1) Tectonics, (2) Melting of the Greenland and Antarctic icecaps, (3) Surface and Groundwater storage, (4) Ocean thermal expansion and (5) Bathymetry (Melloul and Collin 2009). The major impacts of the sea level rise are increased flooding and inundation of low-lying areas, shoreline retreat and loss of land, livelihood and wetlands (Mclean et al. 2001). Barth and Titus (1984) analysed that rise in sea level would accelerate coastal erosion, threaten coastal structures, raise water tables and increase the salinity of rivers, bays and aquifers. The low-lying areas such as beach ridges, coastal plains, deltas, mudflats, estuaries, lagoons and bays would be the most suffering areas due to the coastal inundation under enhanced SLR. Other impacts are increase in salinity of ground water, oceanic acidification and increased burden of vector borne and water borne diseases associated with extreme weather events (NAPCC 2008).

Several studies have showed the estimates of the potential impacts for some developed countries (Baarse et al. 1994; Bijlsma et al. 1996; Ng and Mendelshon 2005; Zeidler 1997); developing countries (Adam 1995; Dennis et al. 1995; French et al. 1995; Han et al. 1995; Warrick et al. 1996); or specific areas of the world. Only few studies such as: Nicholls and Mimura (1998), and Nicholls and Tol (2006), have estimated the impacts of SLR on a great extent of regional or world scale. As the certainty that human-induced climate change is increased (Solomon et al. 2007), so the assessment of potential impacts to identify key vulnerabilities and adaptation and mitigation needs becomes more pressing (Parry et al. 2007).

The objectives of this paper were to identify and quantify the vulnerable low lying coastal areas to the adverse effects of sea level rise for Kanyakumari District. We have employed four projected sea level rise scenarios for assessing the impacts of sea level rise for the study area. In this study, we assessed the impacts on the coastal fishing villages, landuse, sensitive areas and tourist spots that may be at risk. The results derived from the study can be used for taking policy decisions and adaptation measures regarding the climate change and sea level rise issues.

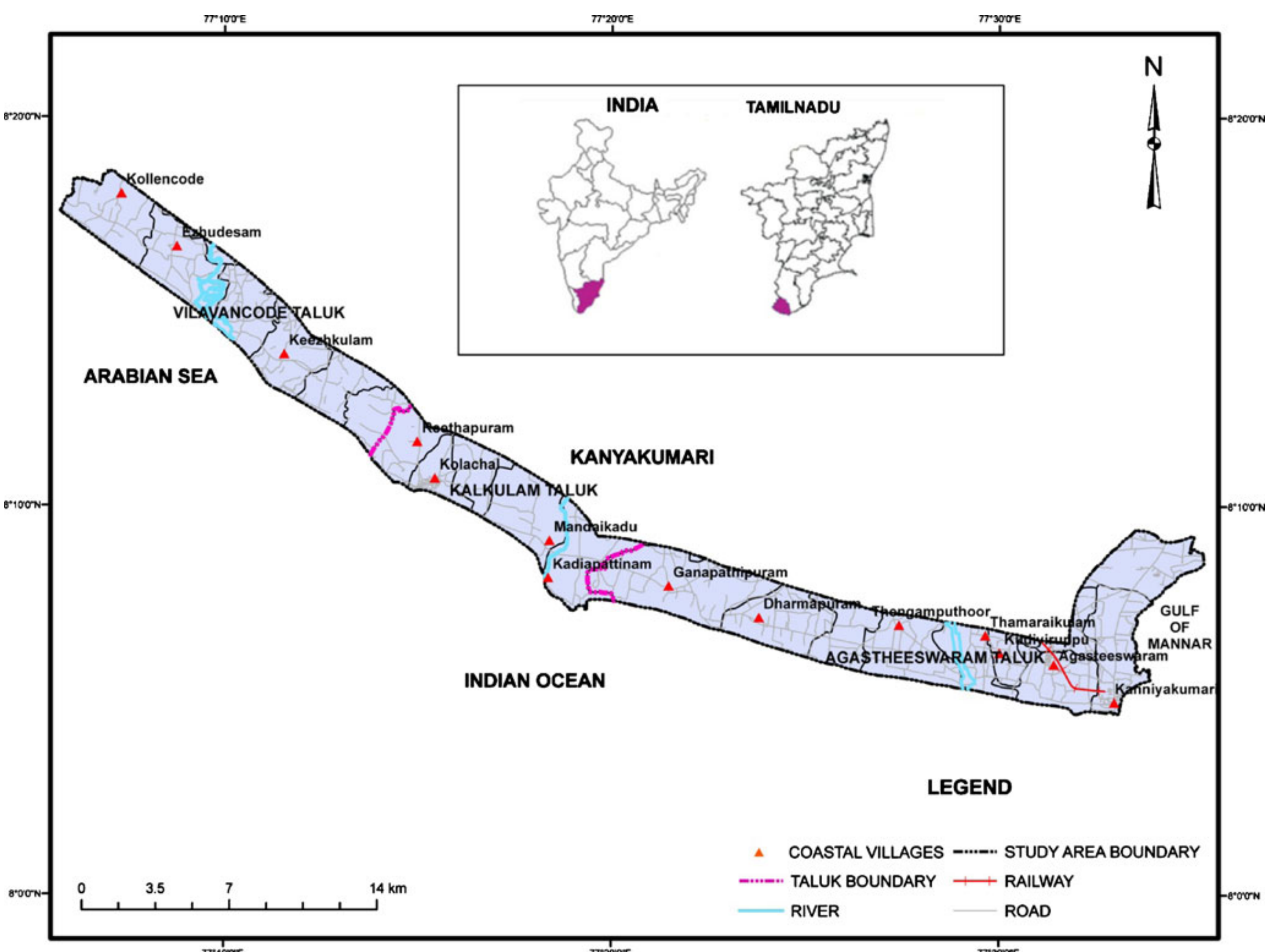

Fig. 1 Location of the study area

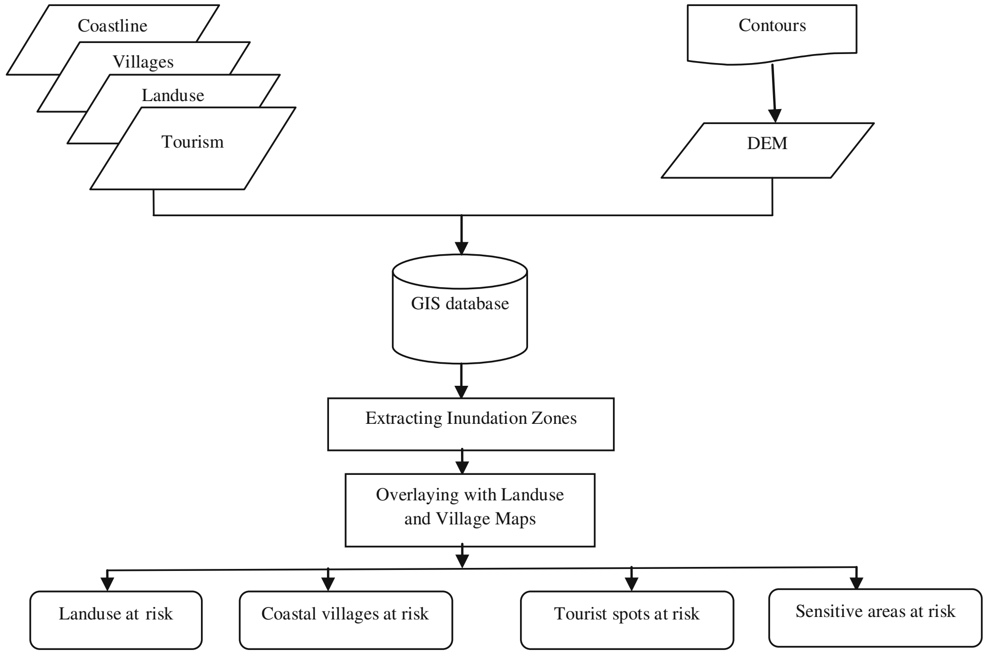

Fig. 2 Analysis flow chart

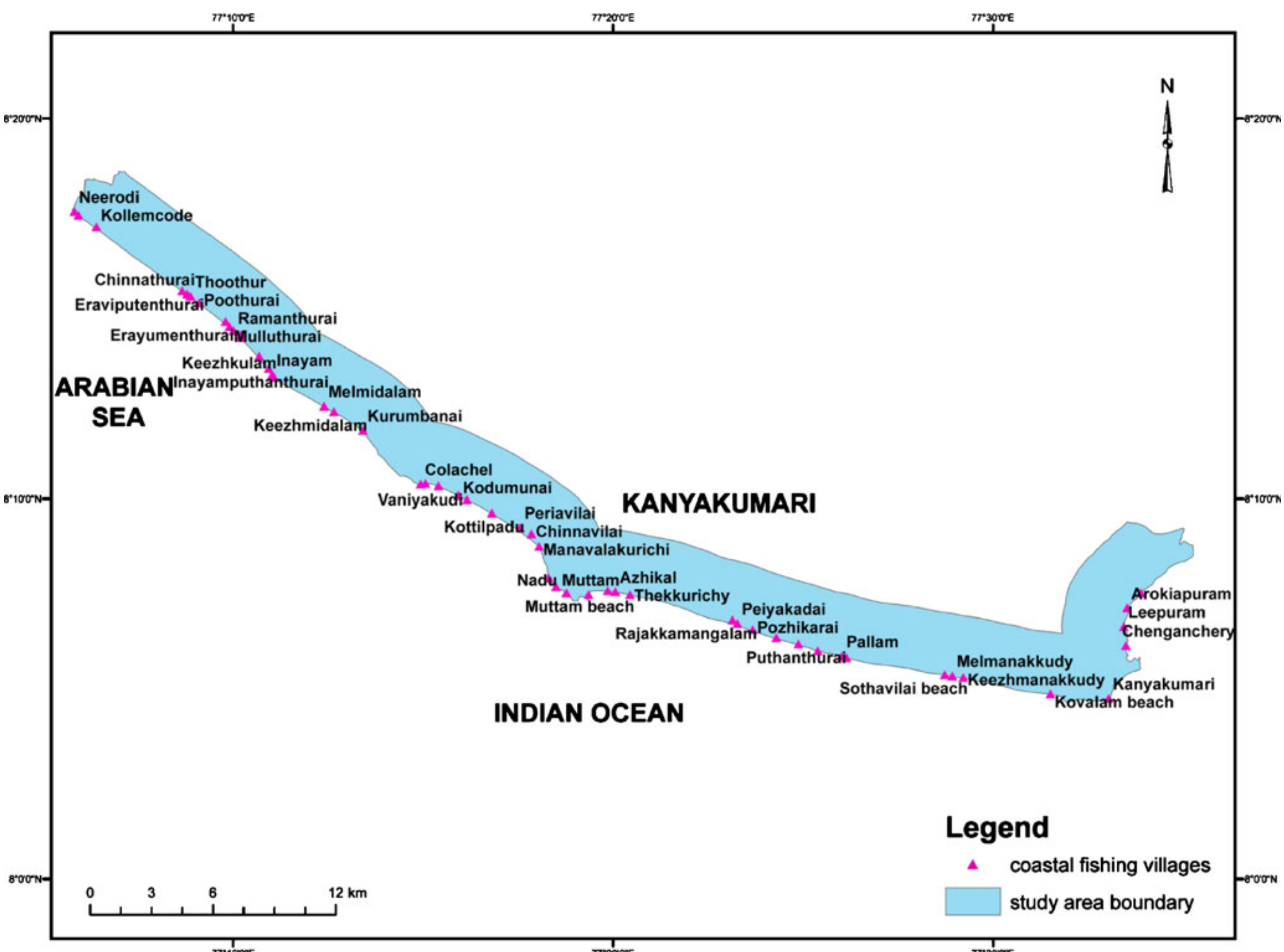

Fig. 3 Coastal fishing villages in the study area

Study area

Kanyakumari District is situated at the southern tip of peninsular India and its coastal area comprises of about 68 km in length. The coastal stretch of this District is studded with 44 coastal fishing villages. The coast has a heavy concentration of fisher-folk, almost one village per 1.5 km. The coast encompasses a diverse range of features including beach terraces, low cliffs, sandy beaches, dunes, rocky shores, estuaries, wetlands and forests. Colachel Port and Chinnamuttom harbour are found along the western side of the District. Apart from that, there were 3 major and 2 minor estuaries are draining into the Arabian Sea. Many tourist spots, cultural sites and archaeological sites are found along the coastal areas of Kanyakumari. The coast has a wide range of wild flora and fauna. More than 200 species of marine fishes have been recorded in the coastal region of Kanyakumari District, which includes skates, rays, sharks, sardine, mackerel etc. Apart from fishes, different species of prawns, lobsters, crabs, bivalves, gastropods, cephalopods and turtles are seen along Kanyakumari coast. The southern parts of the coast are sandy beaches with beach sands containing heavy minerals on the eastern and western sides of Kanyakumari. Garnet, Illimenite, Monazite, Thorium and Gypsum are the main mineral resources of this coast. Figure 1 represents the location of the study area.

Data sources

We have employed GIS software to overlay the inundation zones with the coastal villages, landuse, tourist and sensitive areas for the projected sea level rise of 1 m at an interval of 0.5 m. Study area boundary, coastal villages and contours were obtained from the Survey of India topographic maps. Landuse was collected from Institute of Remote Sensing (IRS), Anna University, Chennai, India. Tourist spots and sensitive area maps were derived from a web portal. Population data were collected from Census of India, 2001.

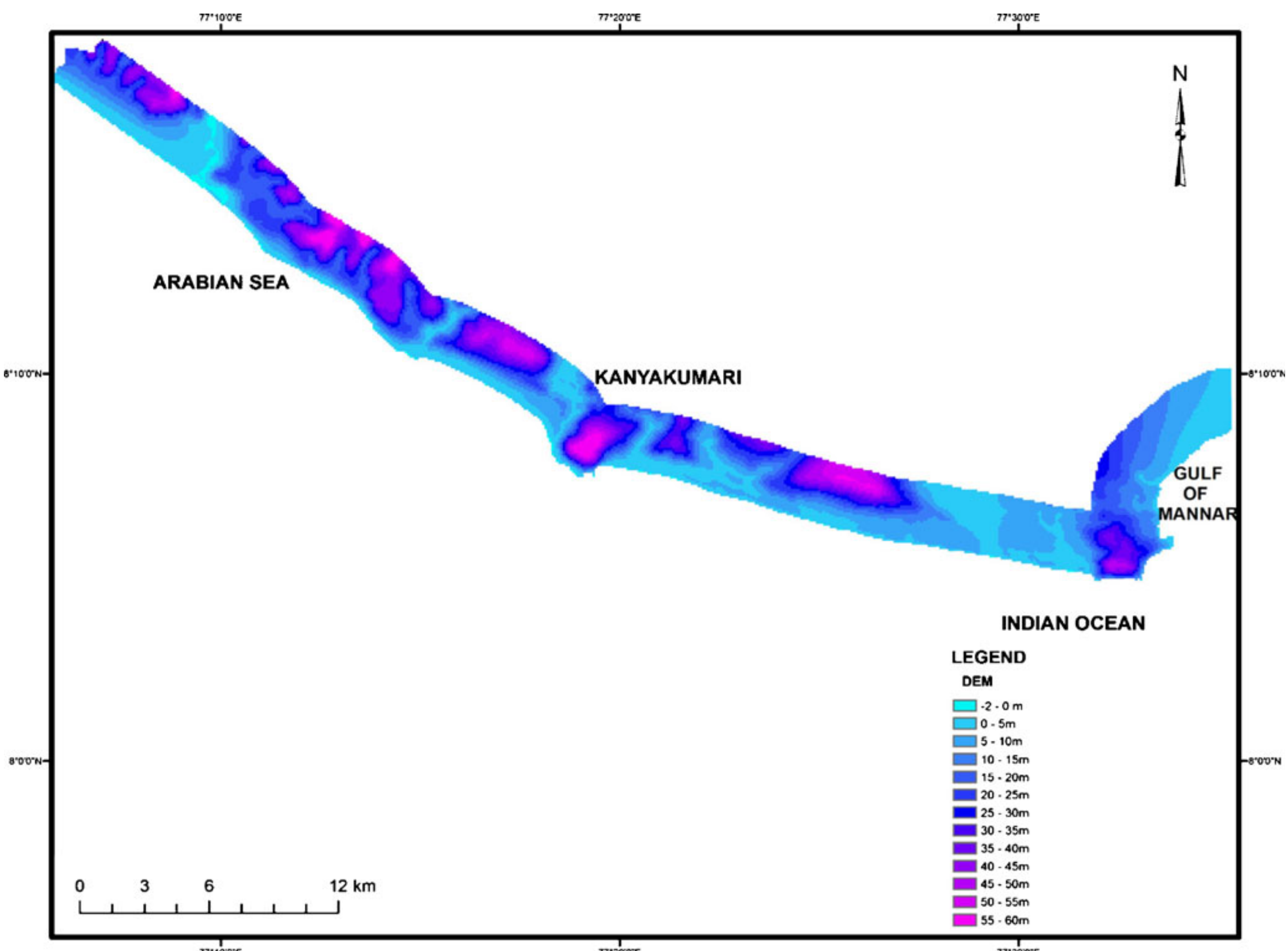

Fig. 4 Digital Elevation Model of the study area

Methodology

The procedure used in this analysis follows several steps. Figure 2 represents the steps involved during the analysis. Arc GIS software was used to process the vector data. A first-order estimate of potential losses of land to SLR was arrived at by integrating digital elevation data with the above sea-level rise scenarios using a geographical information system. The first step was to prepare the contours from the topographic maps. The second step was to generate the Digital Elevation Model for the identification of the inundation zones for the projected SLR scenarios. The third step was to prepare theme maps for coastal village, landuse, tourist spots and sensitive areas, and to overlay with the inundation zones. The analysis then determined the area and inundation distance that could be exposed to various SLR. The procedure details were followed as:

1) **Preparation of study area boundary and coastal villages:** In order to create GIS database, point and region vector data were used. Study area boundary and coastal villages were extracted from the topographic maps in the scale of 1:25,000 by manual digitizing methods. Figure 3 represents the coastal fishing villages present in the study area.
2) **Preparation of contours:** Contours were obtained from the topographic maps of the scale 1:25,000 at an interval of 5 m.
3) **Generation of DEM**: The effort to analyze the impact of coastal inundation requires data on the land surface elevations (Titus and Richman 2001). DEM data of the Kanyakumari coastal area were derived from the elevation data in GIS software using interpolation method (Fig. 4).
4) **Computing the inundation zones:** Inundation zones were derived from the DEM by setting the value 0.5 m and 1 m for the SLR scenarios.
5) **Identification of the inundated areas:** Inundated areas were identified by overlaying the inundation zones with landuse, village, tourism and sensitive area maps.

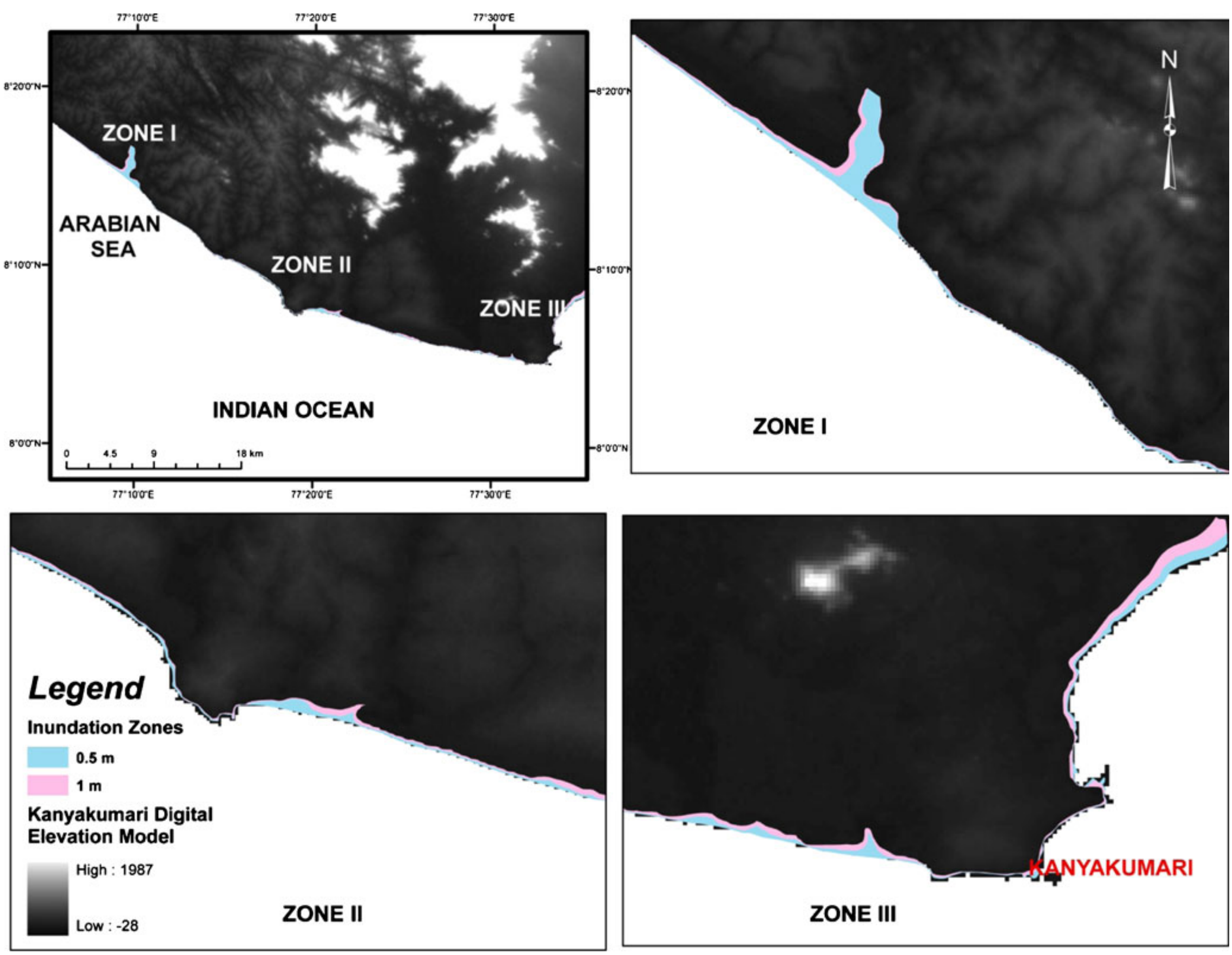

Fig. 5 Inundated zones of the study area

Results and discussion

Results for the inundation level are included in the analysis. Coastal zone elevation to sea level rise is illustrated by using DEM and GIS models. 44 coastal fishing villages are partly located below 2 m contour line in Kanyakumari District, and hence it is highly vulnerable to sea level rise. These villages have significant values of fishing and agricultural production. The vulnerability of inundation is based on rate of sea level rise, coastal erosion rate, geomorphology and slope factors. Inundation distance of 0.6 km is found in Agastheeswaram and 0.7 km was observed in Ganapathipuram and Azhagappapuram for 1 m SLR. Narayan et al. (2005a) reported that the extent of inundation ranged from 0.2 km to 7 km along the Tamilnadu coast. Figure 5 represents the inundation areas along Kanyakumari coast for different SLR scenarios. Chandrasekar et al. (2007) reported that cliff coasts at Kanyakumari and Kadiapattinam, experienced less inundation and this had impeded by the rock exposures with very steep faces. Narayan et al. (2005b) and Mohan et al. (2005) confirmed the above fact that the inundation was less on elevated landmasses and beyond dune ridges. The villages viz., Kanyakumari, Kolachel, Azhagappapuram, Ganapathipuram and Kollencode are having high elevated mass so that it experiences less inundation where Agastheeswaram is having less elevated mass so it experience high level of inundation. The coastal areas vulnerable to inundation of a sea-level rise of 0.5 and 1 m were 7.93 and 12.29 respectively. Approximately 7% of the total land area would be impacted by 1 m SLR. Agricultural production including coconut, banana, paddy, plantain, rubber and other vegetation is one of the major economic outputs in the coastal zone of Kanyakumari. 35% of the beaches and 20% of the coconut plantations are getting inundated by 1 m SLR. Approximately 1.8 km^2 of the rural villages is getting submerged by 1 m sea level rise.

The high risk of coastal inundation is found along the revenue villages of Ezhudesam, Arudesam, Puthukadai, Madhusoodhanapuram, Thamaraikulam, Dharmapuram and Agastheeswaram. The medium to low risk coastal area inundation is found along Kollencode, Balapallam, Keezhkulam, Karungal, Kolachel, Ganapathipuram, Reethapuram, Kanyakumari, Thenmgamputhur, Kadiapattinam and Azhagappapuram.

There are 44 fishing villages in the coastal area and neighboring the coastline, which are most vulnerable to coastal inundation. Valla Vilai, Neerodi, Chinnathurai, Thoothur, Kollemcode, Eraviputhenthurai, Poothurai, Erayumenthurai, Mulluthurai, Ramanthurai, Inayam, Inayamputhanthurai, Keezhkulam, Melmidalam, Keezhmidalam, Kurumbanai are the coastal fishing villages likely to be affected in Vilavancode taluk. Colachel, Muttam, Vaniyakudi, Simon colony, Kodumunai, Periavilai, Manavalakurichi, Kadiapattinam, Nadu Muttam, Kolachel and Reethapuram are the villages inundated in Kalkulam taluk. Azhikal, Thekkurichi, Rajakkamangalam, Kesavan Puthenthurai, Pallam, Manakkudi, Chenganchery, Leepuram, Agastheeswaram and Arokiapuram are the coastal villages likely to be affected by sea level rise in Agastheeswaram taluk. The coastal fishing villages of Kanyakumari is densely populated i.e., fisher-folk coast, thus causes great damage to the coastal population due to SLR. Table 1 represents the total population present in the coastal fishing villages.

Touristic coastal villages are particularly under threat which will cause destruction of many cultural sites by sea

Table 1 Population of the study area

Name of the habitation	Approximate population in each habitation (in thousands)
Arokiapuram	3,076
Chinnamuttom	2,674
Kanyakumari	7,617
Keezhamanakudy	4,568
Mela Manakudy	6,474
Annai Nagar	2,974
Pallam	6,360
Puthenthurai	995
Kesavamputhenthurai	1,049
Rajakkamangalam	178
Azhikal	7,268
Muttom	1,059
Kadiapattinam	9,458
Chinnavilai	3,160
Periavilai	3,687
Colachel & Simon colony	22,886
Kodimunai	9,737
Vaniyakudy	7,020
Kurumbanai	5,582
Melmidalam	4,828
Enayam	7,804
Enayam Puthenthurai	8,555
Enayam Chinnathurai	3,831
Ramanthurai	5,127
Mullorthurai	4,218
Irumanthurai	5,183
Poothurai	8,311
Thoothur	7,744
Thoothur Chinnathurai	7,851
Iraviputhenthurai	5,204
Vallavilai	7,308
Marthandamthurai	5,801
Neerodi	6,496

Census of India, 2001

level rise. Gandhi Mandapam and 16 Leg Mandapam are the tourist spots likely to be affected by sea level rise. Recreation sites near the coastal zone would be affected by sea level rise. The recreational and archaeological sites to be submerged by 1 m sea level rise are Sanguthurai beach, Sothavilai beach, Thengapattinam beach, Kovalam beach, Muttom beach and Vattakottai fort. The cultural sites affected due to 0.5 m SLR is Kumari Amman temple and for 1 m SLR, Vinayakar and Bhagavathi Amman temple in Kanyakumari. The ecologically sensitive areas that could be submerged due to sea level rise are Manakudy estuary and Thengapattinam estuary. The harbour/port that could be inundated due to sea level rise are Colachel port and Chinnamuttom harbour. Mining area in Manavalakurichi is also submerged by sea level rise. There is a great need to identify those areas that are most vulnerable to the impacts of sea level rise. The identification should focus on densely populated low lying areas.

Mitigation measures

Special attention should be paid to the low-lying coastal zones that are vulnerable to sea level rise and the critical areas should be delineated as high risk zones. Highest priority should be given to mitigate the effects of sea level rise mainly due to anthropogenic activities. Preventing the development near the coastal areas is the best mitigation option. Measures that can be taken to protect the coastal regions were creation of wetlands or mangroves and construction of engineering facilities like dikes or coastal barriers to reduce the effects of sea level rise along the sensitive areas. Improving the coastal monitoring systems (tide-gauge measurements) and utilizing the satellite data measurements, inundation zones were calculated and awareness can be created towards the people. Finally suitable policy decisions and adaptive responses can be established in order to mitigate SLR.

Conclusion

The extent of inundation of the coastal plains of Kanyakumari district was identified using digital elevation model. Even if greenhouse gas emissions were stabilized in the near future, thermal expansion and melting of glaciers would continue to raise the sea level for many decades. Expected SLR would impact on the vulnerability of the coastal areas of Kanyakumari and become a potential hazard to those areas both physically and economically. Broad range of population and landuse will suffer from extended coastal inundation due to SLR. Disaster preparedness and mitigation measures at all government levels, such as potential hazard and loss assessment program on the coastal area must also concern the possible impacts of SLR. The result provided from the study is used for the state governments to develop the adaptation plans and appropriate policies to avoid the losses in future.

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