Italian Journal of Remote Sensing - 2010, 42 (3): 67-76

Coastal Multi-Hazard Vulnerability Mapping: A Case Study Along The Coast of Nellore District, East Coast of India

Mahendra R.S.[1], Prakash C. Mohanty[1], Srinivasa Kumar T.[1], Shenoi S.S.C.[1] and Shailesh R. Nayak[2]

[1]Indian National Centre for Ocean Information Services (INCOIS), Hyderabad – 500 055, India
[2]Ministry of Earth Sciences (MoES), New Delhi – 110003, India. E-mail: mahendra@incois.gov.in

Abstract
The study area coastal zone of Nellore district is experiencing frequent inundation by natural disasters. The current study is focused on generating Multi-hazard vulnerability map using the parameters historical storm surge heights, future sea level, future shoreline and high resolution coastal topography. The area is experiencing the severe coastal erosion up to 7 m/y along some stretches poses a threat. An area totalling 1708.36 sq. km. is found to fall under the multi-hazard zone and the coastal population are under threat due to future storms, erosion, accelerated sea level rise, etc. The image enhancement, interpretation and GIS overlay techniques along with data used here are effective to produce Multi-hazard vulnerability maps. These Maps are become vital tools for the coastal disaster management during an event and to take suitable decision on the future developments.
Keywords: Multi-hazard, Vulnerability, Nellore, Shoreline Change, Sea Level, Return Period.

Mappatura della vulnerabilità costiera: un caso di studio nel distretto di Nellore nella costa est dell'India

Riassunto
La zona costiera del distretto di Nellore è soggetta a frequenti inondazioni a causa di catastrofi naturali. L'obiettivo del presente studio è la produzione di una mappa di vulnerabilità multi-rischio utilizzando dati storici delle altezze dell'onda di tempesta, previsioni sul futuro livello dei mari e dell'andamento della linea di costa, e dati a alta risoluzione della topografia costiera. L'area esaminata è sottoposta a una intensa erosione che in alcuni tratti raggiunge valori di 7 m/anno. Una superficie di circa 1708,36 km² si trova in aree vulnerabili e la popolazione ivi residente è a rischio di tempeste, erosione costiera, innalzamento del livello del mare, ecc. Le tecniche di miglioramento e interpretazione delle immagini, le operazioni di overlay con sistemi GIS e i dati qui utilizzati sono risultati efficaci per produrre mappe di vulnerabilità multi-rischio. Tali mappe sono divenute strumenti importanti per la gestione delle catastrofi costiere sia durante l'evento sia in fase pianificatoria.
Parole chiave: *Multi-pericolosità, vulnerabilità, Nellore, erosione costiera, livello del mare, tempi di ritorno.*

Introduction

Tremendous population and developmental pressures have been building in the coastal areas for the last four decades. According to the estimates of the United Nations in 1992, more than half of the world's population lives within 60 km of a shoreline. There were only 2 mega cities in 1950 (New York and London), whereas there were 20 mega cities in 1990. It has been projected that there will be 30 mega cities by 2010, having a population of 320 million people [Nicholls, 1995]. The ratio of people living in coastal zones compared with available coastal lands further indicates that there is a greater tendency for people to live in coastal areas than inland. According to a United Nations Environment Programme (UNEP) report, the average population density in the coastal zone was 77 people/sq. km in 1990, 87 people/km^2 in 2000 and projected 99 people/km^2 in 2010 [UNEP, 2007]. Hence the vulnerability maps are important and help to save the highly dense coastal population from the natural disasters.

A widely accepted definition characterizes natural hazards as "those elements of the physical environment, harmful to man and caused by forces extraneous to him" [Burton et al., 1978]. More specifically, the term "natural hazard" refers to all atmospheric, hydrologic, geologic (especially seismic and volcanic), and wildfire phenomena that, because of their location, severity, and frequency, have the potential to affect humans, their structures, or their activities adversely. The natural hazard here mainly considered are the coastal inundation caused due to oceanic disasters. The study area taken for the present study is experiencing flooding almost every year by one or the other natural disaster. The region is suffering from large inundation due to floods, storms, tsunamis and cyclones due to large low lying coastal plains.

Remote sensing and GIS tools can be effectively used to study the shoreline change and vulnerability assessment [Nayak et al., 1985; Gornitz, 1990; Pethick and Crooks, 2000; Thieler, 2000; Pendleton et al., 2005; Hegde and Reju, 2007; Kumar et al., 2010]. The coastal vulnerability assessment studies were carried out by Thieler [2000], Pendleton et al. [2005], Hegde and Reju [2007], Kumar et al. [2010], etc. They have categorized the coastline based on the parameters shoreline change, Geomorphology, Sea-level change, Slope, Tidal Range, Wave Height. As per as hazard mapping is concerned there are many works pertaining to the individual hazards. The works related to combining multiple hazards to bring out comprehensive multi-hazard assessment and mapping is limited [Habib and Fahmi, 2009; Tate et al., 2010]. Watson [2002] has been used numerical models to assess multi hazards. The current work is focussed on assessment and mapping of multi-hazards using the historical data to measure trends and future projections.

The generation of different vulnerability map for the different hazards will be tedious task. The inducing or triggering mechanism which can interconnect several hazards can more easily be seen through the use of a multi-hazard mapping. Characteristics of the natural phenomenon and its trigger mechanisms are synthesized from different sources and placed on a single map. The main purpose of multi-hazard mapping is to gather together in one map the different hazard-related information for a study area to convey a composite picture of the natural hazards of varying magnitude, frequency, and area of effect. The historical datasets indicating the multiple hazards were synthesized to generate a composite map representing the multi-hazards. In general, coastal areas are suffering due to threat from the various hazards. Using individual maps to convey information on each hazard can be cumbersome and confusing for planners and decision-makers because of their number and their possible differences in area covered, scales, and detail.

Study Area

The present study area is the coast of Nellore District, Andhra Pradesh East Coast of India (Fig. 1) between the coastal Coramandal in the south and Ramaypatnam in the north. The geographical constraints of the area are 79º 50’ to 80 º 20’ E longitudes and 13º 35’ to 15º 00’ N latitudes. The Bay of Bengal is one of the six regions in the world where severe tropical cyclones usually originate in the months of May, November, and December. They are well known for their extreme destructive potential and impact on human activities. Associated with the severe cyclones are strong winds, storm surges along the coast, and there is heavy rainfall which results in destruction to life and property. Humid tropical climatic condition prevails in the area with experiencing the rainfall during southwest monsoon follows the summer up to October and northeast monsoon during October-November. Basically this area is dominated by waves recording the maximum wave height 3m during monsoon periods. Spring tides 1.15 m and 0.33 m neap tides in the area reveal that micro-tidal condition.

Data Used

Data used pertaining to the present study are given in Table1. The satellite data from the Multi-spectral Scanner (MSS), Thematic Mapper (TM) and Enhanced Thematic Mapper (ETM) sensor on-board Landsat satellite data for the duration 1972-2000 were used. These data were downloaded from the website Landsat.org. The Digital Terrain Model (DTM) derived using the Cartosat1 data used for the topographic analysis and for the generation of contours. Long term monthly mean tide data pertaining to Chennai station were downloaded from GLOSS network. The extreme storm surge heights were used from the published work of Rao [2005].

Table 1 – data used for the current study.

Data	Resolution (m)	Period
Cartosat1 DTM	10	2006-07
Landsat, MSS	57 (resample)	1972
Landsat, TM	30	1990
Landsat, ETM	30	2000
Tide Gauge data	--	1952-2005
Extreme Storm Surge	Published data from Rao (2005)	

Methodology

The multi-hazard mapping has been carried out using the parameters sea level trend, shoreline change rate, contours, extreme water level and the return periods. These parameters were derived using the satellite data and in-situ observations. The flow chart (Fig. 2) shows the general methodology of the current study. The long term tidal observations from the tide gauges close to study area are were used to estimate the sea level trend. The return period considered here is 50 years that is represented as ‘T’. These sea level trends were projected for the next 50 years (A) which is sea level at ‘T’. Historical storm surge heights were extracted from continuous hourly tide data observed by Chennai station during 1975-87.

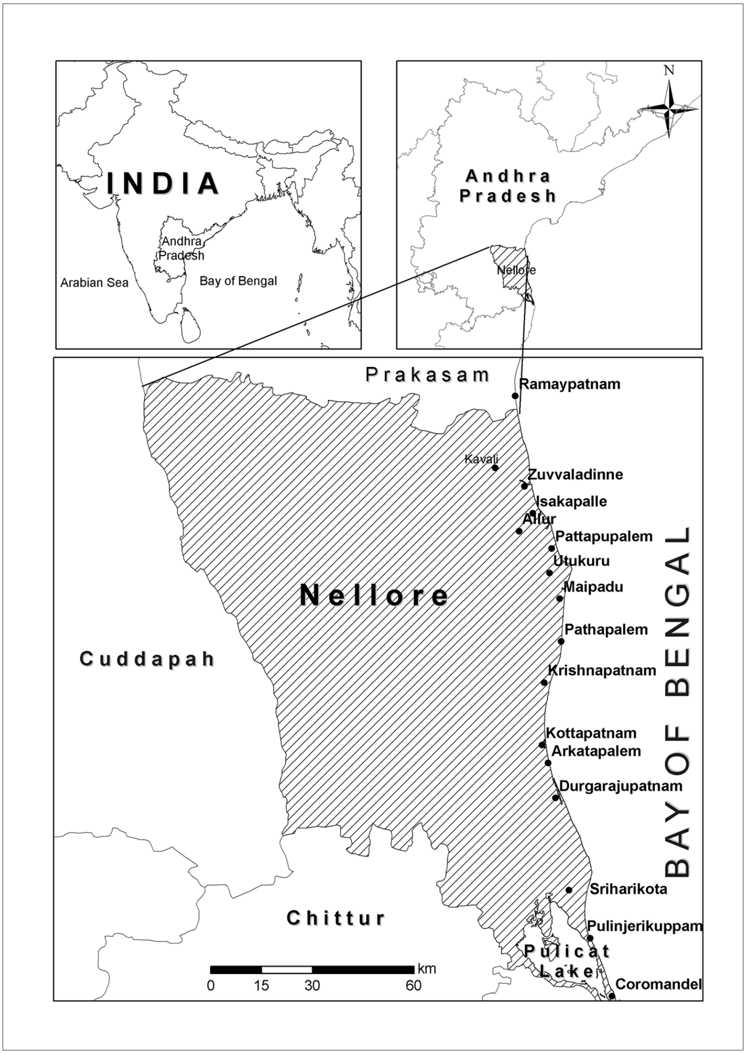

Figure 1 - Study area.

These storm surge heights are further estimated the extreme surge levels (B) after the return period (T i.e. 50 years). The extreme storm surge level and sea level after 50 years were summed up to estimate the probable inundation level which is 'C' for the study area. DTM generated using the Cartosat1 data is used as the source of the topographic information. The elevation contours were generated using this DTM. The contour line coincide with the inundation level is selected as the composite multi-hazard line. The Landsat data were used to assess the historical shorelines and the shoreline change rate was estimated. Based on the rate of the shoreline change the future shoreline position for the erosion areas were estimated (D). These future erosion areas were combined with the composite hazard line. Coastal zone falling under composite hazard line and the future erosion areas considered as multi-hazard zone. Finally map representing the multi-hazards was prepared.

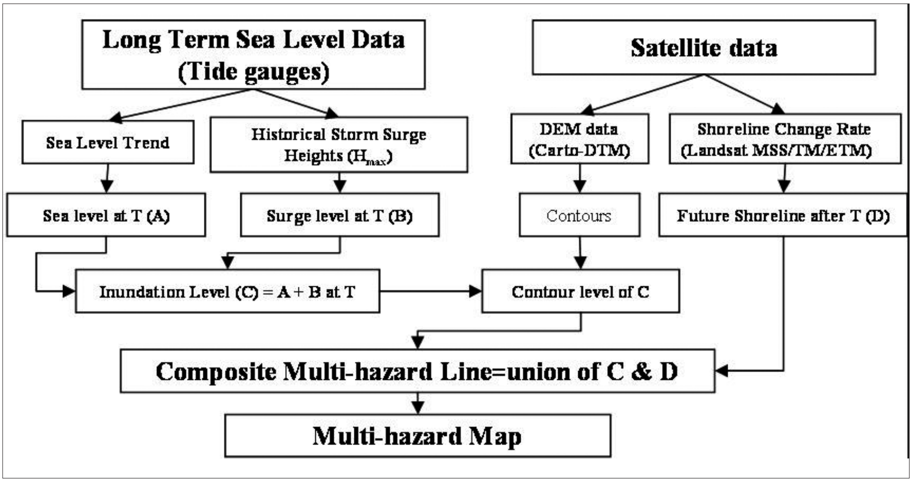

Figure 2 - The flow chart depicting the current methodology (T is return period).

Calculation of the Shoreline Change Rate

Ortho-rectified Landsat MSS and TM images covering the study area for the period 1972, 1990 and 2000 were downloaded from the website www.landsat.org. The data has been projected to Universal Transverse Mercator (UTM) projection system with WGS-84 datum. The shoreline along Nellore coast was digitized using ArcMap 9.2 and ERDAS Imagine software using on-screen point mode digitization technique. Near infrared band that is most suitable for the demarcation of the land-water boundary has been used to extract the shoreline. The digitized shoreline for the years 1972, 1990 and 2000 in the vector format were used as the input to the Digital Shoreline Analysis System (DSAS) to calculate the rate of shoreline change (Fig. 3). DSAS is a tool developed by the United States Geological Survey (USGS) to calculate the rate of shoreline change. It calculates the shoreline change rate using the shore-normal transects spaced at a user specified distance from the baseline. The inputs required are the shorelines pertaining to all the periods in a single shape file with corresponding date field and the baseline adjacent to the shorelines. The End Point Rate (EPR) which is the net rate of the shoreline change has been used. The transect spacing of 1 km in our current study has been considered to estimate the shoreline trend (Fig. 3). Further these trend estimates were used to project shoreline position after 50 years for the areas those were under erosion.

Calculation of the Sea Level Trend

Tide gauge dataset of the Global Sea-level Observing System (GLOSS) during the past century is used as the primary source of information for sea-level trend in the study area. Long term monthly mean tide gauge data recorded for Chennai which is nearest to study area during the period from 1952 to 2005 was used to estimate sea-level change rate. The monthly mean values of sea level recorded from Chennai tide gauge has been plotted month versus sea level. The straight line of best fit using least squares method has been drawn to calculate the trend (dashed line in Fig. 4).

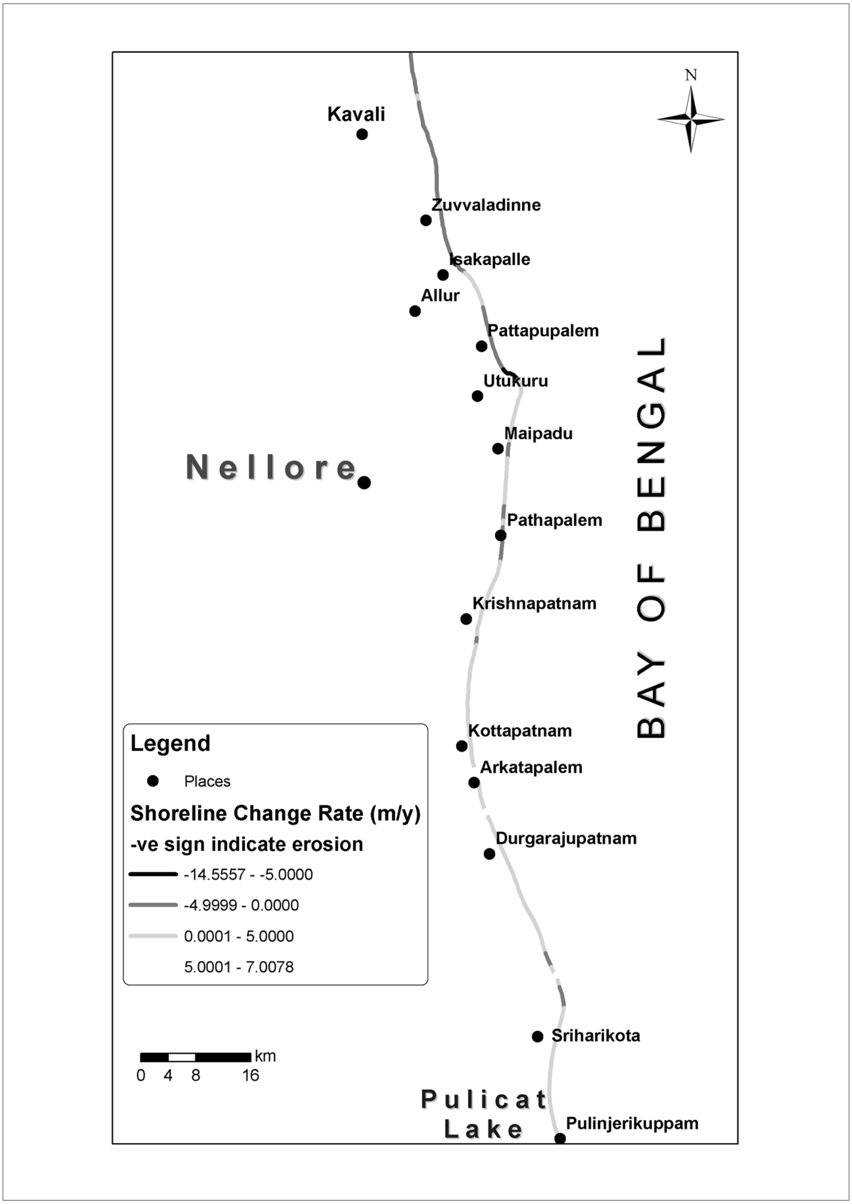

Figure 3 – Map depicting the shoreline change rates during 1972-2000 in the study area. Negative sign in the legend shows the areas of erosion and positive accretion.

The linear regression equation (y=mx+c) presented on the Figure 3 recorded the slope (m) value 0.0071 mm and offset value (c) is 6983.4 mm. Slope value reveals the average sea level rise at the rate of 0.0071 mm/month. The sea level rise observed from the Chennai tide gauge observation is 0.0852 mm/y. The rise of sea level after 50 year is estimated to be 4.26 mm above the current level.

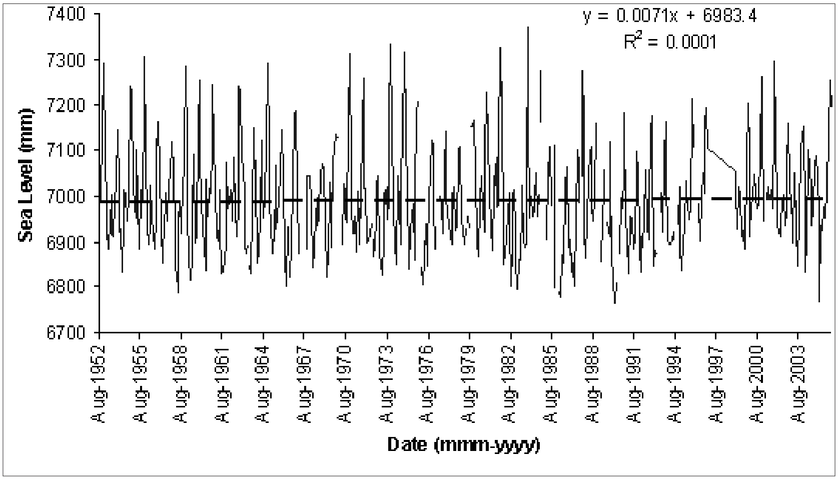

Figure 4 - Graph depicting the monthly mean sea level data from Chennai tide gauge. The dashed line is depicting the sea level rise trend.

Generation of Elevation Contours

The DTM (Fig. 5) generated using the Cartosat-1 stereo data supplied by National Remote Sensing Centre (NRSC) has been used to generate the contours. The DTM data has been smoothed using the low passing filtering technique using the ERDAS Imagine software to avoid the noises in the contour. The elevation contours have been generated using the Golden Software Surfer with one meter contour interval. The *Krigging* interpolation technique has been used to generate contours and contour lines were smoothed. Further these contour lines imported into ArcMap GIS environment.

Generation of Multi-hazard map

The sea level change rate has been forecasted for the next 50 years based on the rate of the sea level rise. The future shoreline after 50 year has been drawn based on the rate of the shore line change. Rao [2005] estimated the storm surge return period estimated using the synthesized tracks by numerical model was 4.1 meter recorded for the study area. However the researchers are reported that storm surge observed about 3-4 meter surge due to November 1989 Kavali Cyclone [Rao et al., 2009]. Another report from Rao [1968] classified the present study area in to 2-5 meter storm surge height category. The surge height after return period including the future sea level after 50 years will be 41426 meters. Hence the five meter contour line considered as extent of inundation due to storm surge for next 50 years. The surge of a water level 5 m will impact up to 5 m land contour, 10 m will impact 10 m land contour [Dube et al., 2009]. The shoreline after 50 years and coastal zone under 5 meter elevation were overlaid in GIS environment. The union of these two layers constitutes a coastal zone that is vulnerable to multi-hazards. The line along maximum extent of multi-hazard vulnerable zone is the composite multi-hazard line (Fig. 6).

Results and Discussions

The results of the shoreline change in the study area during 1972-2000 recorded maximum rate of erosion 7 m/y and accretion is up to 14 m/y. Study area dominantly under the accretion, the coastal erosion observed along the northern parts and most of the southern parts are under accretion (Fig. 3). The sea level change rate calculated using the monthly mean tide gauge data during 1952-2005 for the Chennai station depicts the net sea level rise of 0.0852 m/y. The topographic data from DTM depict that the large coastal area is under low elevation (Fig. 5).

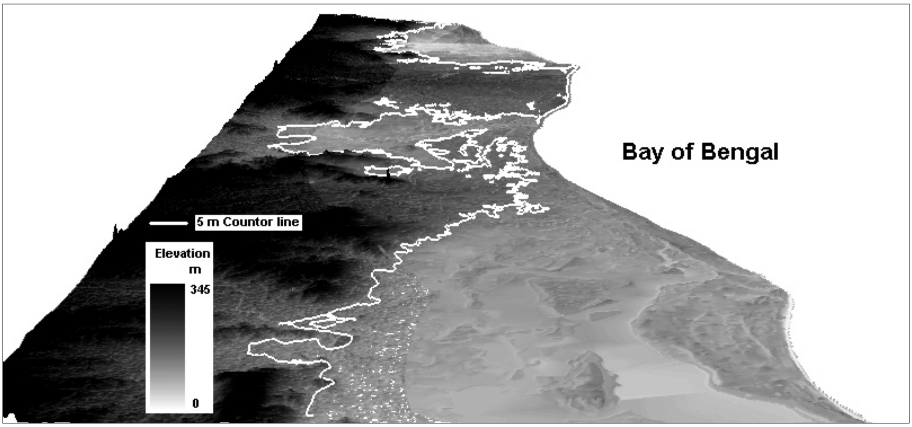

Figure 5 – image showing the coastal topography as depicted in the Cartosat DTM. The black line overlaid is 5m contour line.

The Nellore district is experiencing a large inundation to disaster such as cyclone, storm and folding. The current study deciphers the large area under the vulnerability by multi-hazards. Results of the multi-hazard mapping reveal that total 1708.36 km^2 is under multi-hazard zone (Fig. 6) in the coastal area of the Nellore district. The extent of the multi-hazard zone from coast observed varies from few metes to 23 km from the coast. The maximum extent observed in southern parts around Sriharikota (23 km), central parts near Krishnapatnam (19 km) and northern parts around Zuvaladinne-Isakapalle (16 km) coast due to gentle low lying coastal planes. The northern parts of the Nellore recorded 16km of extent is exactly matching the observations of the inundation caused due to May 1990 cyclone with surge height 5 meters [Mascarenhas, 2004]. Hence the results obtained in the current study are accurately represented to equate with the earlier events. The maximum extent towards upland observed in the vicinity of the water inlets river/creek systems.

Conclusions

The remote sensing and GIS techniques used in the current study yield better information in producing the Multi-hazard vulnerability maps. The river/creek systems here act as the corridors for the oceanic hazards causing the inundation. The multi-hazard maps produced here will be effectively used by the coastal administrators and the managers to manage the coastal hazards which cause inundation. The historical storm surge data used here is taken from the published work. Long term continuous hourly data from the tidal observations are required to yield in better results in calculating the extreme water level during storm surge. This study further diverted more towards the hazard management by incorporating the spatial themes such as landuse, roads, village boundaries etc., to access risk within the hazard zone and the evacuation plans.

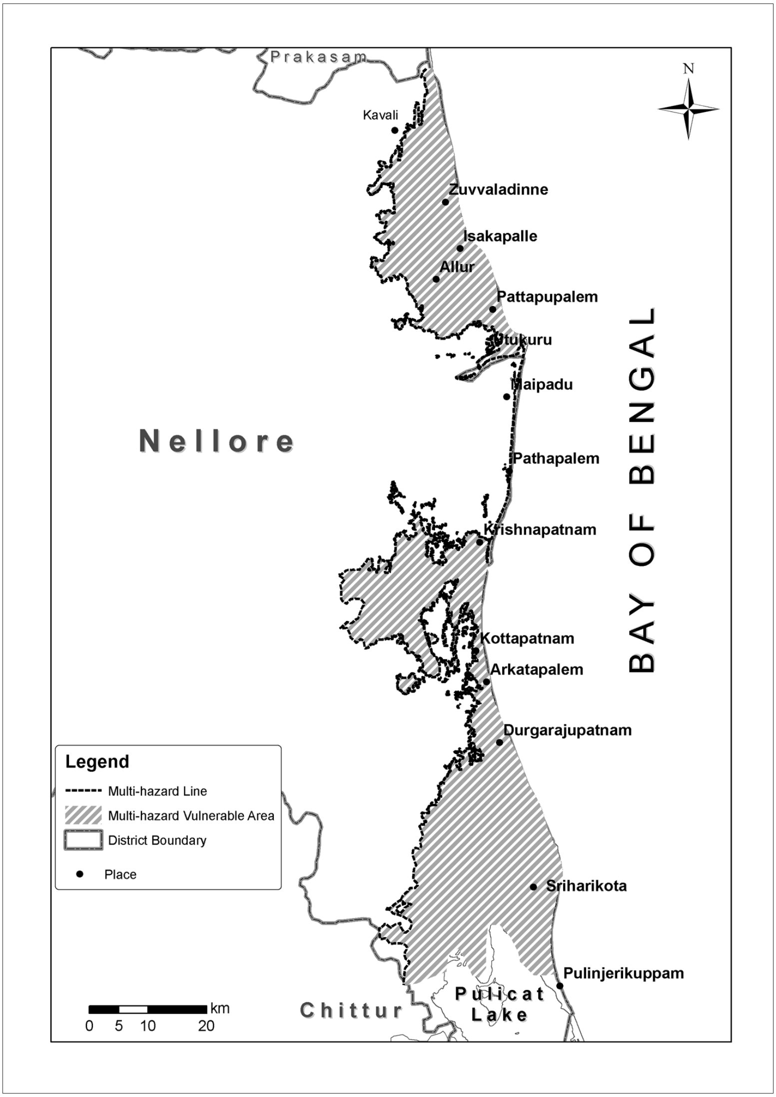

Figure 6 - Multi-hazard map of the Nellore District.

Acknowledgements
The authors would like to thank Global Observatory for Ecosystem Services (GOES), Michigan State University for the Landsat data, Global Sea Level Observing System (GLOSS) for the sea level data and USGS for the making available Digital Shoreline Analysis Software (DSAS) on their Website.

References

Burton I., Kates R.W., White G.F. (1978) - *The Environmental Hazard.* New York: Oxford University Press.

Dube S.K., Jain I., Rao A.D., Murty T.S. (2009) - *Storm surge modelling for the Bay of Bengal and Arabian Sea.* Natural Hazards, 51 (1): 3-27. DOI 10.1007/s11069-009-9397-9.

Gornitz V. (1990) - *Vulnerability of the east coast, U.S.A. to future sea level rise.* Journal of Coastal Research, 9: 201-237.

Habib S., Fahmi A. (2009) - *On Integrating of Multi-Hazard Mapping in Indonesia*. http://www.gisdevelopment.net/application/natural_hazards/overview/mma09_habib.htm (Accessed August 23, 2010)

Hegde A.V., Reju V.R. (2007) - *Development of Coastal Vulnerability Index for Mangalore Coast, India*. Journal of Coastal Research, 23: 1106-1111.

Kumar T.S., 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: 523-534. DOI: 10.2112/09-1186.1.

Mascarenhas A. (2004) - *Oceanographic validity of buffer zones for the east coast of India: A hydrometeorological perspective*. Current Science, 86 (3): 399-406.

Nayak, S., Sahai, B. (1985) - *Coastal morphology: a case study in the Gulf of Khambhat (Cambay)*. Int. J. Remote Sens., 6 (3-4): 559-568.

Nicholls, R. J. (1995) - *Coastal megacities and climate change*. Geojournal 37(3): 369-379.

Pendleton E.A., Thieler E.R., Jeffress S.W. (2005) - *Coastal Vulnerability Assessment of Golden Gate National Recreation Area to Sea-Level Rise*. USGS Open-File Report 2005 - 1058.

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

Rao A.D., Jain I., Ramana Murthy M.V., Murty T.S., Dube S.K. (2009) - *Impact of cyclonic wind field on interaction of surge–wave computations using finite-element and finite-difference models.* Natural Hazards, 49: 225–239, DOI 10.1007/s11069-008-9284-9.

Rao A.D. (2005) - *Development of long -term hazard planning, management and Vulnerability reduction action plan in respect of cyclones*. International Symposium Disaster Reduction on Coasts, Scientific-Sustainable-Holistic-Accessible, Monash University, Melbourne, Australia

Rao N.S.B. (1968) - *On Some aspects of local and tropical storms in India*. Ph.D. Thesis, Univ. of Jadavpur.

Thieler, E.R. (2000) - *National assessment of coastal vulnerability to future sea-level rise*. USGS Fact Sheet, fs-076-00, US Geological Survey, 2.

Tate E., Cutter S.L., Berry M., (2010) - *Integrated multihazard mapping*. Environment and Planning B: Planning and Design, 37 (4): 646-663.

United Nations Environment Programme (UNEP) (2007) - *Physical Alteration and Destruction of Habitats*. http://www.gpa.unep.org/content.html (accessed February 27, 2008).

Watson C.C. (2002) - *Using Integrated Mulihazard Numerical Models in Coastal Storm Hazard Planning*. Solutions to Coastal Disasters 02, conference proceedings Feb 24-27, 2002, San Diego, CA.

Received 14/02/2010, accepted 23/09/2010