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Sea Level Rise and Coastal Vulnerability along the Eastern Coast of India through Geo-spatial Technologies

Malay Kumar Pramanik[1,*], Sumantra Sarathi Biswas[2], Tanushree Mukherjee[3], Arup Kumar Roy[4], Raghunath Pal[2] and Biswajit Mondal[2]

[1]Centre for International Politics, Organization and Disarmament (CIPOD), Jawaharlal Nehru University, New Delhi-110067, India

[2]Centre for the Study of Regional Development, Jawaharlal Nehru University, New Delhi-110067, India

[3]NE SAC, Shilong, Meghalaya, India

[4]Lucknow University, Lucknow, UP, India

Abstract

The study emphasizes the local and regional level coastal vulnerability in the context of climate change induced present sea level rise using Sea level and tidal gauge data and advanced geo spatial technologies along the eastern coast of India. The coast is a potential hot spot zone were found the immediate effect of sea level rise. Presently climate change induced global warming and the melting of ice sheets and continental glaciers continually increase the sea level, which leads the natural hazards such as Tsunami, storm surges, thermal expansion of sea water and cyclones. The study was used SRTM global DEM with 90 m resolution to derive the coastal elevation, inundation risk zones along the eastern coast of India. The sea level rise scenario has been explained by using a 5th order polynomial curve which also interpolates and extrapolate the gaps within the available data of four tidal gauge stations. The results show that northern portion (Ganga-Brahmaputra delta region) of the coast, mostly affected by the sea level rise (4.7 mm per year) where the Sundarban region is the most vulnerable region due to the lower elevation (ranges 0 to 20 m) and higher tidal influence. Also Visakhapatnam and Bhubaneswar have a higher rate of sea level rise respectively 0.73 and 0.43 which increase the erosional activity and probable inundation level. As this study reveals the level of vulnerability, it helps to develop mitigation and adaptation measures in those most vulnerable areas to sea level rise problems. The final results support and suggests planners and decision makers in the spatial identification for the future strategies.

Keywords: Sea level rise; Coastal vulnerability; Geo-spatial technology; Coastal morphology; Inundation level

Introduction

Recently, climate change induced sea level fluctuation is a global phenomenon. As the global sea levels are projected to rise continuously at an accelerated rate in the 21st century causing by the thermal expansion of local and regional climatic fluctuation sand the melting of Greenland and Antarctic glaciers and ice sheets. Thermal expansion is associated with the sea water expansion and it is the effect of high sea surface temperature [1]. The level of the water in the ocean is the result of water volume increase which is caused by increase of sea surface temperature [2]. According to IPCC (The Intergovernmental Panel on Climate Change) report, the Predicted sea level fluctuation of 21st century, gradually increases at the rate of 1-2 mm per year [3] where church et al. [1] has mentioned that the average sea level has increased in the 20th century is about 1.5 ± 0.5 mm per year causing by physical and human-induced climate change. The IPCC report also have predicted that the sea level may rise in the order of 0.17 m to 0.59 meters in the next 100 years. But this is significantly different than the 0.06-0.37 meters (4-10 inches) that the sea level has been raised over the last hundred years. Generally, sea level is fluctuated with the Glacial and Interglacial Period. During the ice ages, the sea level is lower, but when the ices get started melting in the Inter-glacial period, sea level is increasing [4].

An improved understanding of sea-level rise and variability [2] will help to reduce the uncertainties associated with sea-level rise projections [5] thus, effective to more effective coastal management and planning. Adaptation measures to minimize the potential losses include restrictions on where, what and how to build, strengthened building codes, and developing local infrastructures which are mostly suitable for flooding [6].

Sea level rise poses greater impacts on the coastal environments [7], as these are the densely populated area that may be submerged fully or partially and easily exposed to face the natural disasters [8]. Eastern Coast i.e. Bay of Bengal is not exception of that. The Coastal Zones, Tidal Zones, Estuaries get imprinted by the Sea Level Changes [9]. The eastern coast is also affected by the several storm surges of the Bay of Bengal. That also takes few responsibilities for the rising of sea level. This may be due to thermal expansion of seawater, ice melting, etc. [1]. But, in general, for every 1 centimeter (0.39 inches) that the sea level rises, 1 meter (39.3 inches) of coastal land will be lost. The SLR will also contribute to the recession of the world's sandy beaches, 70% of the sandy beaches have been retreating in the past century. East Coast of India had also experienced the rising tendency of the sea level not in an equal tendency, but it varies differently throughout the coastal areas [10].

However, increasing coastal population, recent observed cyclones and storm surges, and climate change induced sea level acceleration stressed the importance of the scientific studies on coastal vulnerability and the collect appropriate information for government decision makers, community residents [11]. In addition, to addressing this issue stakeholders need is to classify the coastal areas according to their

***Corresponding author:** Malay Kumar Pramanik, Centre for International Politics, Organization and Disarmament (CIPOD), Jawaharlal Nehru University, New Delhi-110067, India, Tel: 8587081820; E-mail: malay65_ise@jnu.ac.in, malaygeo@gmail.com

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resilience and sensitivity to coastal flooding, inundation and coastal erosion. In the past, the prime barrier in understanding vulnerability analysis has been a lack of information and data [12]. However, recent development image processing techniques and spatial data gathering, including Geographic Information System (GIS) and satellite remote sensing, have helped to overcome this constraint. The present study identify the sea level rising trends and their effects on coastal geomorphology as well as other coastal environments. Finally, proposed some response strategies and adaptations for the sustainability of the eastern coastal region of India.

Description of the Study Area

As the Sea level is not a regional phenomenon, so whole eastern coast of India is considered as the study area. The Eastern part of the Indian coast stretches from West Bengal in the east to Tamil Nadu in the south. These areas extend between 77º40´-89º06´E longitude and 8º 20´-21º42´N latitude (Figure 1). The East Coast region is a narrow shelf and wide stretch of land area with bays, estuaries, lagoons, deltas and some smaller islands and salt marsh (Nayak, [10]) which lying between the Eastern Ghats and the Bay of Bengal. The temperature in the coastal regions often exceeds 30 C, and is coupled with high levels of humidity. Most of the coast receives both the southwest monsoon and northeast monsoon rains. The Annual rainfall in this region is of about 1,000 and 3,000 mm. The coast is active with cyclones and flood [13] during the period mid-October to November and receives maximum northerly wind. Most of the Indian rivers flow across the east and they brings large quantities of sediments, which are suitable for agriculture. Numerous backwaters and rivers inundate the region. The coast experience regular cyclonic damages and high sediment flow rate by flooding [14].

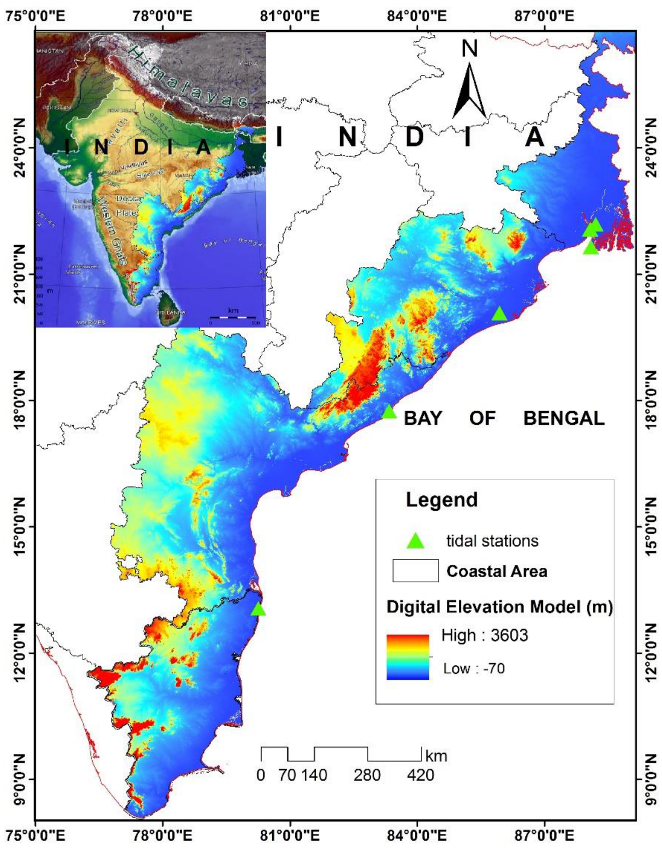

Figure 1: Map of the study area in the Eastern coast, India.

In the southernmost part of the coast lies in Tamilnadu, which has a large delta formed by the Cauvery River with narrow coastal plain. Andhra Pradesh lies in the middle part of the coast, which was formed by river Krishna and Godavari delta. Major landforms along Andhra Pradesh and Tamilnadu coast are alluvial plains, bays, tidal mudflats, creeks, ridges, bars, spits, mangrove swamps, marshes and lagoons [10]. These landforms are most dynamic due to climate change induced sea level rise and coastal erosion.

Database and Methodology

The present research methodology can be analyzed to have two parts where first part considered the trends of sea level rise through the available sea level data (PSMSL). While another part involves to the analyses of sea level rise effects by using by using shuttle radar topographic mission (SRTM) Global Digital Elevation Model (DEM) and the satellite images(Details about the data used are given in Table 1. The following procedure was followed for the analysis of the effects of climate change induced sea level rise.

Sea-level Change along the Eastern Coast of India

Sea level data collection and analysis

The sources of monthly and annual values of Mean Tidal Level (MTL) are: Survey of India, Permanent Service for the Mean Sea Level (PSMSL). PSMSL contains annual mean values of sea level from almost 2000 tide gauge stations around the world. However, in present study areas have five sea level gauging station, these are: Chennai, Vishakhapatnam, Bhubaneswar, Sagar and Diamond Harbour. After collecting the data fitted by 5^{th} order polynomial trend line (Figure 2) for interpolate or extrapolate unknown data which are not recorded by the stations. Also calculate the regression coefficient for the analysis of future sea level trends.

Digital elevation model and sea level analysis

Global Digital Elevation Model (DEM) of the eastern coast was extracted from Shuttle Radar Topographic Mission (SRTM) data with a resolution of 90 m obtained during February 2000 (downloaded from the United States Geological Survey website). The SRTM Global DEM was utilized to prepare coastal elevation, point based elevation extraction, cross sectional profile of the tidal station (from coastline of 100 km) and contour demarcation Using Spatial Analyst and 3D analyst tool of ARC GIS 10.2.1.

Identification of coastal vulnerability

All the extracted parameters and statistical results from DEM and

Types of data and software	Details of the data	Techniques	Sources
Sea Level Data	Monthly and yearly tidal gauge data	5^{th} order polynomial curve fitting	PSMSL
SRTM DEM	3-ARC (90 m) , 2000	Elevation profile, Point based elevation Extraction. Contouring, slope etc.	USGS
Landsat MSS and TM satellite imagery	Path/row: 149/45 and 139/46 dated 18/01/1990 and 22/05/2005	Extract the innundable and erosion prone region	USGS website

Table 1: Data used in the present study

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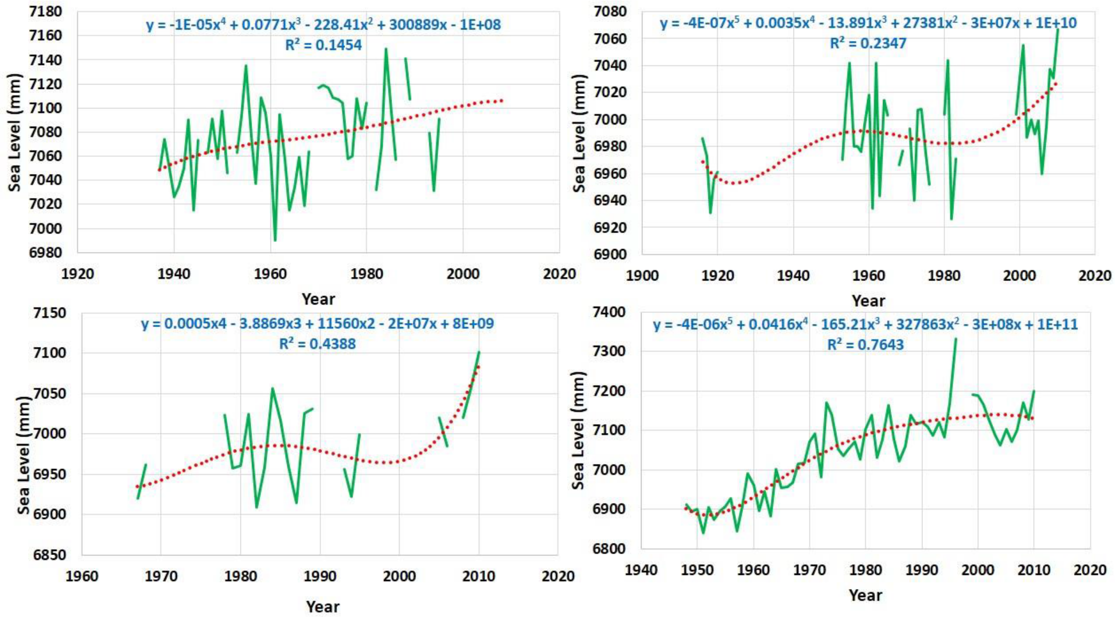

Figure 2: Sea level rise trend and 5th order polynomial curve at the station Visakhapatnam, Chennai, Bhubaneswar and Diamond Harbour respectively.

sea level data helps in the determining of inundation level and their impacts of the eastern coast of India. The inundation level has been analysed comparatively of four coastal tidal stations with the help of elevation and tidal records. Also identified the most coastal erosion prone regions from satellite images and highly innundable vulnerable places from contour mapping.

Historical Sea Level Change

On the east coast, sea level fluctuations were mostly inferred from the studies pertaining to major river deltas and various coastal landforms like islands, beach ridges, rock terraces, caves and relict sediments in the continental shelves [15-17], Studies on Holocene sea level changes off Visakhapatnam shelf indicated a late Pleistocene regression down to about 130 m below the permanent mean sea level [18]. Banerjee and Sen related the red sand exposures of the Vishakhapatnam coast, resting over a rock outcrop at about 7 m above MSL to a high stand of sea level [19]. Niyogi studied the floral and faunal assemblages and informed an Opinion that tidal mangrove forests flourished further north of the present extent of Sundarbans at about 6000 to 7000 YBP [20]. Niyogi reported three levels of terrace at 6.1 m, 4.7 m and 3.8 m above MSL in the Subarnarekha River delta and the adjoining coast of West Bengal. In the Godavari Delta, Samba Siva Rao and Vaidyanadhan [21] grouped four strand lines under the Holocene period. Samples such as peat/ wood material, shell fragments, calcite rich mud etc. taken from the farthest beach ridge to the Krishna Delta gave an age range of 6500 YBP to 2050 YBP [22]. Radiocarbon dating of mollusc shells from a bar at about 25 km from the present coastline in the Nizampatnam Bay gave an age of 8200 ± 120 YBP, suggesting a Holocene sea level drop of about 17 m. Here, Rao [22] postulated a rapid rise in the sea level at around 8000 YBP, thereby drowning the barrier island. Evidences of low sea stands at -49 m and -56 m near the Pulicat Lake in the form of pebble horizons have been identified by [22,23] inferred a low strand line at 70 m, at the close of the Worm glacial stage. The sea level rose rapidly to the present level in the course of post-glacial transgression, thereby inundating 11000-12000 years old Pleistocene fluvial deposits of the Cauvery region. A series of beach ridges in Cauvery delta, each rising 7.2 m, 6.9 m and 5.5 m above the PMSL are related to three strand line at their respective positions related coral reefs and few terraces lying close to Rameswaram Island between Tamilnadu and Sri Lanka to the emergence of the coast. Morphological analysis of coastal landforms indicated emergence of the Rameswaram coast at about 4000 YBP [22]. Along the Tamilnadu coast, during the late Quaternary (Upper Pleistocene) transgression, the sea level rose to+2 m and+8 m during the last interglacial stage. The Holocene transgression reached its maximum height during 6240 YBP to 2740 YBP, the level hardly rising 0.5 m to lm above the PMSL [24]. The terraces around Mandapam and Rameswaram coast ranging in height from 0.20 m to 0.62 m above MSL, gave ages varying from 5440:1: 60 to 140:1: 45 YBP [25].

Present sea level rise scenario

On the eastern coast of India, sea level fluctuation is very prominent due to larger variation of relief features. Most of the largest rivers of the subcontinent get a confluence point at the Bay of Bengal. Lots of sediments is transported to the sea from these sediments carrying rivers. There are six tidal gauging stations are present in the coastal area, these are: Chennai, Vishakhapatnam, Bhubaneswar, Sagar, Diamond Harbour and Haldia. All the study stations have the positive sea level rise within the study period. Chennai has the positive sea level rise obviously the rate is much lower than to the other stations. In Vishakhapatnam, from the 73 years of data, the trend of sea level is positive, i.e. 0.73 mm/year in approximately constant rate. From 1937 to 2010, this station enjoys with about 64 mm rise of sea level. In the Bhubaneswar, there are also positive rate of sea level rising i.e. 0.43 mm/year and the Diamond Harbour abruptly rising, which is about 4.7 mm per year (Figure 2). This may be the result of several causes such as Tropical Cyclones, Tidal Ingression, Sand Encroachment, Sedimentation etc. Diamond Harbour is located near the sea area that's why this is more affected by the path of river water and tidal phenomena. The station also affected by the lots of anthropogenic activities are doing alarming condition due to higher population density in this area (Details about the sea level data used and output results are given in Table 2.

Station	No of years of data used to compute the trend	Range of the years Used	Trend in mm/year	5th order polynomial coefficient of determination	Data gap within the collected data	Standard error in mm/year	Standard deviation of the residual variability about the fitted line
Chennai	95	1916-2010	0.39	0.2347	1921-52, 1988-91	0.55	31.3
Visakhapatnam	73	1937-2009	0.73	0.1454	1996-99, 2001-04	0.28	34.5
Bhubaneswar	44	1967-2010	0.43	0.4388	1973-77, 1996-02	0.23	28.9
Diamond Harbour	63	1948-2010	4.7	0.7643	1997-98	0.44	53.5

Table 2 Details about the data used and results.

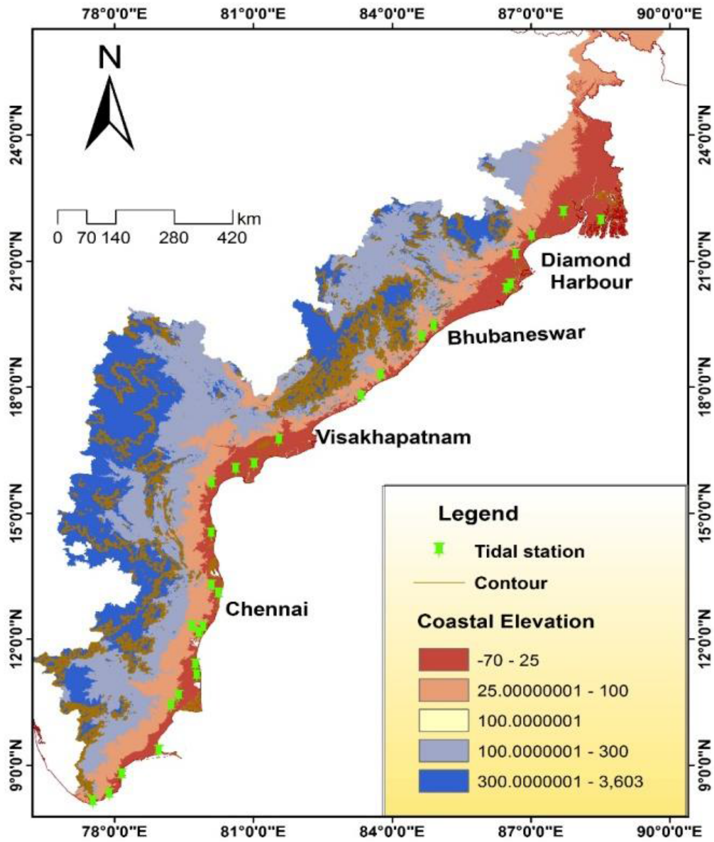

Figure 3: Coastal elevation and location of tidal station along the Eastern coast, India.

Results and Discussion

In the present study, analyse the impacts of sea-level rise which is determined by the relative sea-level change, reflecting not only the global-mean trend in sea level, but also regional and local variations in sea level change and in geological uplift and subsidence of the study coast [10]. Relative sea-level rise has a wide range of effects on coastal systems. The immediate effect is submerged and increased flooding of coastal land, particularly during extreme events, as well as saltwater intrusion into surface and groundwater. Therefore, subsiding areas are more threatened due to the combined impactin inter annual variability and extreme sea levels resulting from storms and the globally-averaged sea-level rise. Extreme sea-level scenarios due to changing storm characteristics has been considered for analysis the sea level rise effects [5] along the eastern coast of India.

Coastal elevation and sea level rise effect

Coastal Elevation is the major factor to analyze the impact of sea level rise along the coastal region. The elevation characteristics have been shown by the Shuttle Radar Topographic Mission(SRTM) global digital elevation models (DEM) of four coastal state, i.e. West Bengal, Orissa, Andhra Pradesh and Kerala and shows the contourpatterns at 50 m interval which are interpolated using the 3D Analyst tool in ArcGIS software. But the generated contour map was noticed inconsistencies owing to the coarse resolution (90 m) of the SRTM DEM data. So, classify the area in five elevation zone to represent the coastal elevation along the coastal area. The elevational trend (Figure 3) reveals that most of the areas lie within 25 m elevation which are mostly affected by the sea level rise. The coast between Bhubaneswar and Visakhapatnam are less vulnerable areas of inundation for the coastal cliffs which fall directly to the sea. On the other hand low elevation coastlines are most vulnerable due to higher beach erosion intensity which have degraded or remove protective coastal features such as sand dunes and vegetation, further increasing the risk of coastal flooding. The region of Godavari, Krishna, the Mahanadi and the Ganges delta are more vulnerable due to lower elevation which further increases the flood intensity. The impacts include coastal inundation and its Consequences, and increased rates of coastal erosion.

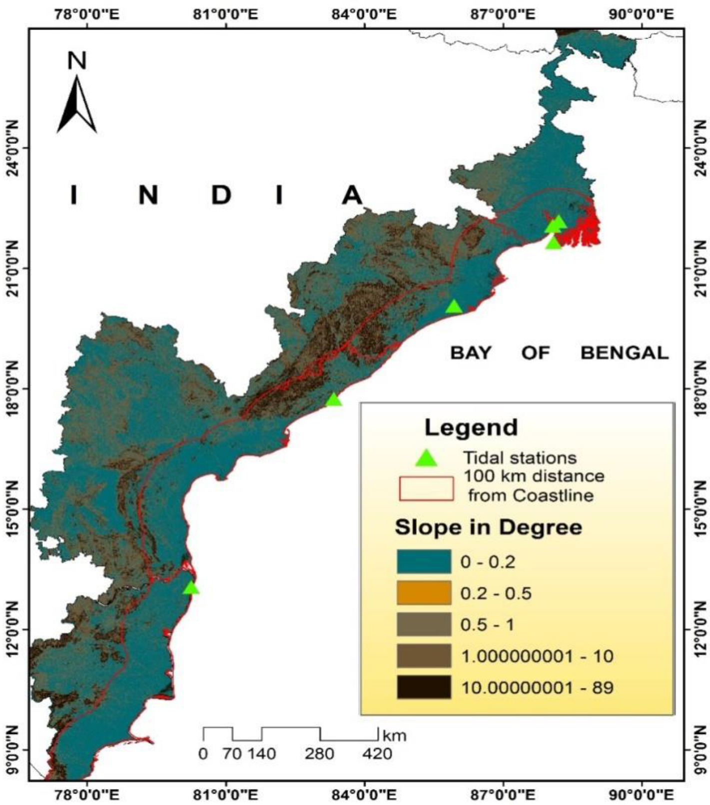

Figure 4: Slope and 100 km buffering land area along the Eastern coast, India.

Slope and sea level rise effect

Coastal slope is another major factor to be considered along with the coastal morphology in estimating the impact of sea-level rise on the eastern coast (Figure 4). Most of the areas of the study coast are laying in 0.2 degrees except the rocky cliff between Bhubaneswar to Visakhapatnam along the 100 km buffering area. On the steep and cliff coast, the impact of sea-level acceleration would be insignificant in respect to gently sloping coast where a small rise in sea water would inundate larger spatial extents of land. This condition is found throughout the eastern coast as specifically threatened to the 100 km buffer areas. The coast is also exposed to multiple hazards such as tsunamis, sea storms, cyclones, coastal flooding, storms urges, and shoreline variance due to sea level rise and their effects varies spatially. The spatial variation of intertidal areas can be concluded through the mapping of the coastal slope along the eastern part of India. Lower the value of the slope indicates the more vulnerability to the study region. Therefore, in the eastern coast all the intertidal areas lie between 0- 0.2 degree slopes which have a greater vulnerability.

Tidal gauge record and sea level rise

For the analysis of tidal amplitude in the eastern coast of India total 28 tidal stations has been taken where the tidal amplitude reveals that amplitude gradually increases from Kanyakumari(approximately 40 m) in the south to Diamond Harbour (approximately 200 m) in the north (Figure 5). The data on the significant wave heights (SWH) adequately represent the large scale sea level changes throughout the region. Among the 28 selected stations tide gauge data (green point in Figure 3) and point based SRTM DEM height has been extracted from the nearby altimeter grid point. Hence, the relationship between tidal amplitude

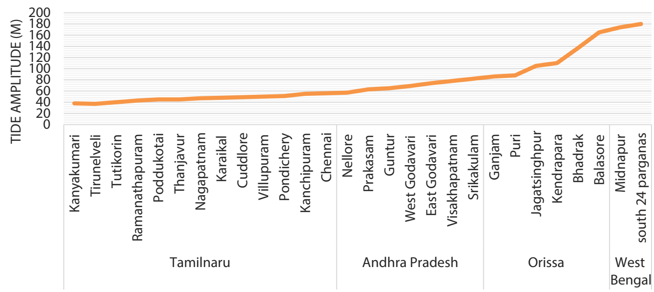

Figure 5: Tidal amplitude at 28 stations along the Eastern coast of India.

and extracted elevation was drawn by a logarithmic trend line (Figure 6) where the coefficient of determination (R^2) value is 0.069. The results reveal that the significant decrease of coastal height represents the effective amplitude of tide level, which indicates the large scale sea level fluctuation and offshore variability. However, the Diamond Harbour station of South 24 Parganas exhibits a significant relationship over the broader regions of the Ganges-Brahmaputra delta.

Coastal erosion assessment

Sea level rise accelerates the intensity of coastal erosion. According to Bruun [26,27] the coastal erosion assessment generally represented by the following formula, R=SG [L/(b+h)]. Where R is the coastal retreat due to sea-level rise, S is the Sea Level Rise, G is the proportion of eroded materiel which remains in the active profile, L is the active profile width, b is the dune height, and h is the depth of closure. Finally, the results showed that eastern coast and beaches are more vulnerable, which would completely disappear within 2050. The tidal data and the digital elevation delineate the accurate shoreline position and erosional activity throughout the eastern coast [28]. These tidal effects have been generalised the erosional intensity and shoreline mapping for calm sea conditions where the erosional activity increases from south to north with decreases coastal height throughout the eastern coast.

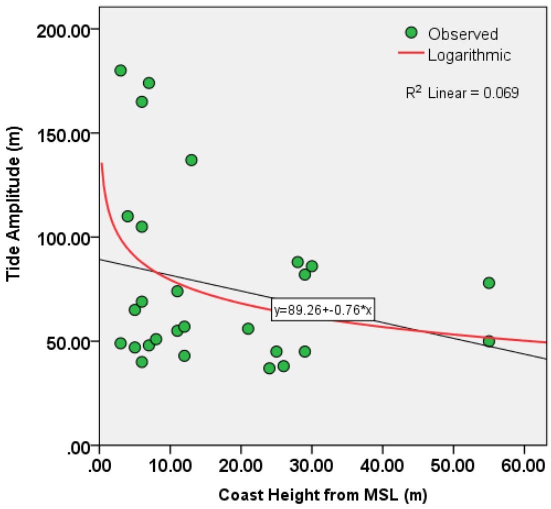

Figure 6: Logarithmic relationship between Tidal amplitude and point based Coastal height from mean sea level.

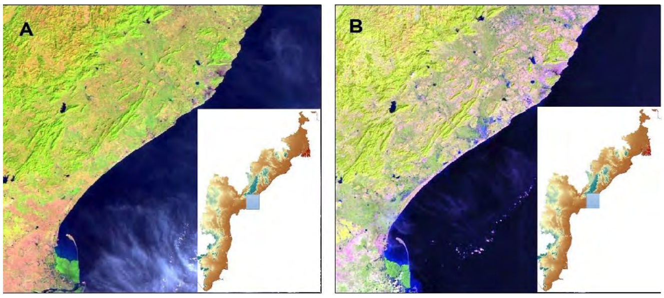

Figure 7: Inundation scenario of Visakhapatnam area for sea level rise A) Nov, 1977 (Landsat MSS) B) Nov, 2005 (Landsat TM) with true colour composition.

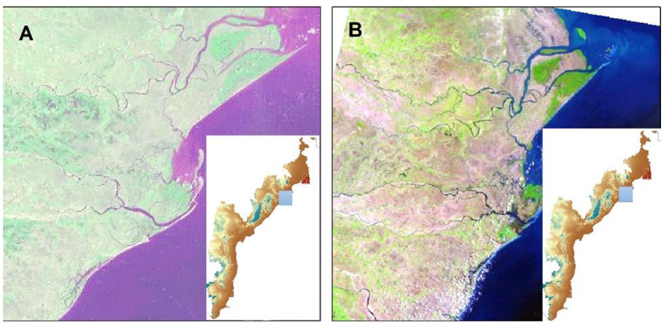

Figure 8: Inundation scenario of Paradeep area for sea level rise A) Nov, 1977 (Landsat MSS) B) Nov, 2005 (Landsat TM) with true colour composition.

Assessment of inundation level

One of the first consequences of a rise in sea level is an increased flood risk associated with storm surges, in low-lying coastal zones. Nichols et al. [29] defined the risk zone as the land area between the coastline and the "maximum" design water level, which can be calculated from the Equation, Dft=MHW+S+Wf+Pf. Where Dft is the inundation level, MHW the mean high water level, S is the relative SLR, Wf the height of waves and Pf the SLR due to a lowering of the barometric pressure and two levels of inundation were considered which are minimum (1.71 m) and maximum inundation (2.29 m) due to sea level rise. However, according to Jimenez et al. [30], sea-level rise will induce a decrease of the return period of water levels associated with storm surges. However, land loss resulting from inundation is dependent upon sediment availability, as well as the potential for the coastal systems to migrate landward. It can inundate the bars of the coastal area. SLR disturbs the formation of sand dunes the non-rocky coastal area and The Estuary islands are submerged as an effect of the Sea level rise. However, the East coast is a sand-deficiency and a heavily humanized system where inundation level, mostly accelerates the coastal lowlands that has been found in Visakhapatnam (Figure 7) and Paradeep (Figure 8) within 20 year interval. The areas are heavily affected by the higher inundation frequency with the increasing sea level rise which will not be able to cope with the rise of the sea level, if no protective measures are undertaken. Indeed, potential loss of people living in the area at risk of flooding, as well as industrial infrastructures will have serious socioeconomic impacts in the region.

Coastal vulnerability to sea level rise

In the present study, using geospatial technology total five parameters/variable was selected to analyse the overall vulnerability in the eastern coast of India. The elevation from mean sea level and slope has been calculated from digital elevation model and the tidal amplitude, coastal erosion, and inundation level scenario have been presented with the based on extensive literature reviews, Stakeholder input and different experts view. These result analyse the vulnerability with respect to elevational difference, sea level rise trend and tidal amplitude along the coastal region. Area of vulnerability (Figure 9) estimates that with the minimum inundation level of 1 m to 5 m at 1 m interval where a Sundarban region of West Bengal and Godavari and Krishna delta region are more vulnerable in a 1 m increase of inundation level. The inundation level of 5 m along the coastal regions are would be potentially inundated and the 50 m inundation level or sea level fully destroys along the 100 km coastal buffer areas (Details about the sea level rise trends and coastal vulnerability is given in Table 3 and the 10 m inundation level is potential in the urban and industrial areas of the coast.

From the results obtained that the region of Diamond Harbour and adjoining areas of Hugli estuary, Sundarban regions are most potential to sea level rise trends due to the lower elevation (Figure 10), negligible

Sea level rise trends (mm/year)	Location (station wise adjoining area)	Elevation from mean sea level(m) (fig. no. 11)	Slope (in degree)	Inundation level and erosion	Tidal amplitude (m)	Vulnerability and risk zone
Below 0.5	Bhubaneswar and Chennai	Up to 200 m	0.10	medium	40-120	high
0.5 – 1.0	Visakhapatnam	Up to 1000 m	0.3	medium	60-85	medium
Above 1.0	Diamond Harbour	Up to 20 m	0.05	very high	180	very high

Table 3 Details about the Coastal Vulnerability factors and sea level rise trends.

slope and higher tidal amplitude. The relationship between the tidal amplitude and the sea distance of Diamond Harbour and all nearest stations has been shown in Figure 9 which indicates the sea level rise effect will increase with the increasing distance from the sea (Figure 9). Ericson et al. [31] estimate that the mean global 2 m sea-level rise (Figure 11). Including the effect of related natural hazards like tsunami, storm surge and cyclone will affect near about 3,430,000 people in the Bengal coast and adjoining areas. These estimates do not take account of increased exposure to storm surges. Niyogi [20] reported three levels of terrace at 6.1 m, 4.7 m and 3.8 m above MSL in the Subarnarekha River delta and the adjoining coast of West Bengal. Sagar Islands have loss its area about 26 sq. Km from 1920-2000 [32]. However, the Delta region is only a few m above the sea level and is subject to frequent flooding during the summer monsoon season and also when tropical cyclones from the Bay of Bengal hit the Delta region. The storm surges generated by tropical cyclones have killed hundreds of thousands of people over the last four centuries [14]. In recent times, sea level rise and related intense tropical cyclones struck the Delta region on November 13 1970, killing an estimated 200,000 thousand people, largest fatalities in a single weather-related disaster.

Response Strategies and Adaptation

In spite of the large uncertainty regarding projected climate scenarios and empirical calculations, and given the potential impacts of SLR on various socioeconomic sectors of the East Coast of India, an anticipatory adaptation strategy must be developed. This should be based on a pro-active approach and 'no regrets' policy. In fact, coastal adaptation processes to climate change interact with existing management practices and can be considered multi-stage and iterative processes [33]. Therefore, an integrated coastal zone management (ICZM) plan is the most appropriate and necessary tool for long-term sustainable development, which could tackle current and future vulnerabilities of the coastal area. The plan should actively involve the

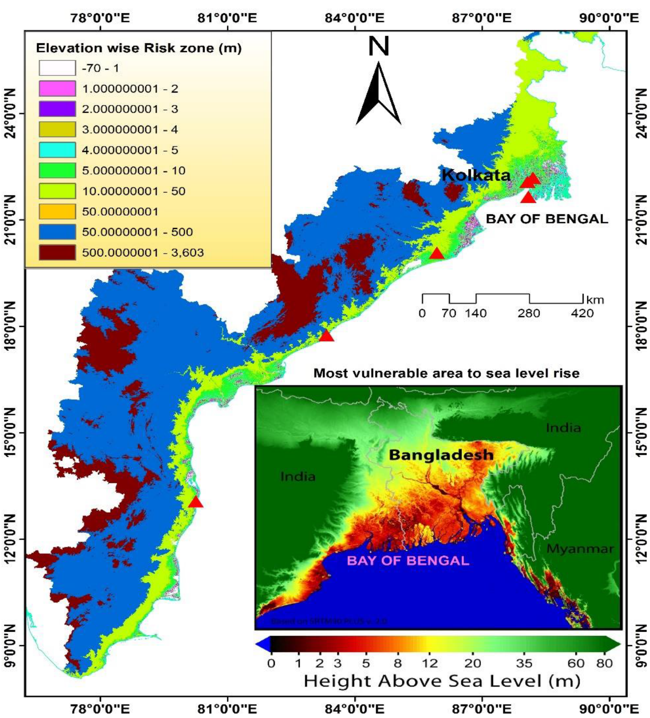

Figure 9: Coastal Vulnerability map to sea level rise in 1 m, 2 m, 3 m, 4 m and 5 m.

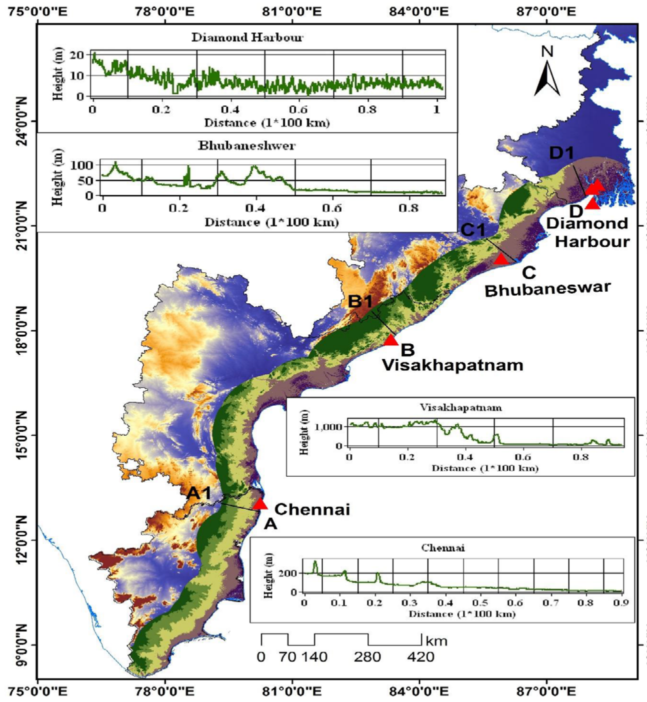

Figure 10: Cross profile along the 100 km buffer area from mean sea level of Diamond Harbour, Bhubaneswar, and Visakhapatnam and Chennai station.

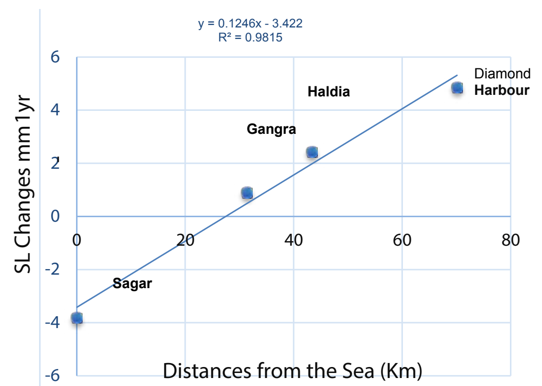

Figure 11: The relationship between sea level changes and distance from the sea in most vulnerable coastal area of West Bengal.

local communities, and include building regulations, urban growth planning, building institutional capacity and raising awareness [34]. Such plan should deal with both SLR and other impacts of climate change and/or human activities, and ensure that coastal development does not increase the vulnerability of the region. It requires the availability of a geographic database with relevant, detailed and accurate information, a monitoring system and a decision support system. Rehabilitation of Coastal Embankment, Construction of New Cyclone Shelters, Increasing Embankment Heights, Coastal Afforestation, Mangrove Greenbelt, BankProtection Works, and Changing Cropping Patterns are a major influencing factor for the adaptation of long term sea level rise [34]. Short-term adaptation measures are also necessary. The most suitable range or mixes of options that are recommended for the study area include: 1) Beach nourishment, including building artificial dunes as storm buffers and beach sand reservoirs. This option would be beneficial (e.g. for tourism) even in the absence of SLR; 2) Hard structures should be designed, as much as possible, to avoid adverse environmental impacts. Breakwaters could reduce the energy of the north-eastern waves reaching the shoreline. Building of seawalls is a high cost option; it would be used only for settlements and industrial areas of high value and at direct risk of inundation.

Conclusion

Sea level rise is a realistic approach with the coastline geometry. The conclusion from this study has some implications with short term and long term. From the statistical analysis and obtaining data from different years, we may conclude about some major historical storms, sea level and the coastal elevation effects to the different segments of the coasts. The total level of water definitely helps to find out the combination with sea level changes and its impacts to the Eastern Coast of India. Obviously, sea level change solely affects the configuration of the coastal areas other factors such as river discharge, tidal current etc. also play a major role in hammering the east coastal environment of India. Therefore, the analysis of coastal vulnerability to sea level rise has many advantageous sights. The vulnerability analysis provides a valuable information that helps to priories major issues which need to be addressed. It is also useful in communicating and summarizing the vulnerability analysis results to stakeholders, planners and decision makers. The vulnerability analysis of the different coastal station gives an idea about the future probability of sea level rise and their impacts where the Kolkata city is more potential to sea level rise and need a suitable planning to reducing their impact. Here, also needs some policy initiative, disaster preparedness infrastructure and suitable strategy for vulnerability reduction. In the planning strategy, local community needs to be involved in reducing vulnerability at every stage of the planning process. Proper management of locally available resources and appropriate land use planning play an important role in reducing the effects of sea level rise and probable natural hazards.

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