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Monitoring shoreline changes along Andhra coast of India using remote sensing and geographic information system

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A shoreline is dynamic in nature which makes the interface of land and water that offers socio-economic and cultural protection to its adjacent population. The purpose of this study was to understand long-term (1973-2015 and 2015-2057) shoreline transformation as well as the patterns of soil loss/sedimentation owing to physical and anthropogenic activities along the Andhra coast. Satellite imageries of LANDSAT from 1973 to 2015 were utilized to delineate the shoreline. Shoreline fluctuations were analyzed by Net Shoreline Movement (NSM) and End Point Rate (EPR) statistics using the Digital Shoreline Analysis System (DSAS) computer software of USGS. The highest and lowest EPR of about 67.63 m/y and -43.14 m/y were recorded in the Andhra coast. The high rate of deposition was recorded in the Godavari delta, whereas Krishna delta experienced low erosion. This study establishes the use of remote sensing data and statistical techniques such as EPR and NSM for shoreline monitoring are helpful for soil loss/accretion evaluation and future shoreline prediction.

[Keywords: Andhra Coast; DSAS; GIS; NSM; Remote Sensing; Shoreline Change]

Introduction

The shoreline is the intertidal margin between land and sea that keeps altering its position constantly due to a dynamic environment. It is one of the fast-changing landforms of the earth[1]. The world's coastal zone is experiencing an extensive pressure of physical and anthropogenic activities. About 10 % of all earth's surface, coastal zones have become the home of approximately half of the global population. Increased human population, industrialization and unplanned developmental activities threaten and degrade global coastal ecosystems[2]. The shoreline is very sensitive to physical processes *viz*., sea-level rise; wave direction and tidal flooding etc.[3]. Such changes are the long and short terms processes that encompass geomorphological, tectonic, hydrodynamic, and climatic forces[4], which have a positive and negative impact concerning accretion that may create a more usable land and erosion that leads to loss of the economic and ecological viable land. The loss and gain of economically, ecologically and culturally valuable land is a noticeable result of the way shorelines are reshaped. The shoreline change rate differs depending upon the magnitude of contributing factors, melting of continental ice, warming of oceanic waters etc.[5]. Therefore, precise delineation and observation of shoreline alterations (long-term, seasonal and short-term) are essential to know the coastal mechanisms.

For shoreline mapping, various studies have been done[6-10]. The most common methods for mapping are field observation, such as measuring tide and wave, identifying and comparing of shoreline from top sheets, multi-spectral satellite imageries and aerial photographs[11]. But recently, satellite imageries with the combination of GIS replace the conventional method because of repetitive, less time consuming, cost-effectiveness and accuracy[12]. Several techniques viz., End Point Rate (EPR)[13], Average of Rate (AOR), Linear Regression Rate (LRR) and Jackknife[14] have been proposed. EPR model is very simple and easy among all models, and is the accurate estimation for prediction of future shoreline changes[13], and there is no requirement of other information such as sediment transport or wave interference[15].

The Andhra Pradesh coast is a more vulnerable coastal zone because of high anthropogenic pressure. Salt-water intrusion into the agricultural lands creates a problem for the coastal agrarian population too[16]. Therefore, the study of shoreline changes and predictions of the future becomes important for coastal management. Thus, the purpose of this study is to evaluate the historical and future shoreline variations in the Andhra coast of India, by using geospatial techniques and to demarcate the area, which is susceptible to coastal erosion.

Materials and Methods

The study area

The study region lies in Andhra Pradesh, which is the part of the east coast. It is a passive continental margin developed during the separation of India from Antarctica in the Late Jurassic[17]. It is stretched (about 974 km) from the Nuralrevu village (near Ichapuram) adjoining the Orissa State to Therunattam village adjacent to Pulicat Lake forms the southern Andhra coastal plain. Andhra Pradesh is extended between 12°41' N and 22° N and 77° E and between 84°40' E, surrounded by the states of Chhattisgarh, Maharashtra, and Orissa in the north, Karnataka to the west, Tamil Nadu to the south, and the Bay of Bengal in the East (Fig. 1). Physiographically, the state can be divided into three broad divisions: (i) Rocky coast (North of Godavari delta), (ii) Deltaic coast (Krishna-Godavari Region), and (iii) Sandy coast (South of Krishna delta up to Pulicat lake). The maximum and minimum temperatures in the area are 41.5 ºC and 11.1 ºC, respectively. The state welcomes rain from the north-east and south-west monsoons. The annual mean rainfall varies from about 74 cm in the South to about 200 cm in the North with considerable fluctuations. It has a mean annual rainfall of 92.5cm, of which, 68.5 % is experienced during south-west monsoon (June to September), about 22.3 % during north-east monsoon (October-December) and the remaining 9.2 % during winter and summer[18].

Data source

In this research, the Landsat MSS, TM, and ETM+ datasets were obtained from 1973, 1990, 2003, 2009 and 2015 to demarcate the shoreline alterations along Andhra coast. The satellite data were obtained preferably from December to February to minimize seasonal effects. Table 1 specifies the data sources utilized for the study.

Data processing and mapping

For shoreline mapping and statistics generation, all required data sets were resampled to make the pixel size equal. Re-sampling certainly enhances comparability among various data sets of equal pixel

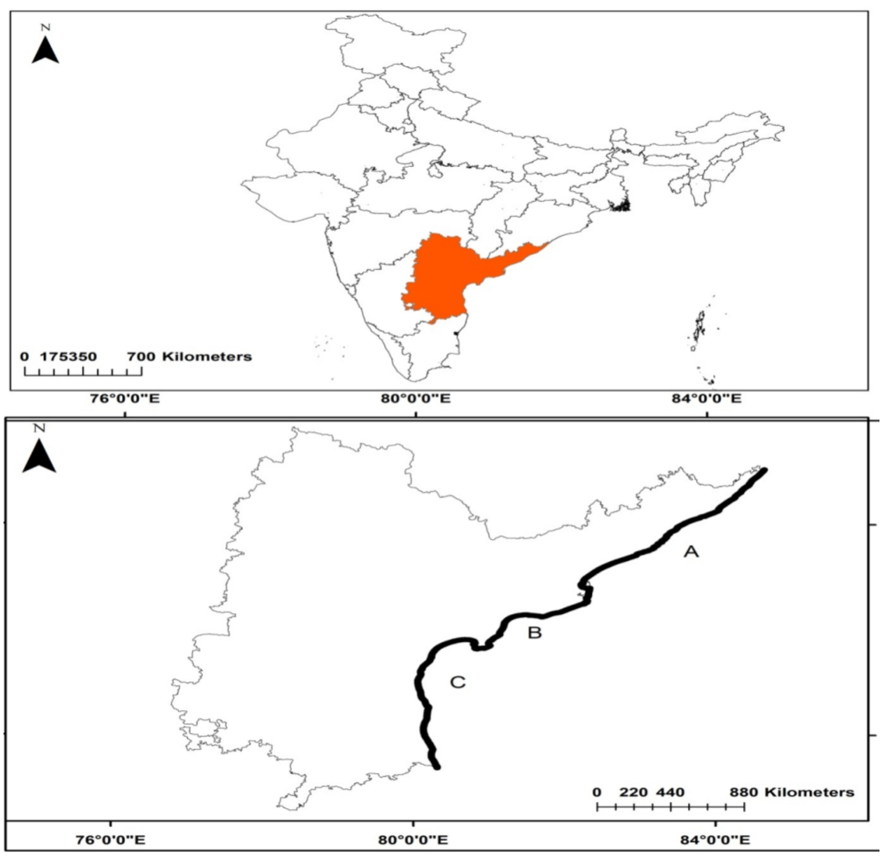

Fig. 1 — Showing location of study area, A. North Andhra coast, B. Middle Andhra coast, and C. South Andhra coast

Table 1 — Data sources used for the shoreline change detection

Acquisition date	Satellite data and its sensor	Resolution	Parameter
1/1/1973	Landsat 1-4(MSS)	60 m	
28/1/1990	Landsat(TM)	30 m	
20/3/2003	Landsat(ETM)	30 m	Shoreline
15/3/2009	Landsat(ETM)	30 m	
7/3/2015	Landsat8	30 m	

size. Several methods were developed for extracting shoreline from optical imagery, but for this study, screen digitization techniques were applied. Blue, green, near-infrared band, has been used to understand the land and water edge clearly. The shoreline datasets from the multi-data satellite data from 1973-2015 were extracted using GIS software. These vector file has been used as an input parameter to estimate the historical shoreline movements[19].

Shoreline changes and change rate assessment

To quantify the shoreline change magnitude of shoreline shifts along the Andhra coast, the Digital Shoreline Analysis System toolset was used which is an extension of ArcGIS software developed by the USGS, which creates baseline and transect perpendicular to the coast and computes the rate of changes of shoreline. Net Shoreline Movement (NSM), EPR, and LRR were useful to calculate statistical parameters[20]. The NSM has been measured by the distance between the youngest and oldest shorelines and EPR was calculated through dividing the NSM by the time elapsed between the oldest and the most recent shoreline. The LRR are the average rate of changes that are measured by using a number of shoreline position over time. For this study, 1045 transects, which are perpendicular to the shoreline were drawn at the interval of 1000 m and baseline created at 2000 m distance from the shoreline, derived from 1990s LANDSAT data was taken as a reference line. Movement of all shorelines over the 42-year period (1973-2015) has been detected in reference to the baseline. The movement of shoreline with respect to the baseline is considered erosion, where it moves toward land at each transect and statistical values have been denoted as negative and accretion. When it moves seaward at each transect shows the positive sign and was categorized into stable, low, medium, high and very high erosion/accretion zones according to EPR.

Shoreline prediction based on EPR model

The accuracy of the forecasted shoreline position depends on the historical process and provides precise information related to the future shoreline location[11]. In the context of shoreline research, spatial prediction of a constant rate of shoreline changes is the most frequently used methods for predicting the shoreline[21]. The shoreline alteration rate is continually used, to sum up, the past shoreline movement and its future forecast. Various techniques have been applied for the future shoreline prediction, which are functions of the rate of soil loss, sedimentation, and time, or sea level trend *viz*., non-linear mathematical models like cyclic series models, the exponential model, and higher-order polynomial[15]. LRR and EPR models are the most common, easy and reliable methods, which are based on historical shoreline behaviour[13].

For the present study, we have adopted the EPR Model to delineate future shoreline. The future shoreline for a given period is assessed based on the rate of shoreline movement (slope), time interval, and forecasted shoreline and model intercept that has been described as follows:

$$\text{Shoreline location} = \text{Slope X Time interval} + \text{Intercept} \quad \text{... (1)}$$

The model calibration is well-defined as follows:

Step-1: Let Y denote to future shoreline position, X for a time interval, B for model intercept and M_{EPR} for the slope or rate of shoreline change then the equation [1] can be written as:

$$Y = (M_{EPR})\, X + B_{EPR} \quad \text{... (2)}$$

Step-2: The rate of shoreline movement/slopes for a given set of samples, M_{EPR} can be calculated as:

$$M_{EPR} = (Y_1 - Y_2) / (X_2 - X_1) \quad \text{... (3)}$$

where, Y1 and Y2 are recent and oldest shoreline position, X_1 and X_2 is the recent and oldest time period, respectively.

Step-3: EPR intercept can be calculated as:

$$B_{EPR} = Y_1 - M_{EPR}\,(X_1) = Y_2 - M_{EPR}\,(X_2) \quad \text{... (4)}$$

Step-4: Since the Endpoint line can extend beyond the most recent point (t), equation [2] can be rewritten to use that position, (Y_2) and the elapsed time (X_t-X_2):

$$Y_t = M_{EPR}\,(X_t - X_2) + Y_2 \quad \text{... (5)}$$

Therefore, after the calculation of EPR and NSM values, the values are used to calculate M_{EPR} for both x and y location of each point of transects locations. The model again calibrated with 1973 and 2003 shoreline samples and the rate of movements (M_{EPR}) was calculated to predict the shoreline for 2015. This value was used for future prediction of shoreline movement for 2057. There is a question, why 2057? The reason being the historical shoreline changes are calculated for the 42 years, therefore, the prediction also set to the limit for the 42 years.

Results and Discussion

Shoreline changes monitoring

The result of the study shows that accretion/erosion is active in different places. During 42 years (1973-2015), Andhra Pradesh coast experienced erosion with an average EPR -0.67 m/y. NSM is -28.09 m. Maximum accretion/erosion rates of 67.63 m/y, -43.14 m/y, were observed based on EPR at Krishna-Godavari delta. The standard deviation rate was 8.08 m/y. Net shoreline shift showed 2852.53 m and -1819.75 m along with transect id 576 and 559, respectively (Fig. 2). Major accretion/erosion was observed along Krishna-Godavari delta. Similar results were also reported along Godavari and Krishna river course[22, 23]. Eroding shorelines are observed at the southern part of Krishna delta, whereas progressing shorelines are observed at Vishakhapatnam and Srikakulam coast (Fig. 3). The hasty coastal retreat and physical habitat loss were

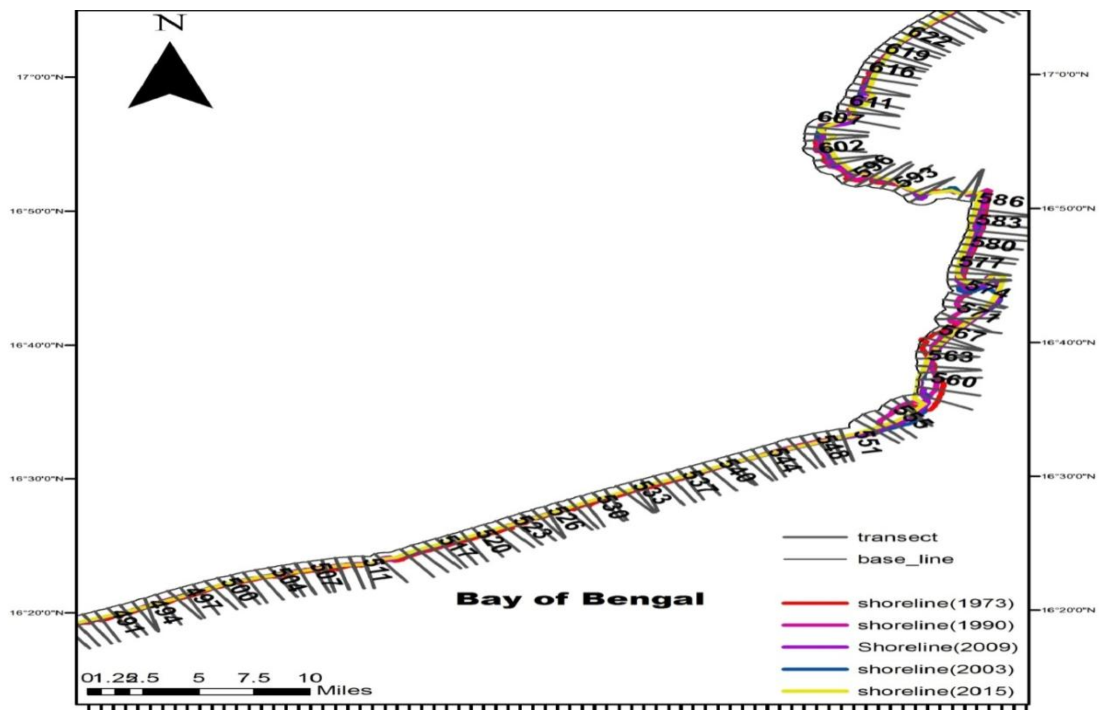

Fig. 2 — Places with the maximum changes along Andhra coast

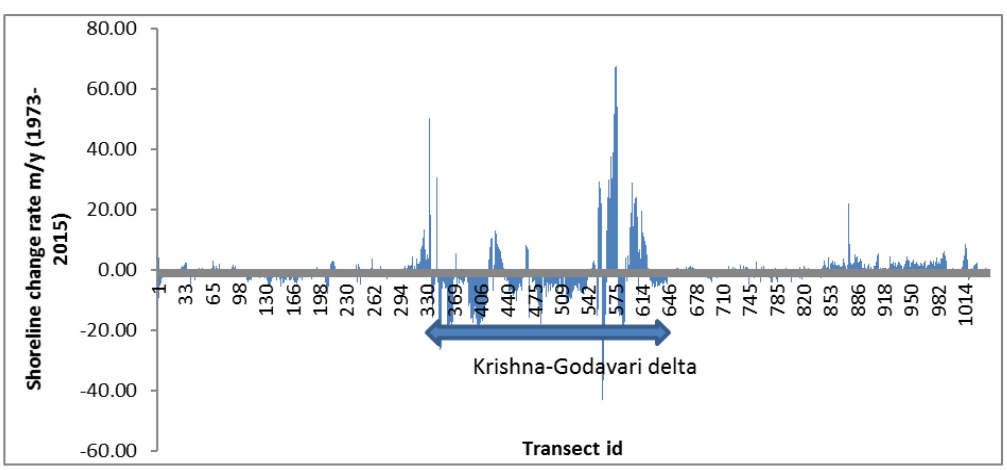

Fig. 3 — Shoreline behaviour along the Andhra coast

reported owing to wide-spread denudation observed in major parts of the Andhra Pradesh coast in recent decades[16]. The impact of the rising sea levels is due to anthropogenic induced climate change. The other parts of the Andhra Pradesh coast also demonstrate almost similar conditions. About one-half of the total length of 285.8 km in this sector is in the high-vulnerable category.

Apart from that, an average rate of shoreline in some different intervals, such as 1973-1990, 1990-2003 and 2003-2015 along the coast are negative, which shows that most of the shoreline experienced erosion in comparison to accretion and also indicate high shoreline movement in coming decades (Fig. 4). The result showed that erosion during 1990-2000 was 36.39 %, but it has been increased to 44.76 % in 2006-2012[21].

Validation of NSM model

Various statistical methods are available to estimate shoreline movement, but in this study, we used the EPR model for extrapolating the future shoreline position. To attain the accurate prediction, a model has been validated with the current positional scenario of the shoreline. Thus, we estimated the predicted shoreline for the period of 2015 using 1973, 1990 and 2003 shorelines and then the predicted shoreline movements have been validated with actual shoreline movements (Fig. 5).

The positional error has been then calculated with actual shoreline movement and the predicted shoreline. The positional error varies from -250 to 463 m (Fig. 6), however, the average error was observed 22 m (RMSC). The model prediction error is lower on the northern coast and higher in the southern

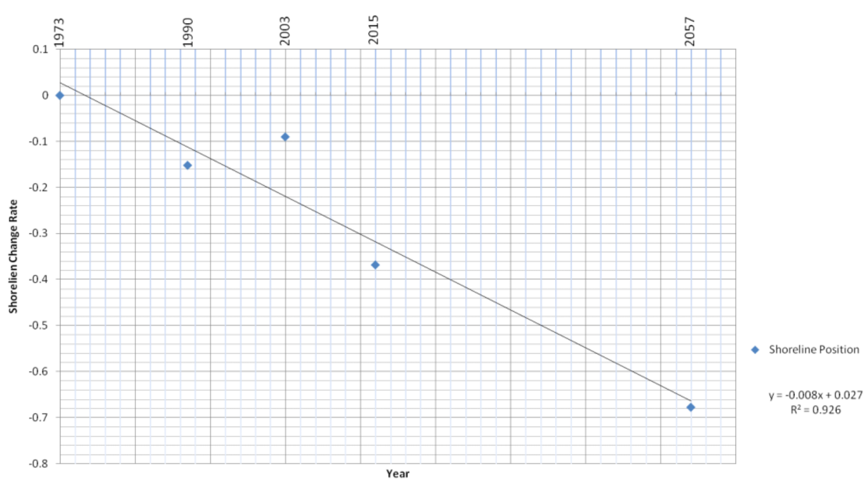

Fig. 4 — Average shoreline movement of the Andhra Pradesh coast

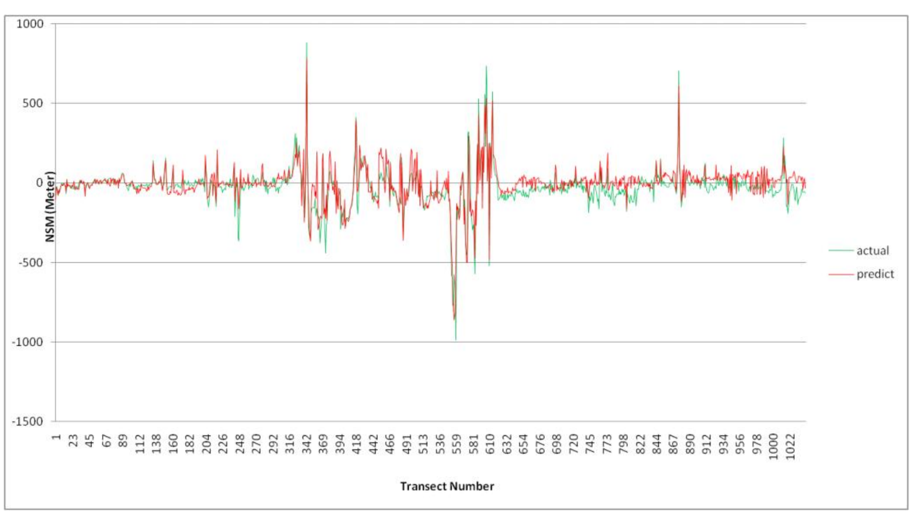

Fig. 5 — Actual and predicted shoreline movement in 2015 from the baseline along Andhra coast

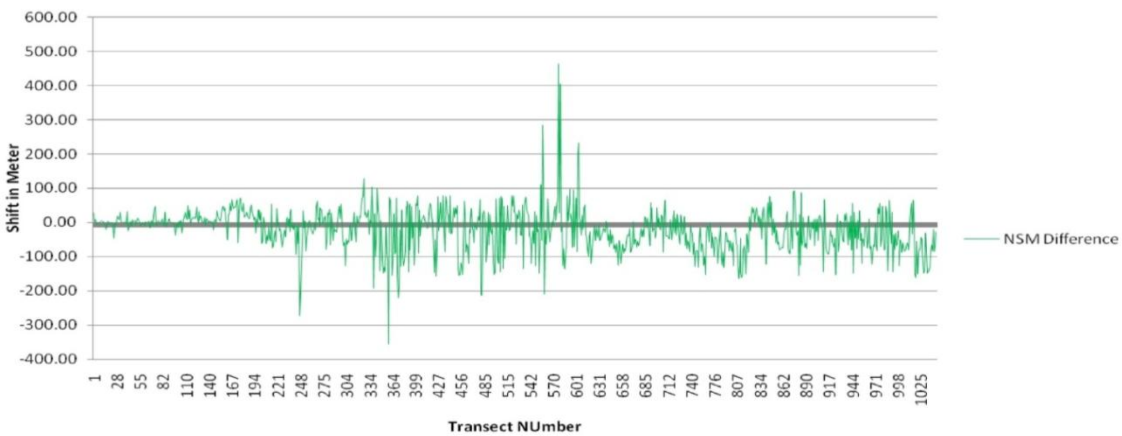

Fig. 6 — Positional shift in between actual and estimated shoreline of 2015

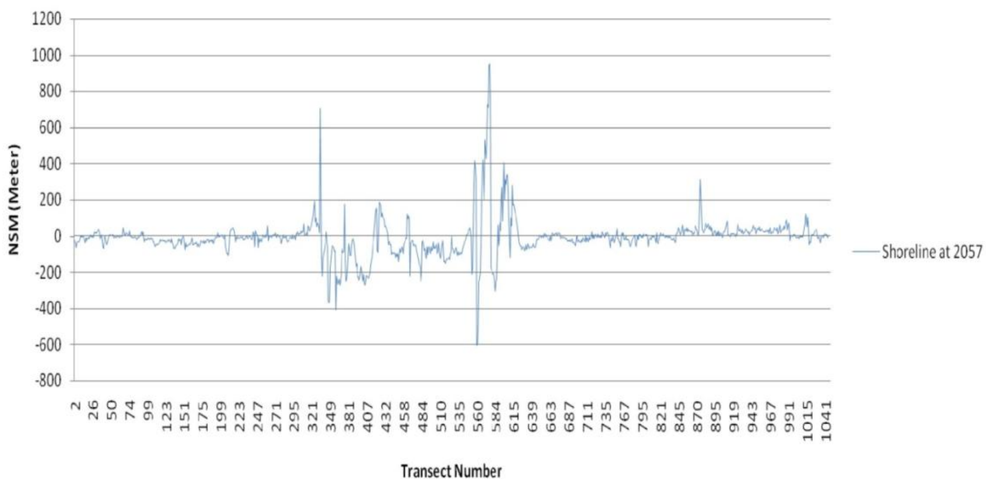

Fig. 7 — Predicted Shoreline movement from baseline in 2057

and central parts of the study area. It may be due to the nature of the coast. The central and southern part of the coast is deltaic and sandy in nature which is very sensitive to any changes.

Future shoreline prediction using EPR model and error adjustment

Using the EPR Model, the coastline position of the region has been extrapolated for the long-term period of 42 years (2057). In this prediction, the coastline alteration rate has been generated from the past shoreline movement using satellite imageries from 1973 to 2015. However, we excluded such events like tsunami, cyclone and associated storm surge impact of the coastline for the prediction. Figure 7 illustrates the net shoreline movement for the year 2057.

The result of this study demonstrates that the maximum erosion/accretion takes place in the Krishna-Godavari deltaic region. The earlier studies also observed that the various natural processes, i.e. sea level rise, and fluvial process24, frequently affect the area. The positional error adjustment has been applied in this study. The shifting of shoreline in x and y-direction (Latitudinal and Longitudinal) was measured by relating the actual and predicted shoreline of 2015. Then the estimated shifts were used to extrapolate the shoreline for 2057.

Conclusion

The findings of the present study revealed that geospatial techniques are very useful for analyzing and predicting shoreline dynamics. Long-term analysis (1973-2015) shows that maximum accretion was at Vishakhapatnam and Srikakulam coast, whereas eroding shorelines at the southern part of Krishna delta. The model for predicting future shoreline since 2057 also revealed the same result. It is because of deltaic and low-lying nature. Short-term analysis for the period of 1973-1990, 1990-2003 and 2003-2015 revealed that average EPR is negative for all duration except 2003-2015, which shows positive value. EPR model for the prediction of future shoreline (2057) stated that erosion would further increase during the predicted period. The results of this study will be useful for policymakers and coastal communities' livelihoods. It is suggested that the regular monitoring of the coastline is vital for proper planning and management of the coast.

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