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Estimation of long and short term shoreline changes along Andhra Pradesh coast using Remote Sensing and GIS techniques

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Abstract

Identifying shoreline changes and its variability is a fundamental task for various coastal studies undertaken by coastal scientists, engineers and coastal managers. ICMAM-PD has implemented a national project for monitoring the shoreline changes for entire Indian coast using satellite imageries to maintain a long-term database in GIS environment. In this paper an attempt has been made to implement a "shoreline proxy" for monitoring the shoreline changes along Andhra Pradesh coast for last 22 years (1990-2012). Multi-resolution satellite data such as Landsat TM, Landsat ETM+, IRS-P5 (Cartosat-1) and IRS-P6 (LISS-III & LISS-IV) were used to assess the short and long-term shoreline changes. The Standard Operating Protocols were followed for image rectification, shoreline extraction and the map accuracy as per NNRMS standard. The changes were classified as stable, erosion (low, medium and high) and accretion (low, medium and high). 974 km long Andhra coast was divided into 89 segments identical to Survey of India toposheets of 1:25000 scale. The analysis revealed that 275 km long shoreline was under erosion, 417 km has shown accretion and 153 km coastline is under stable condition. Region like Korakupalaiyam, Pallikuppam, Toppalappalaiyam, Virrasettitannippandal, Vatturupallipalem (above the Upputeru River), Ramulapatisangam, Binginipalle, Rayaduruvu, Peddaboyanapalem, Ullapalem, Uppada etc are identified as high erosion prone areas. However, the regions like Bangarapalem, Yerraipetta, Pedhatheenarla, Kothachodupallipetta, Konapapapetta, and northern Kakinada were seen with low to moderate erosion. Pattapupalem, Pallepalem, Kesavapalem, Gundamala regions were noticed with moderate accretion. Southern coast i.e. Nellore to Sriharikotta is mostly stable or accreting nature. Further in northern parts, Ichchapuram to Beemunipatanam coast does not depict any significant change as it is covered with sand dunes and sandy beach.

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1. Introduction

Shoreline is subjected to continuous change due to natural causes and human interventions in coastal zone. Identifying the areas vulnerable for erosion and quantifying its extent is essential for coastal zone management. Coastal erosion is a severe problem, particularly for a country facing explosive population growth along the coastal areas. Shorelines are always subjected to changes due to coastal processes, which are controlled by wave characteristics, sediment characteristics, beach form, etc. (Kumar *et. al.,* 2010). Studies examining long-term and short-term shoreline changes have generally utilized satellite data (Maiti and Bhattacharya, 2009; Ford, 2013); beach profile analysis (Thom and Hall, 1991; Dora *et al*., 2012) and aerial photographs (Anders and Byrnes, 1991; Jimenez *et al*., 1997; Kurosawa and Tanaka, 2001; Ford, 2013). Factors influencing coastline changes in an intermediate time scale are more complex and which includes both natural and anthropogenic causes. In most of the studies shorelines are manually digitized from satellite images and calculate the changes using GIS analysis (Chen and Rau 1998). The GIS and Remote sensing technology has been recognized as one of the most dominant tool for quantifying the shoreline changes on temporal scales as it provides the information in digital form (Nayak 2002; Zuzek *et al*., 2003; Thieler *et al*., 2009). Dolan *et al*. (1991) compared long-term and short-term erosion rates with various methods such as end point rate (EPR), linear regression (hereafter ordinary least squares, OLS), jackknifing (JK) and average of rates (AOR). The objective of this research work is to determine the baseline information of shoreline changes for entire Andhra Pradesh coast using remote sensing (Satellite) data in GIS environment for short and long term period. Monitoring and understanding of long-term, seasonal and short-term shoreline changes are necessary to develop a sustainable shoreline management plans.

2. Study area

The study area chosen in the present work is the coastal stretch of Andhra Pradesh (A.P.) state which is located in the east coast of India. Andhra Pradesh has second largest coast line in the country covers ~974 km long coastal stretch. The coast is known for diverse coastal geomorphic features like deltas, dune system, rocky cliff, red sediments, beach rock etc. The A.P. coast is known for cyclones prone which causes loss of agriculture, life etc. The study area was segmented in 89 grids of 1:25000 scale maps as shown in figure 1.

3. Materials and methods

3.1 Data used

The multi-resolution satellite data such as Landsat TM, Landsat ETM^+, IRS-P5 (Cartosat-1) and IRS-P6 (LISS-III & LISS-IV) of different periods were used as primary data to calculate the shoreline change for different years (table 1). Shoreline change rate was computed for short term and long term (22 years) using systematic and practical approaches with limited field observations.

3.2 Georefernacing

The satellite image was rectified with the use of Ground Control Points (GCPs) taken at permanent features such as road intersection, building corners, bridge corners, rail-road intersection etc. In each image an average of 20 GCPs were collected for a distance of 20 km from the coast to inland. For georeferencing the satellite image, ERDAS Imagine 2013 software was used. 2nd Order polynomial was employed with 8-10 GCPs (minimum of 6 GCPs required). GCPs were spread evenly over the coastal region of the image to give best coverage for calculating the transformation. For all the images RMSE was maintained within a pixel.

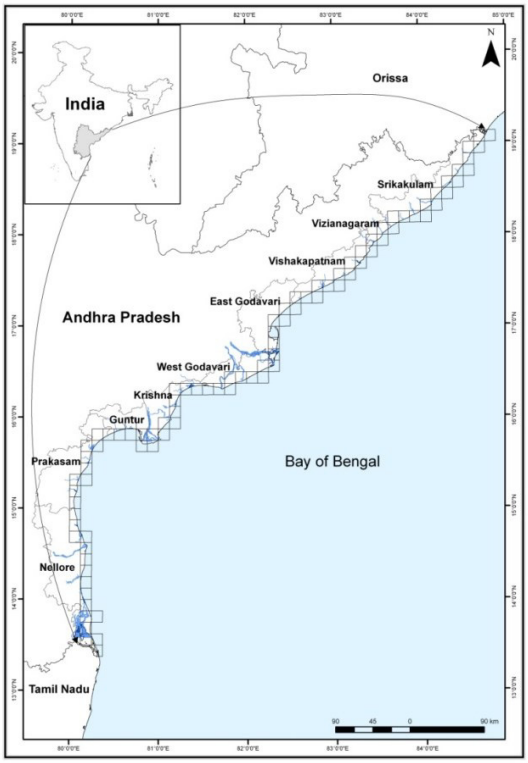

Figure 1: Study area overlaid with grids of 1:25,000 scale.

Table.1 Data sets used in the study

List of Image	Pixel Size(m)	Year	Source
Landsat- 5 TM	30	1989-1991	USGS
Landsat-7 ETM^{+}	30	2000	USGS
Cartosat-1	2.5	2005-06	NRSC
Resourcesat-1 LISS-III	23.5	2008	NRSC
Resourcesat- 2 / Catosat-1	5.8/2.5	2012	NRSC

3.3 Shoreline extraction

An idealized definition of shoreline is that it coincides with the physical interface of land and water (Dolan *et al*., 1980). Determination of a shoreline position in satellite data is very subjective one. In past, researchers had used various proxies for shoreline position such as high tide line (Fisher and Overton, 1994; Stockdon *et al*., 2002), high water line (Fenster and Dolan, 1999), wet-dry line (Overton *et al.,* 1999), vegetation line (Hoeke *et al.,* 2001), dune line (Stafford and Langfelder, 1971), toe or berm of the beach (Norcross *et al.,* 2002), cliff base or top (Moore *et al.,* 1998), mean high water (MHW) line (Galgano and Leatherman, 1991) etc. After considering all these factors, high water line (HWL) mark i.e. the effective shoreline is equivalent "wet/dry line" of previous tide which is clearly identifiable from all images is found most appropriate to monitor the changes (Kankara *et al*., 2014; Selvan *et al*., 2014). Manual digitization of shoreline is time consuming and accuracy is depending on interpreter knowledge and is very important that the interpreter should replicate the same results.

3.4 Shoreline change analysis

The shoreline positions were compiled in ArcGIS 10 with 5 attribute fields which includes; ObjectID (a unique number assigned to each transect), shape (poly line), shape length, ID, date (original survey year) and uncertainty values. All different shoreline features were merged as a single feature on the attribute table, which enabled the multiple coastline files to be appended together into a single shapefile. Digital Shoreline Analysis System (DSAS) version 4.0, (Thieler *et al*., 2009) an extension to ESRI ArcGIS developed by the USGS was used to calculate the shoreline change rate. A baseline was digitized onshore by closely digitizing the direction and shape of the outer shoreline to generate the cross shore transects for calculating the shoreline changes. Two different approach is adopted to compute the shoreline change i.e. end point rate for short term changes (1990-2000; 2000-2006; 2006-2012) and weighted linear regression for long term changes (1990-2012).

3.4.1 Short term analysis

The short term analysis considers data set of two time scale. The shoreline change rate was calculated by dividing the distance of shoreline movement by the time elapsed between the oldest and the most recent shoreline. End point rate (EPR) is a simple and popular approach adapted to calculate the shoreline change rates. Two shoreline dates is the minimal requirement for rate computation. Following equation is used for EPR calculation.

$$\text{EPR (m/y)} = \frac{\text{Distance(A−B) in m.}}{\text{Time between youngest and oldest shoreline}} \quad (1)$$

3.4.2 Long term changes

The long term shoreline changes are computed using multi dated shorelines. Here a linear regression rate-of-change statistic is determined by fitting a least-square regression line to all shoreline points for a particular transects. In addition to it, a weightage value is added in Weighted Linear Regression (WLR) method. This weightage is the uncertainties associated with each shoreline. The weight (w) is defined as a function of the variance in the uncertainty of the measurement (e) (Genz and others, 2007).

$$w = 1/(e)^2 \quad (2)$$

where, e = shoreline uncertainty value

3.5 Uncertainties and errors

Potential errors associated with coastal maps include errors in scale; datum changes; distortions from uneven shrinkage, stretching, and folds; different surveying standards; different publication standards; projection errors; and partial revision (Anders and Byrnes, 1991; Carr, 1962, 1980; Crowell, *et al*., 1991; Moore, 2000). Five different errors are identified for calculating the rate change. They may be of both positional and measurement related errors. Positional uncertainties are related to the features and phenomena that reduce the precision and accuracy of defining a shoreline position from a given data set such as; seasonal error E_s, tidal fluctuation E_{td} (tide range from nearest station). Measurement Uncertainties are related to the skill and approach such as**;** digitizing error E_d, rectification error E_r and pixel error E_p. Finally, total uncertainty value was estimated for each shoreline by accounting both positional and measurement uncertainties as:

$$Et = \pm\sqrt{E_s^2 + E_{td}^2 + E_d^2 + E_P^2 + E_r^2} \quad (3)$$

The Weighted Linear regression rate (WLR) is 2.6 m/yr for transect number 2967 and the 85 percent confidence interval (WCI85) is 0.78 (figure 2). The band of confidence around the reported rate-of-change is -2.6 +/- 0.78. In other words, it can be 85 percent confident that the true rate of change is between 3.38 to 1.82 m/yr. R^2 indicates regression coefficient.

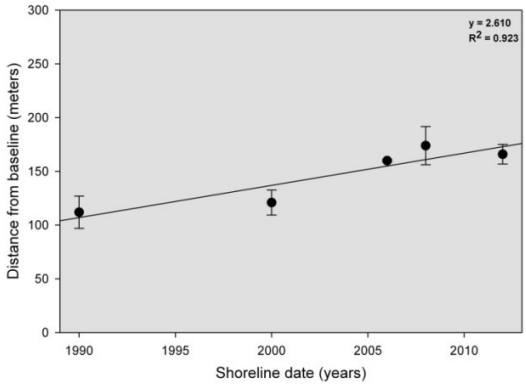

Figure 2: Shoreline positions along with positional uncertainty. The slope of the regression line is the rate.

4. Results and Discussion

4.1 Long term analysis

The overall shoreline changes calculated from the analysis are shown in figure 3. In A.P. coast 275 km coastline comes under eroding category, 417 km is accreting and 153 km coastline falls under stable category. As district wise result is concern East Godavari and Vishakhapatnam district shows high erosion (figure 4). More than 50% of shoreline in both districts exhibit high erosion. In East Godavari district high erosion was observed in the coastal stretch between Uppada and Kakinada (figure 5). From Kakinada to Machilipatnam, both erosion and accretion was observed in many places; however results are largely influenced by Godavari and Krishna river course. Regions like Bangarapalem, Yerraipetta, Pedhatheenarla, Kothachodupallipetta, Konapapapetta and northern Kakinada exhibit low to high erosion. In Vishakhapatnam district, major erosion prone area is Beemunipatnam. Even though the coastal stretch between Beemunipatnam and Vishakhapatnam consist of well developed dunes, some pockets in this stretch are showing erosion. In Nellore district, 53.64 km of shoreline shows erosion pattern and 83 km of shoreline comes under accretion. In Prakasam district, erosion is less (15 km) and the major part of coastline (62.66 km) exhibit accretion pattern. The entire coastal stretch (~32 km) of Guntur district falls under accretion category. In West Godavari district shoreline erosion and accretion are equally distributed (~7 km). Srikakulam is the only district shows maximum accretion in A.P. coast. Also 49 km of shoreline in Srikakulam district falls under stable category. 75% of the coast from Ichapuram to Kongavanipalem was observed with sand dunes, sandy beach and analysis reveals that the coast is in stable condition to accreting in nature.

4.2 Short term analysis

Short term analysis was carried using three different periods (1990-2000; 2000-2006 and 2006-2012). Shoreline changes during each period was estimated and presented district wise (Table 2). It may be seen that Nellore district had accreting pattern during 1990-2000 and 2000-2006. Whereas; after 2006 erosion was more than the accretion pattern. The causes of these changes needs to be further investigated with reference to episodic events, Vizianagaram, Guntur and West Godavari districts shows similar trend throughout the study period. During 1990-2000 periods, Visakhapatnam coast had accretion trend. But, after 2000 erosion has increased. There was no trend in shoreline changes along Krishna and East Godavari districts, where changes was mainly influenced by sediment supply from various rivers. Overall 50.12% and 51.75% of AP coast was accreting during 1990-2000 and2000-2006. But accretion was reduced to 10% during 2006-2012. Thereby erosion has increased by 10% during 2006-2012. During 1990-2000 periods erosion was 36.39%. But it has been increased by 10% to a rate of 44.76% in 2006-2012.

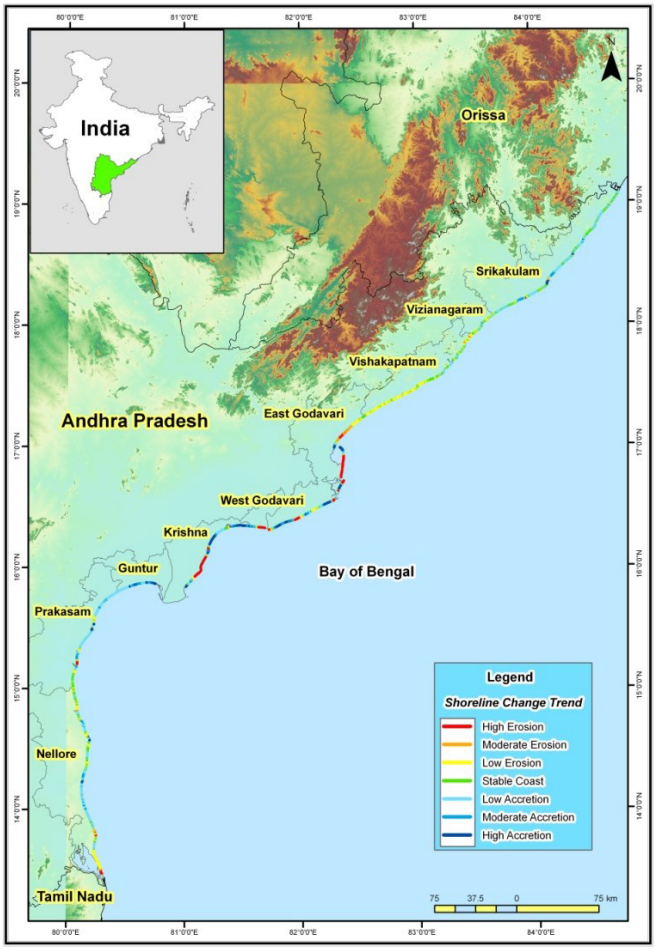

Figure 3: Shoreline change output of Andhra Pradesh coast overlaid on SRTM DEM.

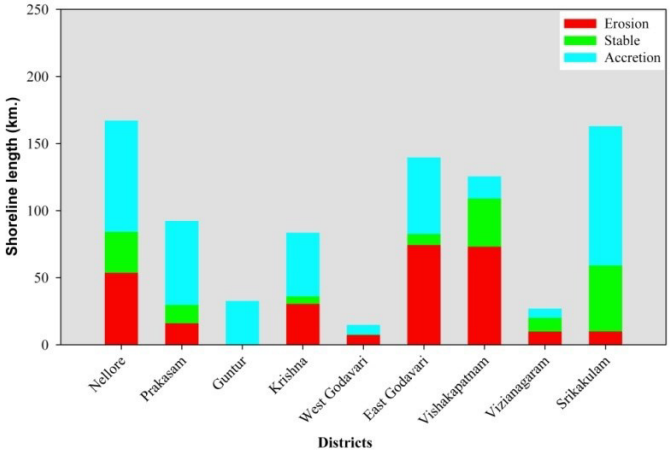

Figure 4: Erosion-Stable-accretion status of Andhra Pradesh coastal districts.

Figure 5.Coastal erosion in Uppada – Kakinada road. Damaged road due to erosion (A), collapsed seawall (B).

Table 2: The shoreline status (km) of Andhra Pradesh districts for different periods.

District	1990-2000			2000-2006			2006-2012		
	Accretion	Stable	Erosion	Accretion	Stable	Erosion	Accretion	Stable	Erosion
Nellore	93.08	20.42	53.6	102.9	10.02	54.18	43.5	15.04	108.56
Prakasam	38.58	17.58	35.58	72.1	4.76	14.88	38.92	20.14	32.66
Guntur	29.54	2.44	1.24	29.66	1.74	1.82	22.86	6.86	3.52
Krishna	24.82	4.34	55.38	52.08	1.44	30.76	36.84	6.56	41.14
West Godavari	2.04	0.28	11.48	11.88	0.84	1.34	7.58	1.32	4.9
East Godavari	75.86	5.86	57.92	31.3	5.46	102.88	54.22	7.84	77.58
Visakhapatnam	94.1	17.64	13.8	16.54	6.02	102.98	33.34	28.1	64.1
Vizianagaram	16.74	4.6	5.62	7.16	2.84	16.96	12.14	4.02	10.8
Srikakulam	48.98	40.86	73.08	113.9	19.4	29.62	101.72	26.06	35.14
Total	423.74	114.02	307.7	437.52	52.52	355.42	351.12	115.94	378.4

5. Conclusion

Five dataset were used in this study to carry out the long term and short term shoreline change analysis for Andhra Pradesh (AP) coast. The AP coastline has various type of shoreline features viz, rocky, sandy, mudflats, riprap, sand dunes, deltas, estuaries etc. The landward wet-dry line is found most suitable morphological signature for analyzing systematic shoreline change using multi-dated and multi resolution remote sensing datasets. Long term analysis was carried out for past 22 years from 1990-2012. Andhra Pradesh has 974 km coastline, out of which 128.54 km coast is covered by rip-rap structures, river, deltas, creek etc. The remaining 845.46 km coastline has been analyzed for long and short-term shoreline change analysis. The results show that 275 km coastline comes under eroding category, ~417 km are accreting and 153 km coastline falls under stable category. Based on the shoreline change rate the entire coast is classified into seven categories such as high erosion, medium erosion, low erosion, stable, high accretion, medium accretion and low accretion). The short term analysis carried out for three periods i.e. 1990 to 2000 and 2000 to 2006 and 2006 to 2012 revealed that 50.12%, 51.75% and 41.53 % of coast had accreting nature. While 36.39%, 42% and 44.76% shoreline experienced erosion. The coast is always under threat of cyclones which may be a major controlling factor for short term changes. Causes of shoreline change are due to both artificial structures and natural processes acting together. However, it is necessary that one has to understand each factor separately to assess their impacts on the coast. Even though the artificial structures are constructed for development or protection purposes but, continuous monitoring is necessary to study their impacts. Weighted Liner regression method is found better approach to understand the shoreline changes as it considers the uncertainties/ errors associated with each shoreline positions with reference to quality of the data.

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