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Shoreline change: a study along South Odisha coast using statistical and geospatial technique

Kar P.K.[1]* Mohanty P.K.[1], Barik S.K.[1], Behera B.[1], Pradhan U.K.[2], Patra S.K.[3], Mishra P.[2], Panda U.S.[2] and Bramha S.[4]
[1]Department of Marine Sciences, Berhampur University-760007, India
[2]Integrated Coastal and Marine Area Management (ICMAM), Project Directorate, Chennai-600100, India
[3]National Institute of Ocean Technology, Chennai-600100, India
[4]Indira Gandhi Center for Atomic Research (IGCAR), Kalpakam, Tamilnadu, India
prabin.kar@gmail.com

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Abstract

South Odisha coast is bestowed with sandy beaches and a series of sand dunes. Keeping in view the development activities such as construction of an all weather port (Gopalpur port Limited) and extraction of beach sand by Indian Rare Earths Limited, a long term monitoring of the shoreline was conducted along 13km stretch including the Gopalpur tourist beach and Gopalpur port area. The monitoring programme involves shoreline mapping through Differential Global Positioning System (DGPS) Arc Pad in the pre-construction (2008-2010) and post-construction (2012-2014) phases of Gopalpur port. The construction at Gopalpur port includes two breakwaters and development of berth on the south and groin field (a series of 11 groins) on the north. Impact of these coastal structures on shoreline are studied and compared with the shoreline in the pre-construction phase. Shoreline change analysis involves geospatial technique (Arc View GIS 3.2a software) and statistical technique involving Digital Shoreline Analysis System (DSAS), an extension tool of Arc GIS software. Polylines are extracted and processed using geospatial technique and the statistics such as Net Shoreline Movement (NSM), Shoreline Change Envelope (SCE), End Point Rate (EPR) and Linear Regression Rate (LRR) are computed. The results indicate high erosion and accretion zones besides the rate of change of shoreline in different stretches of the observed shoreline. The results of the present study have implications on the ongoing integrated coastal zone management programme funded by the World Bank.

Keywords: Shoreline change, Geospatial technique, Erosion/accretion, Coastal structure, Gopalpur coast.

Introduction

The shoreline changes its shape and position naturally at different time scale such as decadal, annual and daily basis due to the dynamic interaction between the sea and the shore. The factors contributing to the diverse environmental changes along the Odisha coast are many and some of them are not explored or understood yet[1]. However, shoreline position is one of the most commonly monitored indicators of environmental change[2] and is an easily understood feature representing the historical movement of shoreline. The natural oceanographic and geomorphologic processes interact with each other and results in complex erosion and accretion environment and exhibit variable patterns and beach state[3]. The impacts of hard structures also make shorelines erode, accrete or remain stable, depending on the rates at which sediment is supplied to and removed from the shore[4]. The shorelines are often derived from various sources such as historical maps, aerial photographs and field GPS surveys[5]. At Gopalpur Port, southern (530m) and northern (362m) groins (SG and NG) were constructed during 2007-2009 along both sides of the previously existing piers. Other developments include intermediate (360m) and southern (1735m) breakwaters on the south and groin field (ten groins of different dimension) on the north during 2011-2012[6]. The present study includes the DGPS field survey on a monthly basis to depict the impact of coastal structures on shoreline change from June, 2008 to June, 2010 (pre-construction phase) and June, 2012 to June, 2014 (post-construction phase).

Several studies have been made to study the impact of coastal structures on shoreline change in different geographic and physiographic environment[4,7,8]. In the present study, different statistical features such as Net Shoreline Movement (NSM), Shoreline Change Envelope (SCE), End Point Rate (EPR) and Linear Regression Rate (LRR) are computed for four years shoreline data to understand geomorphological changes along three provinces such as Gopalpur port south (GPL South), port north (GPL North) and Gopalpur tourist beach (GPL Beach), a total of 13km stretch. Besides, long term shoreline changes are presented to identify the erosion prone zones and to address the risk zone for preventing erosion through coastal protection.

Study area: Gopalpur coastal environment encompasses world famous Olive Ridley nesting rookery adjacent to river Rushikulya on the extreme north of port, ongoing all weather Gopalpur port in the middle and the tourist beach of Gopalpur on the south covering an approximate distance of 23km along southern part of Odisha coast, east coast of India (long 84°91’-

85°13’E and lat 19°24’ - 19°44’N) (Figure-1). The coast is prone to natural disasters arising from tropical cyclone, flooding, surges, coastal inundation and to some extent a low risk of tsunami run up at low land areas. Till now, the coastal environment is described as pristine and the biodiversity is mostly governed by the natural processes. However, keeping in view the future and ongoing development activities (e.g. all weather port at Gopalpur and sand mining by Indian Rare Earths Ltd.), it is essential to understand, assess and investigate the shoreline change and the associated processes in a holistic way. The present study addresses some of the issues relevant to both short term and long term shoreline changes through field data collection. The study is mostly focused on the southern and northern sectors of Gopalpur port and Gopalpur tourist beach located south of the port (Figure-1).

Materials and methods

Present study uses geospatial technique coupled with DGPS survey integrated in a Geographical Information System (GIS) environment to generate shoreline information both spatial and temporal scales. This technology is becoming the common method to calculate the shoreline information due to its advance nature of GIS[9]. Shoreline mapping is carried out every month from June, 2008 to June, 2010 and from June 2012 to June, 2014 using DGPS Arc Pad. The spatio-temporal changes in the berm position and the associated area changes are analysed in a GIS environment using ArcView GIS software (Version 3.2a). It may be mentioned that the first berm, as one move from foreshore to backshore, is monitored each month in order to know the oscillation of the shoreline. The DGPS Arc Pad device is based on the GPS system and receives data with high accuracy. Shoreline change analysis is made between a fixed reference line drawn using DSAS software, an extension tool of Arc GIS at the backshore and the position of the berm line monitored every month over the three target areas; port south, port north and tourist beach at Gopalpur with 5 attribute fields i.e. Object ID (a unique number assigned to each transect), shape, shape length, ID, date (original survey year) and uncertainty values for further analysis. All different shoreline features are then merged within a single line on the attribute table, which enabled the multiple coastline files to be appended together into a single shape file for further analysis. The statistical approach to shoreline change analysis is followed in the present study and statistical features such as Net Shoreline Movement (NSM), Shoreline Change Envelope (SCE), End Point Rate (EPR) and Linear Regression Rate (LRR) are computed following the methods discussed below:

NSM represents the distance between the oldest and latest shoreline from the reference line. SCE represents the distance between the farthest and closest shorelines to the reference line for each transect while there is no relation with time period. EPR is computed by dividing the distance of shoreline movement by the time elapsed between the earliest and the most recent shoreline. If more than two transects are available, the information is neglected and subsequently changes in magnitude of the shoreline movement trend may be missed[10]. LRR is the slope of a line determined by fitting a least-squares regression line to all shoreline points for particular transects. The advantages of linear regression include the following: i. all the data are used, regardless of changes in trend or accuracy ii. the method is purely computational iii. it is based on accepted statistical concepts and iv. it is easy to employ[11].

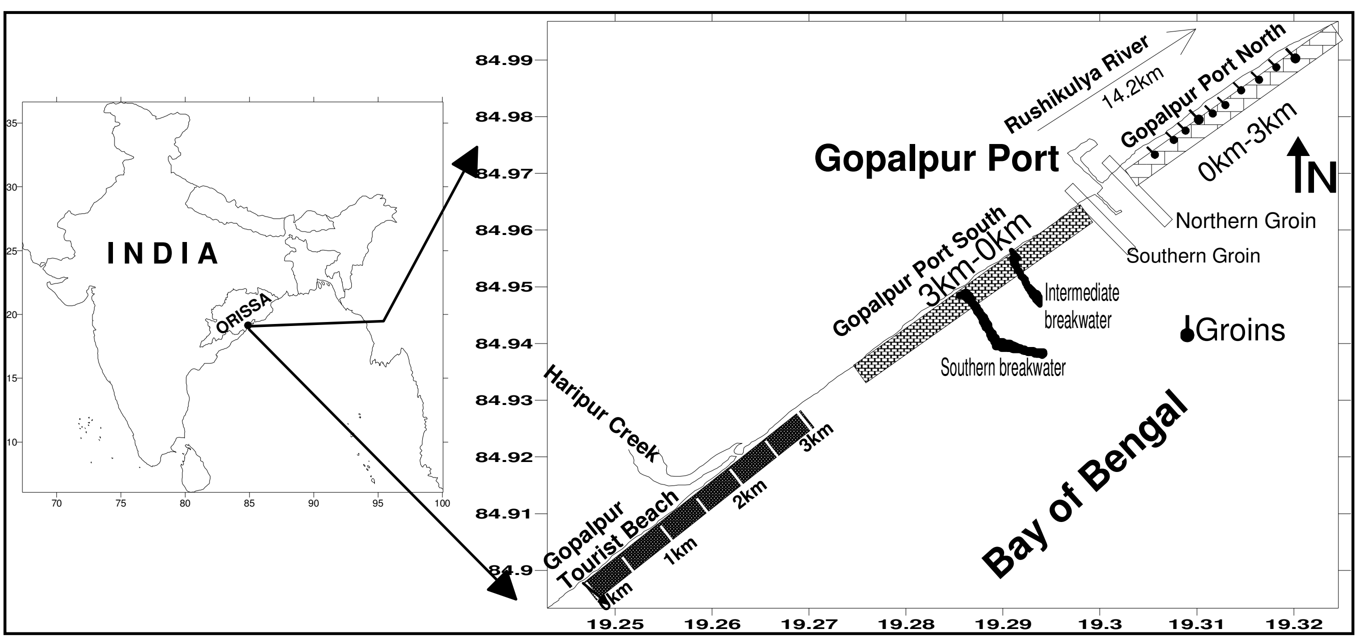

Figure-1: Map showing the study area and station locations.

Results and discussion

The results are presented for three sectors; namely Gopalpur tourist beach (GPL Beach), Gopalpur port south (GPL South) and Gopalpur port north (GPL North) of south Odisha coast, east coast of India. Shoreline change and their statistical features are discussed in the following section.

Shoreline position: The position of the berm at the high-water line and its landward/seaward shifting with respect to time and space represent the shoreline position. Figure-2 depicts the shoreline position and its variation with time on the north and south of the port. Shoreline position of the three targeted beaches is depicted in Figure-3. The information has been generated for every 500m distance covering at least 3 km of the beach in each sector. Series of groins and breakwaters established at port south and north and their impact on shoreline change is discussed.

At GPL Beach (Figure-3), it is observed that the width of shoreline is maximum at 0 km (light house) and then it gradually narrows down towards north during pre and post-construction phases. The width of shoreline is minimum at 2.5 and 3.0 km from light house and it could be due to the impact of Haripur creek (Figure-1), which is situated after 1.5 km to the north of light house. The width of shoreline during post-construction phase is relatively more than that during pre-construction phase. The tourist beach (between 0-1km) is relatively stable and shows minimum oscillation with time. Shoreline between 1.5km and 2km shows maximum oscillation and it could be due to Haripur creek. Maximum width of the shoreline is observed at 0km during December, 2009 followed by February, 2009 in pre-construction phase while in the post-construction period, maximum width is observed during February, 2013. The beach at other transects of this sector remains more or less stable with minimum seasonal variation.

At GPL South (Figure-3), the seaward shifting of the shoreline (deposition) is maximum at 0 km followed by 0.5km, which are to the south of SG in the pre-construction period. There is a distinct landward movement during June 2009 and afterwards, the shoreline shows both landward and seaward movements. As the longshore transport along the coast is from south to north round the year[4], intervention along the shore front in the form of groin helps to trap the sediment along south side leading to deposition while the north side is sediment starved and suffers from erosion. The width of shoreline mostly enhanced during post-construction phase. However, the reduction in width during October, 2013 could be due to the impacts of severe cyclonic storm Phailin which had landfall near Gopalpur on 12th October, 2013. Beach width at 0km and 0.5km show maximum fluctuation with time, while at other positions (1 to 3km) the change is minimum in the pre-construction phase. During post-construction phase, oscillation of the shoreline is maximum at 1.5km, which is between the two breakwaters and the area used for development of berth facilities. Maximum width of shoreline is observed during April, 2010 for pre-construction phase and during June 2012 for post-construction phase.

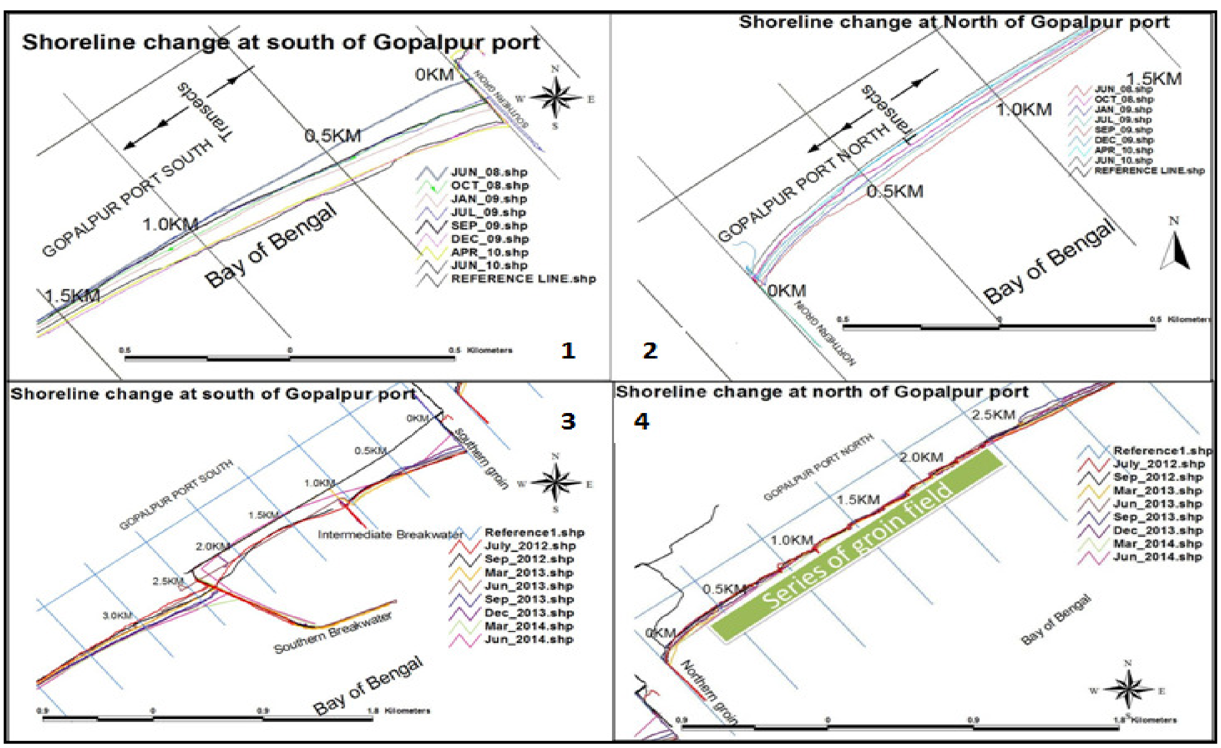

Figure-2: Shoreline change at south and north of Gopalpur port during pre (1, 2) and post (3, 4) construction period.

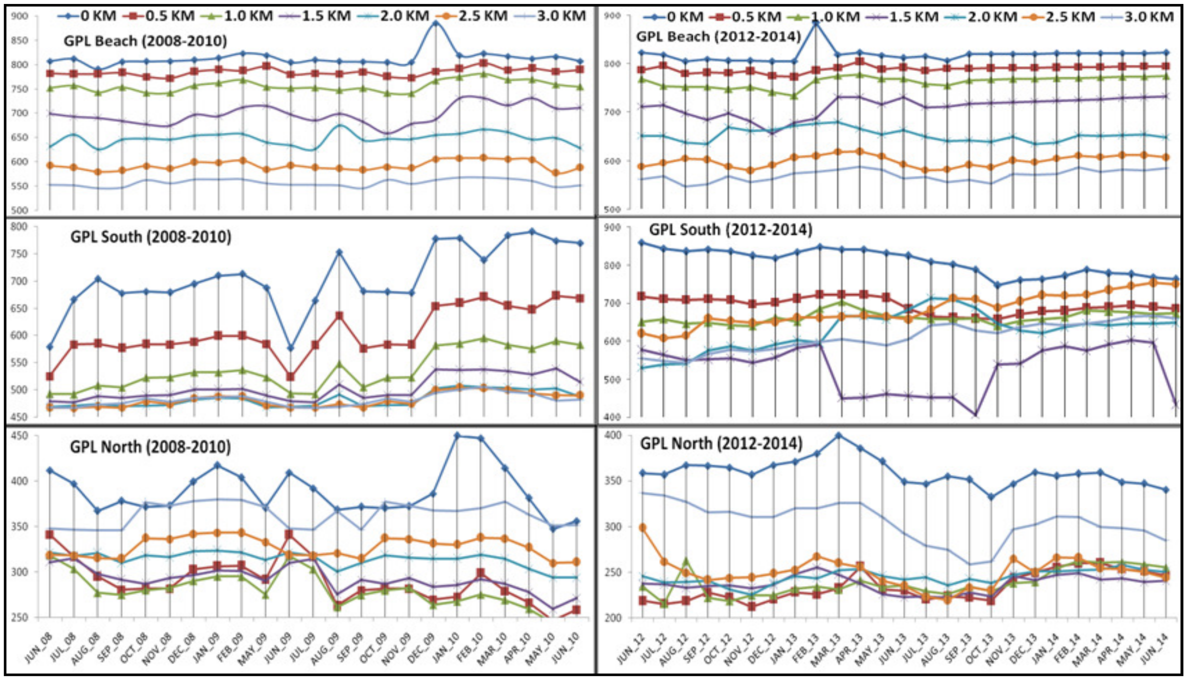

Figure-3: Shoreline positions at different sectors of Gopalpur coast during 2008-10 and 2012-14.

At GPL North, the width of the beach is maximum at 0km and minimum at 1km from NG in the pre-construction phase while it is maximum at 0km and minimum at 0.5km in the post-construction phase. Shoreline at 0km shows maximum oscillation with time followed by the shoreline between 0.5 and 1.5km from NG. However, minimum oscillation of shoreline with time is observed between 2.0 and 3.0km from NG. Maximum oscillation of shoreline between 0-1.5km, could be attributed to the absence of groin and beach nourishment activities in the pre-construction phase. However, in the post-construction phase, maximum oscillation is observed at 0km and 3km, which are respectively due to beach nourishment activities and position beyond the groin field. In contrast to the shoreline oscillation trend at GPL South, width of the north beach shows distinctly peak values during January and February, 2010. However, during March, 2013, highest peak is seen in the post-construction phase. Beach width gain during December, 2009 to May, 2010 at 0km is note worthy and could be due to the beach nourishment by the dredged sand. At the north side of the port, the shoreline shows reduction of width with time and hence an erosional trend.

Statistical features of shoreline change: Statistical evaluation of shoreline change such as SCE, NSM, EPR and LRR or Rate of change is discussed in this section. Fenster et al.[12] used EPR and Dolan et al.[13] used LRR to understand the rate of shoreline change dynamics. The statistical approach to shoreline change study minimizes the potential errors and short term variability and hence is a preferred method[14]. Saxena et al.[15] used statistical approach to evaluate the shoreline change and arrived at satisfactory results. Hence in the present study, the statistical approach is followed to understand the shoreline change both in the absence and presence of coastal structures along south Odisha coast, east coast of India.

Shoreline Change Envelope (SCE): Figure-4 depicts SCE at different transects for the three sectors of Gopalpur coast during 2008-2010 and 2012-2014. SCE represents the total change in shoreline movement for all available shoreline positions. During 2008-2010, for port south and north, SCE gradually decreases from 0 to 3km. However, for GPL Beach, SCE has two peaks, primary at 0km and secondary at 1.5km. The exception at GPL Beach could be due to the presence of Haripur creek to the north of 1.5 km transect. It is evident that the shoreline change envelope is maximum at GPL South followed by at GPL North and minimum at GPL Beach. For GPL South and GPL North, shoreline change envelope is maximum near the SG and NG while it reduces as one move further south and north respectively. However, after the construction of coastal structures, SCE mostly enhanced at south and north of Gopalpur port beyond 1.5km to the south and north respectively. At GPL Beach, although trend of SCE remained same for pre and post-construction phases, there is reduction in magnitude during post-construction phase compared to pre-construction phase.

Net Shoreline Movement (NSM): Figure-5 depicts NSM during pre and post-construction phase. During pre-construction phase, NSM is positive at GPL south and GPL Beach while it is negative at GPL North. At GPL South, from a maximum value at 0km, NSM gradually decreased to 3.0km while at GPL North, negative NSM at 0km tend to become zero or positive at 3km. During post-construction phase, change in NSM is quite significant at GPL South and North while at GPL Beach NSM is more or less same as in pre-construction phase. The variation of

NSM at GPL South between 0-2km during post-construction phase could be due to the position of the two breakwaters and the area in between being developed for berth facilities. On the other hand, beyond 2.5km NSM is positive and the values are higher compared to pre-construction phase. Similarly, the positive NSM between 0-2km at GPL North could be due to the construction of groin field while the negative NSM beyond 2.5km is due to the erosion north of groin field.

End Point Rate (EPR): Dynamics of shoreline change occurs due to intermittent/continuous erosion and deposition forced by both natural and manmade activities. Figure-6 depicts the EPR (my^{-1}) at different transects for the three sectors of Gopalpur during pre and post coastal construction period. Positive EPR values indicate deposition while negative EPR values indicate erosion. For GPL South and North, the trend of EPR is same as NSM. EPR is positive for GPL South while it is negative for GPL North. GPL Beach shows positive EPR from 0-1.5km, which then becomes negative up to 3km. During pre-construction phase, maximum positive EPR is observed at 0km for GPL South and at 1.5km for GPL Beach while maximum negative EPR is observed at 0.5km for GPL North. In the post-construction phase, maximum positive EPR is at 2.5km for GPL South, at 0.5km for GPL North and at 3km for GPL Beach. Thus, the groin field and breakwaters have significant impacts on shoreline which is apparent form the EPR and NSM.

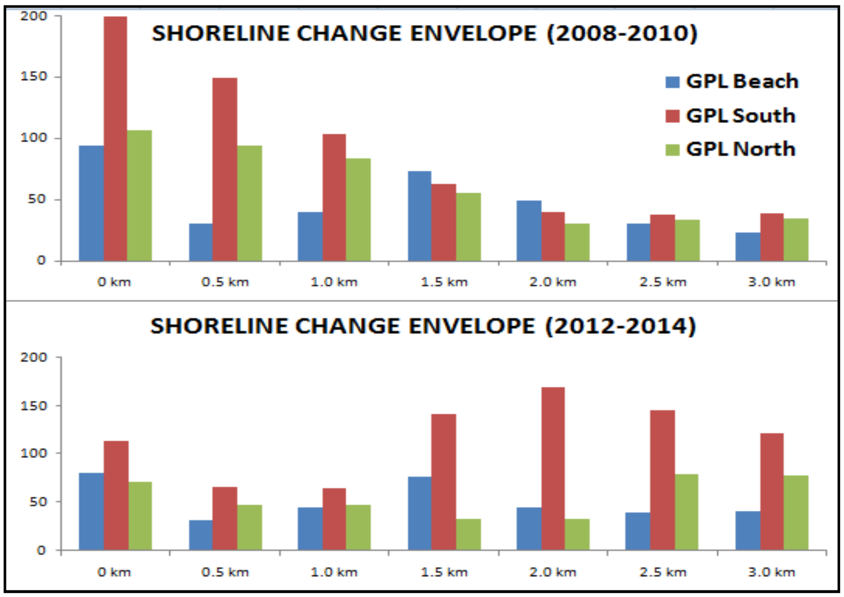

Figure-4: Shoreline Change Envelope (m) at different sectors of Gopalpur coast.

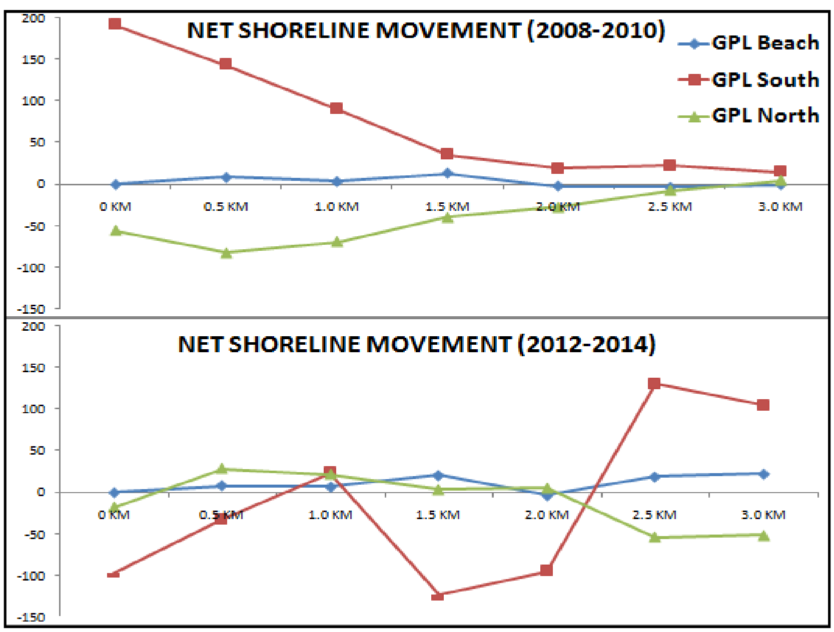

Figure-5: Net shoreline movement (m) at Gopalpur coast during pre-construction and post-construction phase.

Linear Regression Rate (LRR): Linear Regression Rate of shoreline change has been characterized at every transect starting from 0 to 3.0km and are categorized year wise to demarcate the erosion and deposition zones along the three sectors of study. Figure-7 depicts the LRR for the three sectors. As evident from Figure-7, GPL Beach experienced positive rate of shoreline change during 2008-10. Considering the 3km stretch of the beach under study, the beach at 1.5km, located south of the Haripur creek, experienced maximum deposition ($1.30my^{-1}$) during the period. For the period 2012-2014, the rate of shoreline change is mostly positive except at 2.0km, near Haripur creek. In contrast to the observation of coastal protection development advisory committee of Government of India, which identified Gopalpur coast as an eroding coast, the present study indicates that the beach is stable with moderate depositional environment.

Figure-7 depicts the shoreline change rate in the pre (2008-2010) and post (2012-2014) construction phases. During pre-construction phase, both GPL Beach and GPL south experienced positive LRR while GPL North experienced mostly negative LRR. LRR is more at GPL South compared to other two sectors. During post-construction phase, both positive and negative LRR are experienced in all the three sectors, which is an indication of the distinct impact of coastal structures associated with port development on shoreline change. At GPL South, distinct peaks of deposition having highest rate is at 0km gradually reduces towards 3km during pre-construction period while during post-construction period, LRR is initially negative up to 0.5km and later becomes positive. At GPL North, the shoreline change rate is mostly negative (0.1 to 2.2m/yr) in the pre-construction phase while it is reduced (0.4-1.7m/yr) in the post-construction phase. It is also observed that during post-construction phase, shoreline change rate is positive inside the groin field (0-2km), while beyond the groin field, it is negative.

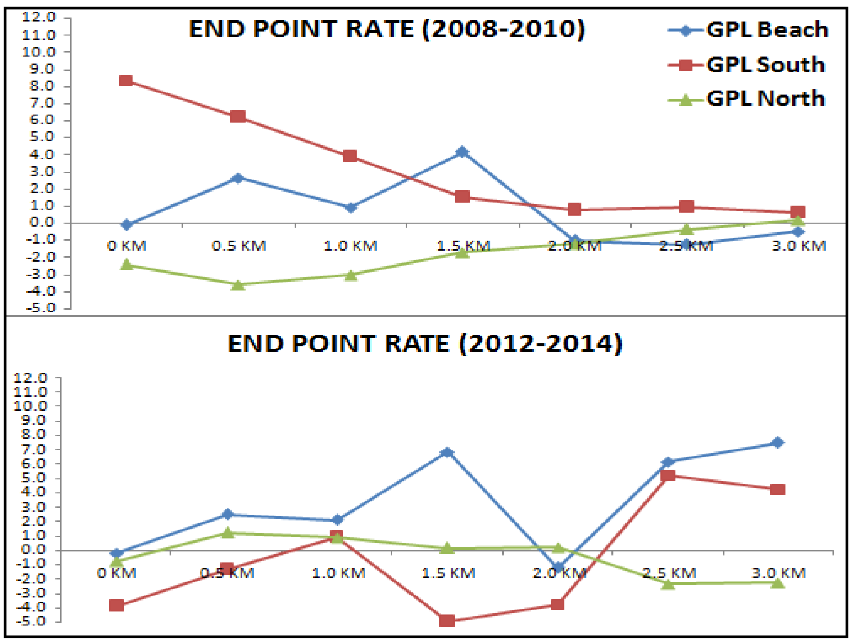

Figure-6: End Point Rate (my^{-1}) Gopalpur coast during pre and post-construction periods.

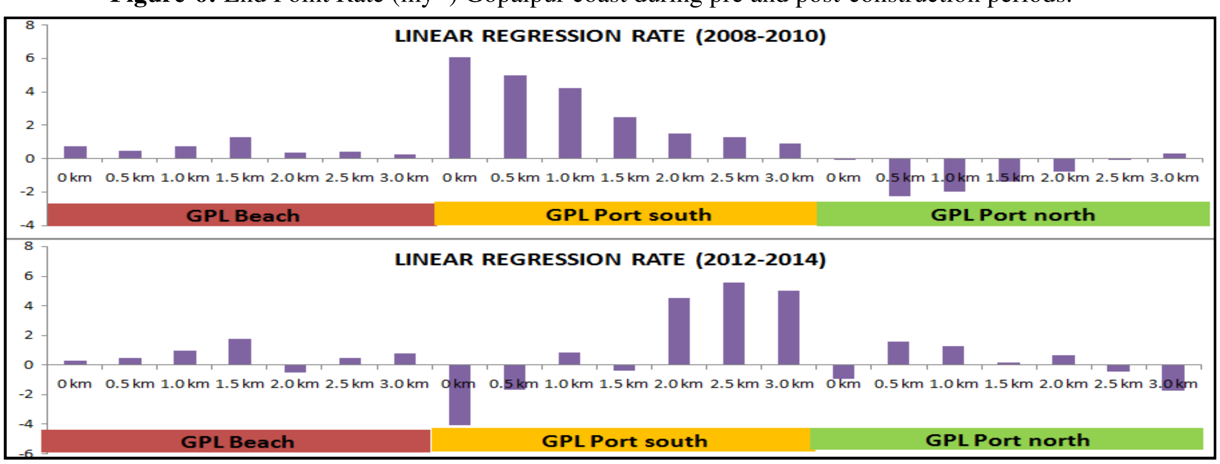

Figure-7: Linear Regression Rate (my^{-1}) along Gopalpur during 2008-10 and 2012-14.

Conclusion

The integrated approach using DGPS and GIS tools to monitor the shoreline change over a stretch of 13 km along Gopalpur coast targeting three sectors; viz: Gopalpur tourist beach, port south and port north during pre (2008-2010) and post (2012-2014) construction phases provides comprehensive shoreline change information both in qualitative and quantitative terms. The study clearly demonstrates the impacts of shore perpendicular structure (Groin) and breakwaters on shoreline change as the longshore transport round the year is from south to north along Odisha coast. DGPS observation and the statistical features of shoreline change; NSM, SCE, EPR and LRR, indicate shoreline change specific to different sectors during pre and post-construction phases. The results distinctly indicate that Gopalpur tourist beach is stable with minor depositional environment. Significant depositional environment of port south beach in the pre-construction phase has changed to both erosional (0-2km) and depositional (2-3km) environment in the post-construction phase. Erosional environment along 0-2km is attributed to the development of berth between the two breakwaters. The distinctly erosional environment of port north in the pre-construction phase has changed to depositional environment (0-2km) and erosional environment (2.5-3km). Depositional environment along 0-2km on the port north is due to groin field and beach nourishment activities. The results clearly suggest that the analysis and representation of shoreline change using statistical approach (SCE, NSM, EPR and LRR) and geospatial techniques provide both qualitative and quantitative information on spatio-temporal scales and hence can be easily assimilated into the ongoing integrated coastal zone management programme of Odisha coast.

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