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Shoreline Change Near Gopalpur Port, East Coast of India

SHORELINE CHANGE NEAR GOPALPUR PORT, EAST COAST OF INDIA

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***Abstract**: Gopalpur Port Limited (GPL) is being developed as an all weather open sea port from a fair weather port which existed since 1987. The port is located in the south Orissa coast (19˚ 18'13" N, 84˚ 57' 52" E), East Coast of India. At present, two groins, 450m in length, have been constructed on the north and south of the jetty which existed earlier. The present study investigates the impact of the coastal structure on shoreline by observing beach profile, shoreline changes (berm position), Littoral Environmental Observations and sediment characteristics every month during May 2008 to April 2009. The results indicate severe erosion to the north of the northern groin and deposition on the south of the southern groin. The intensity of erosion/deposition continues till 1.5 km further north/south but with gradual reduction in intensity. Volume estimate, beach width and beach area estimates indicate very fast rate of change of shoreline with significant erosion/deposition immediately to the north/south of the groins. The mean grain size of the beach on the south of the port having depositional environment are mostly fine and medium in the foreshore while it is mostly medium and fine on the north side of the port having predominantly erosional environment. The preliminary results of the present study, if integrated with long period observations, would be of immense benefit to the planning and design of coastal structures of the port as well as to adapt appropriate mitigation measures to check erosion and modification of the shoreline in future.*

Keywords: *shoreline; groin; erosion; deposition; sediment characteristics, beach profile*

INTRODUCTION

Shoreline is one of the landforms of the earth having wide spatial and temporal variability. The geomorphic processes of erosion and accretion, periodic storms, flooding and sea level changes, action of waves, tides and the littoral transport continuously modify the shoreline (Wright and Short, 1984). 70% of the beaches in the world are considered as eroding beaches (Bird, 1985). However, the factors and processes involved in the erosion processes are still not properly known. Construction of groins, jetty, breakwaters, harbour and the associated changes in the coastline and coastal processes are brought out by Bakker (1968) and Komar et al. (1976). The

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effects of groin parameters on the shoreline change have been studied using both physical and numerical models (Ozolcer et al, 2006; Ozolcer and Komurcu, 2007). Construction of hard structures along the coast either for development of ports and harbours, or for protecting the coast from erosion, significantly modifies the shoreline and the erosion/accretion trend. Besides the impacts of these hard structures, shorelines also erode, accrete, or remain stable, depending on the rates at which sediment is supplied to and removed from the shore. Cross shore sediment transport affect the beach profile significantly (Turker and Kabdasli, 2007). Beach profile perpendicular to the shoreline has characteristic features that reflect the action of littoral processes. Mean grain size of the beach, to a large extent, depends on three major factors; nature of the source sediment, wave energy level and general offshore slope (Komar, 1976). The mean grain size of sediment at any given location and time also indicates the erosional/depositional environment prevailing in the area and reflects on the beach stability. Deposition is marked by decrease in mean size while erosion increases the mean size (Chouhan et al., 1988). For coastal engineering projects like ports and harbours, sediment properties have important implications. Sediment properties have impacts on dredging, types of dredges used, in beach fill, in scour protection and in sediment transport.

Except for Paradip, information on beach profile, shoreline change, erosion/accretion status and sedimentological characteristics of other regions of the Orissa coast are fragmentary (Rao and Pattnaik, 1986; Chauhan et al., 1988; Mishra, 1992; Sundar and Sharma, 1992; Chandramohan et al., 1993; Mishra et al., 2001; Pattanaik., 2004 and Rajawat et al., 2008). Neither long-term nor short- term recent information on shoreline change, coastal erosion and sediment grain size are available for Gopalpur coast, an area demarcated as special economic zone with the development of an all weather port and other industries with international collaboration. Mishra et al., (2001) based on their field investigation during 1990-91, when the fair weather Gopalpur port was operational, concluded that beaches at Gopalpur are mostly accretional, with intermittent erosion during south west monsoon. However, studies made later (Patnaik, 2004 and Sanil Kumar et al., 2006) identified Gopalpur as a site experiencing erosion. Patnaik (2004) based on his field investigation during 2002-2003, observed net deposition in the course of the annual cycle on the north and south of the Gopalpur port. Therefore, periodic data on shoreline and the changing position of this boundary through time are of elemental importance for coastal zone management and engineering design. Since the fair weather port at Gopalpur is being developed as an all weather direct berthing port since 2007, information (past, present and future) on shoreline change, erosion/accretion and sediment grain size are vital for successful design and management of the port, and also for coastal management. Hence, the present study which aims at understanding the shoreline change and erosion/accretion environment of the region associated with the development of all weather port at Gopalpur assumes importance. The results of the present study shall provide an insight on the appropriate mitigation measures to be adopted without aggravating the beach erosion and instability while maintaining the safety and economic design of offshore, coastal and port structures.

STUDY AREA

Gopalpur Port Limited (GPL) is located at latitude 19° 18′13″ N and longitude 84° 57′ 52″ E in the south Orissa coast, East Coast of India (Figure 1). GPL is being developed as all weather open sea direct berthing port from a small fair weather port which existed since 1987. As a fair weather port, it was operational only during November to March, and had a channel of 5m depth across the beach connecting the basin on the backshore to the Bay of Bengal. The structures associated with the fair weather port were a 400m pier to support moving dredgers (to keep the channels free from sedimentation and an 800m pier to support cargo handling. Two groins, 400-500m length, to the north and south of the existing piers, were constructed during the period August 2007- March 2008. The proposed port facilities comprises of construction of southern breakwater (2.6 km long up to -14 m depth of Chart Datum (CD)), development of berths and back up areas, dredging of approach channel and harbour basin (-15m of Chart Datum). The response of the beach to the recently constructed two groins is significant, which is monitored every month during the last one year and reported in this paper.

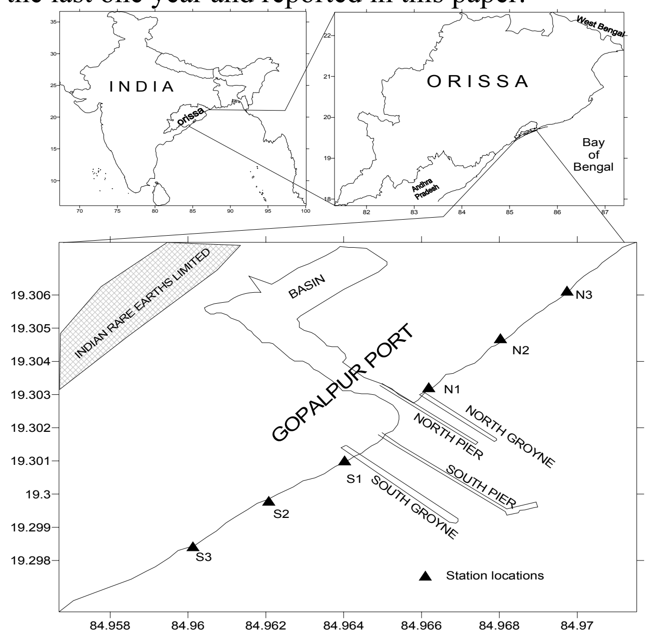

Fig. 1. Map showing study area and station location

The beaches near Gopalpur port are sandy and have an orientation of 48° E with respect to geographical north. Well developed sand dunes rich in rare earth minerals, 10-12 m high, forming continuous ridges run parallel to the shore. The Indian Rare Earth Limited (IREL) factory is located to the south of the port, which mine and process this beach sand for extracting rare earth minerals. The climate is semiarid with annual average rain fall of 1210mm of which almost 80% is contributed by the south-west monsoon (Mishra et al., 2001). Monsoon depressions formed over the Bay mostly during May to September contribute significantly to the annual rainfall. The average wind speed during summer, monsoon and winter are respectively 14.83 km/hr, 13.47 km/hr and 10.3 km/hr.

SURVEY AND COMPUTATIONAL METHODS

Survey of beach profile, sediment characteristics, shoreline changes and berm positions over a stretch of 30 km of the coastline are being monitored every month since May 2008. However, to assess the impacts of the two groins, we focus on the beaches north and south of the Gopalpur port (1.5 km stretch). Three stations on the south of the pier (S1, S2 and S3) and three on the north of the pier (N1, N2 and N3), within a gap of 500m, are chosen and are depicted in Figure 1. The survey method employed here is similar to that of Morton (1993) .The instruments used for beach profile and berm line measurements are Leica SR 1200 Real Time Kinematic (RTK)

Global Positioning System (GPS) with position accuracy ± 1 cm and elevation accuracy ± 2 and Leica DGPS Arc Pad. Cross shore profiles were observed at in interval of 100m from the northern and southern groins of Gopalpur port. However, only three representatives cross shore profiles at 0m, 500m and 1000m on the north (N1, N2 and N3) and south(S1, S2 and S3) of the port (Figure 1), observed every month, are presented here in order to understand the beach changes and to quantify the volume of sand accreted/eroded during successive observations. Beach Morphology Analysis Package (BMAP) version 2.0, developed by the Beach Fill Engineering Work unit of the shore protection and Restoration Program based at the Coastal Engineering Research Centre of the US Army Engineer Waterways Experiment Station was used for computation of beach width and volume changes both in space and time. Due to many analytical functions inherent in the package (BMAP), and its automated and interactive procedures (Mack, 2002), it is not only easy to use but also user friendly. Shoreline change (berm position) was mapped every month using DGPS Arc Pad concurrent with beach profile measurements. The spatio-temporal changes in the berm positions and the associated area changes were analysed in a GIS environment using Arc View software (Version 3.2).

Monthly sediment samples were collected by hand, after removal of the upper layers of reworked sand along each cross shore profile at Backshore (BS), Midshore (MS) and Foreshore (FS) using a Teflon screw-in corer. The collected sediment samples were washed with fresh water and oven dried at 70 ^{0}C, known weight (50-100gm) of the samples were sieved at $\frac{1}{2}\phi$ interval using automatic sieve shaker (AS 200) and A.S.T.M. 20cm diameter sieves(mesh No 10 to 230) for 10 minutes. The graphical computational method of Folk and Ward (1957) was used to calculate the graphic mean. Statistical analysis of the results and graphical analysis of the data were performed using GRADISTAT (Blott and Pye, 2001) software version 4.0.

RESULTS

One year tidal observations(May 08 - April 09) with Valeport non directional tide gauge deployed at the Gopalpur port jetty indicates that the area is subjected to semidiurnal tides with an annual spring and neap tidal range of 2.55 m and 0.77 m respectively. However, earlier studies (Chandramohan and Nayak, 1994) reported the average spring and neap tidal range as 2.39 m and 0.85 m respectively. The range is highest during August and lowest during January. Based on observation of wave rider buoy (Datawell) deployed at 23m depth contour off Gopalpur port, the average wave height observed ranges from 0.25m in December to 0.97m in July while the maximum and minimum wave height recorded are 5.37 m during August and 0.16 m during January. The mean wave period varies from a minimum of 7.2 sec in April-May to 10.8 sec in December-January while the maximum and minimum wave period observed are 17.81s during July and 2.07s during January. Wave direction is southerly during monsoon while south south-easterly waves are observed during rest of the period. The trends in wave height and wave period are in agreement with the previous study (Mishra et al., 2001) but not the wave direction.

Beach profiles

The beach profile is important and is viewed as an effective natural mechanism, which causes wave to break and dissipate their energy. When groins and breakwaters are constructed they upset the natural equilibrium between the sources of beach sediment and the littoral drift pattern. In response, shoreline changes its configuration in attempt to reach a new equilibrium (Ramesh and Ramachandran, 2001). Figure 2 depicts the beach profile of three transects on the north (N1, N2 and N3) and three (S1, S2 and S3) on the south of the Gopalpur port. The distance covered between each transect is 500m and the length of the beach covered both on the north and south of the port is 1.5 km. The beach to the south of the southern groin shows a predominantly depositional environment and wide beach while the beach to the north of the northern groin is narrow and erosional in nature. The results are in agreement with the inferences made by Komar (1976) for Oregon coast and Pandian et al., (2004) for Ennore coast along east coast India. However, the present results are in contrast to the observations made by Mishra et al., (2001), which showed an equilibrium condition on the south side of the port and net deposition on the north side while functioning as a fair-weather port. Since the net drift is northerly along this part of the coastline, the up drift side experiences accretion while the down drift side experiences erosion (Bakker et al., 1970). Beach on the north of the port has narrow beach width, narrow surf zone and wave cut dunes which are the characteristic features of a receding beach (Raudkivi and Dette, 2002), while the beach to the south of the port has wide beach width and surf zones which minimizes the rate of wave energy conversion per unit area by distributing the dissipation energy over a wider area and reduces the erosion potential. Beach profiles at S1 and S2 indicate stable berm on the backshore, large ridge on the foreshore, which migrates towards offshore continuously. Offshore migration is much more pronounced at S1and gradually reduces towards S2 and S3. The results indicate a continuously accreting beach with very high positive change in volume on the south of the port (Table 1). The rate of accretion gradually decreases as one move further south from the southern groin.

Table 1. Change in volume (cu.m/m) and beach width (m) in successive months along north and south of Gopalpur port (May_08) shows the absolute value and is taken as reference month.

Stations	N 1		N 2		N 3		S 1		S 2		S 3	
Month	Volume (cu.m/m)	Beach width (m)	Volume (cu.m/m)	Beach width (m)	Volume (cu.m/m)	Beach width (m)	Volume (cu.m/m)	Beach width (m)	Volume (cu.m/m)	Beach width (m)	Volume (cu.m/m)	Beach Length (m)
MAY_08	200.68	105.97	530.612	95.86	248.248	68.21	523.865	125.66	243.26	92.63	197.988	90.47
JUN_08	-13.781	-20.69	-12.42	-6.55	-8.229	-6.61	59.227	44.21	82.366	37.53	-25.293	-23.4
JUL_08	-31.32	-19.28	-49.004	2.24	-26.519	-0.39	122.494	14.03	28.773	-20.07	-40.56	-17.6
AUG_08	-90.763	-23.33	-58.003	-22.08	-62.239	-18.45	109.983	13.93	15.638	-4.56	13.262	19.83
SEP_08	-75.932	11.04	-39.208	10.04	-18.254	8.36	197.348	1.58	47.353	3.02	1.295	2.83
OCT_08	-65.189	9.12	-36.699	-1.09	-16.046	-1.8	167.757	4.63	52.378	16.86	8.97	-0.77
NOV_08	-67.062	-2.44	-41.114	-1.15	-32.21	4.37	175.089	13.03	24.165	-2.37	9.575	5.63
DEC_08	-9.216	29.14	-43.139	-0.12	2.634	8.41	193.606	3.25	45.643	13.63	46.626	19.53
JAN_09	-51.587	-9.7	-43.84	6.04	141.139	22.39	203.933	11.86	59.167	5.15	30.428	-0.03
FEB_09	-52.095	-12.03	-48.934	-2.53	27.866	-14.82	215.13	3.75	76.241	-1.77	43.44	-1.81
MAR_09	-67.581	-14.32	-36.033	-1.33	14.098	-7.16	204.301	-10.7	75.395	-0.86	25.886	-4.21
APR_09	-67.093	-3.12	-54.469	-2.11	-22.219	-3.89	225.236	13.4	77.93	2.89	33.194	9.38
NET	**-591.619**	**-55.61**	**-462.863**	**-18.64**	**+0.021**	**-9.59**	**+1874.104**	**+112.97**	**+585.049**	**+49.45**	**+146.823**	**+9.38**

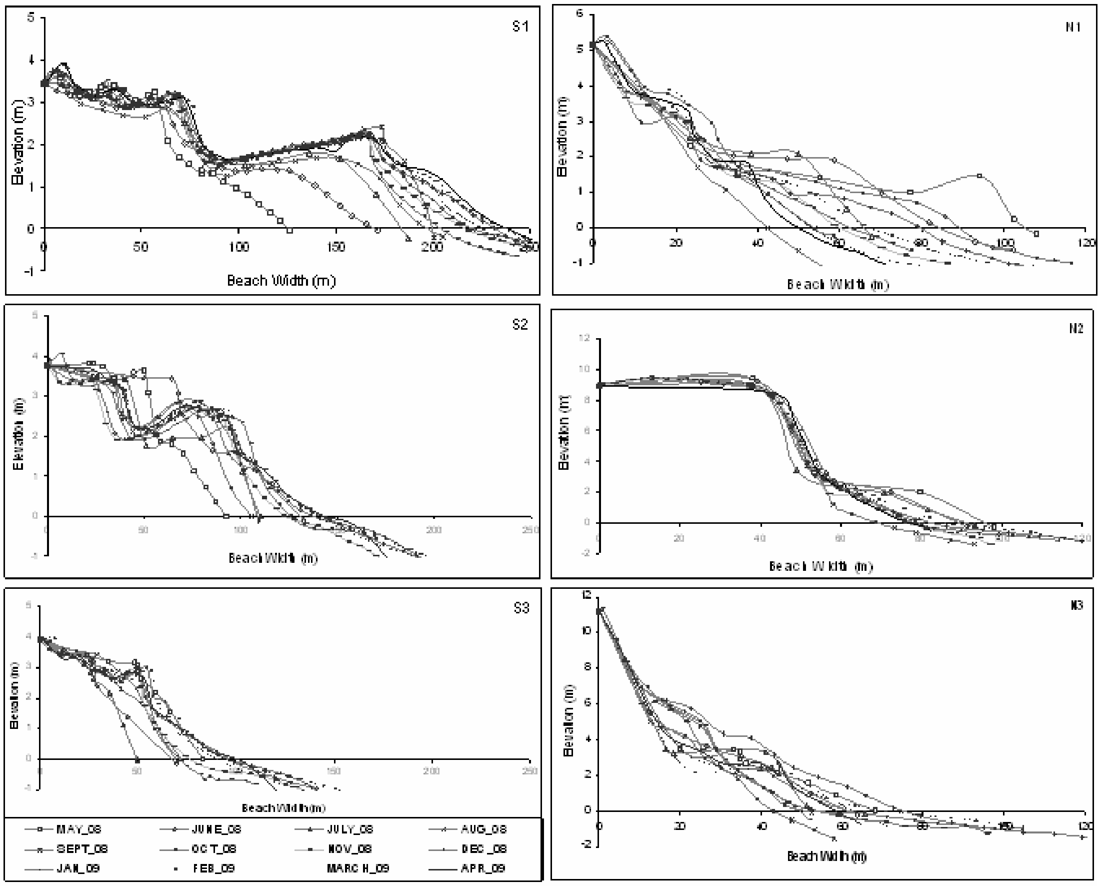

Fig. 2. Beach profile near Gopalpur port; south of south groin (S1, S2, S3) and north of north groin (N1,N2,N3).

The beach on the south of the port starts to erode during the monsoon season, experiences maximum erosion during July/August and then recovers and shows a net positive change in volume continuously. The beaches are at their widest during December to February. In the south of the port, the profile is fine low gradient and is less susceptible to change compared to steeper and coarser profile in the north. The wider surf zone in the south allows the waves to break seaward, thereby facilitating better dissipation of wave energy. The most noticeable features on the profiles south of the port are the trough in the backbeach and the seaward migration of the berm. Continuous deposition of sediment occurs at both first and second berm (from seaward), and the berms migrate seawards. The beach face at all the three profiles south of port has gained sediment allowing the beach to become wider and flat with time. The rates of change in volume and beach width at S1 are respectively 1871.1 Cu.m/m and 112.9 m which gradually decrease at S2 and S3. As the longshore transport is predominantly from south to north during most of the year, the southern groin helps obstruction of longshore transport causing accretion to its south. The impact is very high immediate to the south of the groin and gradually reduces as one moves further south. The nature of deposition on the southern beach is helpful for the development of an all weather port which is planned within 2.5km south of southern groin. Beaches on the north of the port have high sand dunes on the backshore starting from 500m north of the northern groin to about 1.5 km further north. The beach starts to erode from June, remains at its most scoured during August, and then recovers slowly up to December- January, and again starts to erode.

Maximum scouring occurs due to wind induced turbulence and wave energy, which are at their peak during August. High sand dunes exist on the backshore and are subjected to continuous erosion during the course of the annual cycle. Northern beach profiles indicate steep slope at the backshore, no stable berms, absence of ridge on the foreshore. The beach at N1 shows maximum erosion (591.6m ^{3}/m) during the course of the annual cycle because of its close proximity to the northern groin, and the rate of erosion gradually decreases towards N2 and N3. The intermediate beach in the north of the port is of rhythmic bar and beach type. This feature is evident with the beach face which is rhythmic with alternate deeper seaward protruding sections (rip channels) and shoaler landward protruding sections. The results indicate that the beach profile on the north of the port changes perceptibly throughout the year and more so during the southwest monsoon. From the beach profile at N1 and N2, the erosion impact of northern groin is clearly evident.

Shoreline Change

Shoreline is the physical interface of land and water (Dolan et al., 1980) and is associated with geological, physical and anthropogenic processes such as sea level variation, erosion, deposition, flooding, waves, tides, winds, storms and human activities. Besides the temporal variability in shoreline, significance of alongshore variability to shoreline investigation was demonstrated by Eliot and Clarke (1989). Boak and Turner (2005) identified a comprehensive list of shoreline indicators to be used as a proxy to represent true shoreline position. The list clearly depicts High Water Line (HWL) as the most common shoreline indicator. However, it was suggested that the decision as to which shoreline indicator to use at a specific location should be determined by data source and data availability. Pajak and Leatherman (2002) concluded that the GPS method was more accurate than aerial photography and was one of the most recent methods of mapping the shoreline. Therefore, in the present study, a differential GPS Arc Pad has been used to map the berm line (as shoreline indicator) alongshore at monthly interval in order to make a quantitative and process based interpretation of the berm line change in relation to physical processes at play. The berm line in the present study refers to the first berm during spring low tide while moving from foreshore to backshore and is not disturbed at the time of observation. However, it is the high water line (HWL) during spring high tide.

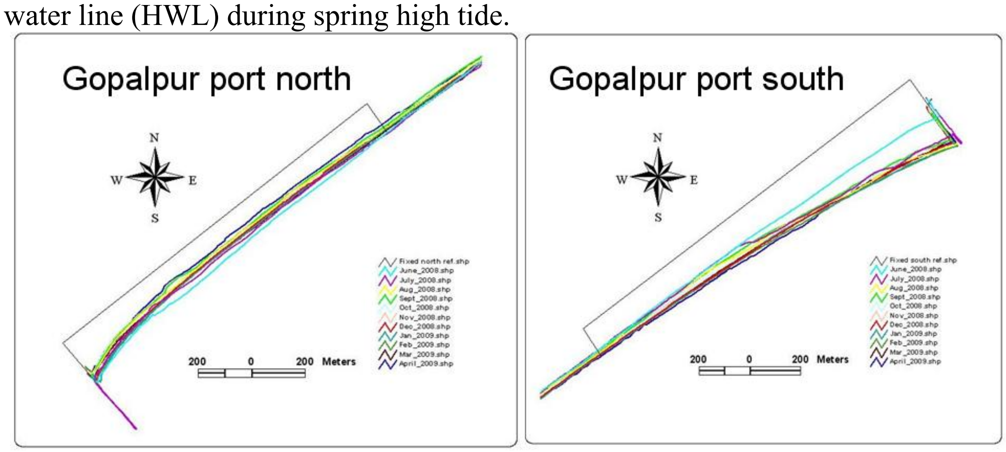

Fig. 3. Shoreline change (berm position) along Gopalpur port north and south

Table 2. Change in beach area (berm line to a fixed backshoreline) on the north and south of Gopalpur Port.

Month	Area in 1000 Sq. m			
	GPL North	Change in area	GPL South	Change in area
JUN_08	94.670	*	37.665	*
JUL_08	75.259	-19.411	91.333	53.668
AUG_08	57.557	-17.703	106.330	14.997
SEPT_08	52.520	-5.036	92.031	-14.299
OCT_08	51.669	-0.852	102.615	10.584
NOV_08	51.302	-0.366	103.870	1.255
DEC_08	67.742	16.439	118.356	14.486
JAN_09	73.959	6.217	123.085	4.730
FEB_09	72.776	-1.183	128.041	4.956
MAR_09	67.748	-5.027	114.916	-13.125
APR_09	53.483	-14.266	130.312	15.396
NET Change in Area		-41.187		92.647

Figure 3 depict the monthly berm positions on the south and north of the Gopalpur port running alongshore for about 1.5 km. Perceptible Landward movement was observed from June-08 to November-08, berm line moved seaward only for a short duration (Dec-Jan) and thereafter, the landward movement was repeated. However, the net change in area due to back and forth movement of the berm line is negative (Table 2) and suggests that the beach to the north of the port is an eroding beach. The present trend of shoreline change would have definite and direct impact on the life and livelihood of the fisherman villages, economic development and land-use management (Chen and Rau, 1998). Therefore, it is imminent to arrest such shoreline change by adopting appropriate mitigation measures. On the other hand, the berm line movement on the south of the port is progressively in the seaward direction during the course of the annual cycle with an exception in the month of September, 08 and March, 09. The exception could be attributed to the very high waves observed during August, 08 and March, 09. The results suggest that the beach to the south of the port is depositional in nature and the area gained during the course of the annual cycle is 92,647 sq meter. The pattern of shoreline change on the south would be beneficial for the port as the proposed limit of the port shall be 2.5km to the south of the southern groin. Gopalpur tourist beach, reported as an eroding beach (Sanil Kumar et al., 2006), and located at an approximate distance of 8km from the southern groin, shall experience less erosion in the forthcoming years when the port develops fully with construction of southern breakwater.

Sediment size distribution

Figure 4 depicts temporal and spatial distribution of mean grain size of sediments in the north and south of the port. Mean grain size of the beach, to a large extent, depends on nature of the sediment, wave energy level and general offshore slope (Komar, 1976; Chauhan, 1988). The mean grain size distribution shows that the sediment sizes mostly vary between fine to medium and occasional presence of coarse sand. Sand size becomes progressively coarser from foreshore to backshore. During monsoon (JJAS), wave heights are higher and wave period are lower. The resultant wave steepness is favourable for offshore movement of sediment and erosion of the beach, resulting in increase of mean grain size. On the other hand during other period, the wave heights are lower but wave periods are higher (refer to section) and hence the resultant wave steepness favours onshore movement of sediment and deposition, resulting in reduction of mean grain size. The results of the present study have general agreement with previous study along Orissa coast (Chauhan, 1988) but for different locality. In the present location, construction of southern/northern groin have definite impact on the deposition/erosion and hence on the mean grain size distribution.

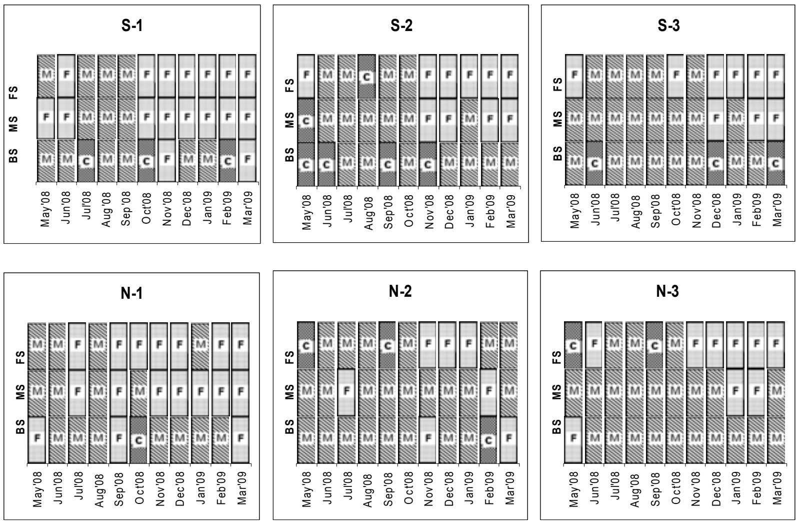

Fig. 4. Mean grain size distribution (BS: back shore, MS: mid shore, FS: foreshore, F: fine, M: medium and C: coarse)

The mean grain size of the beach on the south of the port having depositional environment are mostly fine and medium in the foreshore, medium and fine in the midshore and medium and course in the backshore. On the other hand, on the north side of the port having predominantly erosional environment, mean grain size are mostly medium and fine in the foreshore, mostly medium and occasionally fine in the midshore and mostly medium and occasionally coarse in the backshore. Thus, deposition is marked by decrease in grain size while erosion is marked with increase in grain size. However, exceptions to these trends are noticed at N1. The port authorities nourish the beach at N1 at regular interval in order to check the severe erosion observed here. The beach nourishment resulted in reduction of mean grain size at N1 as compared to at N2 and N3. It is also observed that fine sand is associated with wide and gently sloping beaches where as medium and coarse sand is associated with narrow and steep beaches. Mwakumanya and Bdo, 2007 also arrived at similar inferences while studying the beach morphology in Mombasa, Kenya.

CONCLUSIONS

The results of the present study is based on monthly observations of beach profile, shoreline change(berm position) and sediment characteristics during one year period(May 2008-April 2009) near Gopalpur Port, east coast of India. Impacts of the two groins on the shoreline change are evident from the results. North of the port experiences erosion while south of the port experiences deposition, albeit the latter with double the rate of the former. Net loss (gain) in beach width and beach area during one year cycle are 55.6m(113m) and 41000 m^3 (92600 m^3) respectively on the north(south) of the northern(southern) groin. The mean grain size distribution on the north and south of the port also corroborates the above findings showing depositional/erosional environment on the south/north of the port.

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