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On Numerical Modelling of Waves, Currents and Sediment Movement around Gurupur-Netravathi River Mouth

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Abstract: This paper presents an overview of the investigations that were carried out to understand the coastal process along Bengre and Ullal at the Gurupur-Netravathi River mouth in the west coast of India. This river inlet was facing problems of migration and siltation since several decades and therefore two rubble mound breakwaters were constructed during the year 1994 as an intervention to maintain the inlet mouth. After the construction of these river training jetties, the inlet was stabilized, but severe erosion has been taking place along the Ullal spit on the south side of southern breakwater, since 1996 and heavy accretion on the North of Northern Breakwater along Bengre spit, which is now almost stabilized. This study has been undertaken to understand the hydrodynamics along the beaches adjoining the river mouth. For the present study, various field data was collected for the post monsoon season of 2006. The hydrodynamic (HD), Parabolic mild slope (PMS) and Sediment transport (ST) modules of MIKE-21 software were used to understand the hydrodynamics of the study area. Before the model was made use, it was first validated by using field data to understand the hydrodynamics of the area. Since the field data is of limited duration, data collected from the NMPT wave buoy for an entire year was used for the model simulation. From the studies it was confirmed that current direction and sediment movement follow a similar pattern in monsoon and pre-monsoon and a different pattern during post-monsoon. It is observed that the main cause of erosion is due to direct action of waves on the adjoining beaches of the coast and the beaches in the study area are generally in dynamic equilibrium with a small amount of erosion at Ullal.

***Keywords:** Waves, Currents, Tide, Inlet, Erosion, MIKE-21, Hydrodynamics.*

Introduction:

The Indian coastline is about 7517 km, out of which 5423 km borders the mainland and 2094 km along the Andaman and Nicobar and Lakshadweep Islands. According to the naval hydrographic charts, the Indian mainland consist nearly 43% of sandy beaches, 11% rocky coast with cliffs and 46% mud flats and marshy coast. At present, about 23% of shoreline along the Indian mainland is affected by erosion. Erosion along the beaches near river mouths has been commonly noticed along Karnataka coast. In Karnataka State, about 60 km of the beaches (19% of the total length of shoreline) are affected by erosion. The problem is relatively more severe in Dakshina Kannada and Udupi coasts, where about 28% of the total stretch is critical. As it is difficult to measure ocean parameters very frequently, the use of numerical models provide a valuable insight into the important physical process. Numerical models have reached a very good level of accuracy and detail over the past two decades such that most of the dominant processes in the coastal environment can be quantified. The advantage of numerical modeling approach is that it is economically very efficient and very flexible in adopting towards high temporal and spatial scale marine environment data. For the present study DHI tailored MIKE-21 modules has been made use.

The study area considered was exposed to severe erosion problems since decades for which an attempt to understand the hydrodynamics through numerical modeling has been done. The location of severe erosion at Ullal is shown in Fig.1. The inhabited area with geographic location $12^0 48'$-$12^0 53'$North and $74^0 48'$-$74^0 51'$East off Mangalore with a coastal stretch of 10 km. has been identified for the present study. The river inlet which was under migration towards south has been stabilized by constructing river training jetties during the year 1994. The northern part of the inlet, viz; Bengre and the southern part, viz; Ullal are the worst hit areas. Reddy et. al. (1979) have reported the measurements of flood and ebb tide currents at the Netravathi-Gurupur river mouth. The maximum speeds of surface and bottom currents during monsoon season during flood tide were about 0.98 and 1.04 m/sec. respectively, and the same during ebb tide were about 1.3 and 1.08 m/sec. Ebb currents were stronger than the flood. Karnataka Engineering Research Station, (1989) which conducted a study regarding beach erosion problem at Ullal concludes that the material from the deeper zones are removed and deposited on the fore-shore thereby forming a berm during pre-monsoon and post-monsoon period and then during monsoons, the same material is eroded and deposited in deeper zones. The beach slopes are generally steeper during monsoon and flatter during non-monsoon which leads to a definite conclusion that the beach width is oscillating during a year. The grain size during monsoon was coarser while it was generally finer during non-monsoon periods. Chandramohan et al. (1994) conducted a field study between Bhatkal to Ullal which is dominated by southwest monsoon during June to September. According to the ship observed data, the swells predominantly vary between 1.0 and 3.5m during June to September and 0.5 and 1.0m during October to January. The swell periods predominantly vary between 5.0 and 8.0sec during June to September and between 5.0 to 12.0 sec during October to May. During June to August, the monsoon waves approach the coast predominantly from the sector between southwest and northwest. The tides in this region are characterized by a mixed type, predominantly semi-diurnal. Based on the predicted tide for New Mangalore Port, the average tidal range is about 0.25 to 1.54m. Beach level study indicates the influence of seasonal erosion and accretion condition during South East monsoon and fair weather period. At Ullal, longshore current is around 0.4m/sec in June and 0.25m/sec for the rest of the year, indicating relatively strong longshore current in June. Direction of longshore current was northward from October to December and southward during rest of the year. It was observed that during NE monsoon period, the long shore current direction was predominantly North and during South East monsoon and fair weather period it was southward. The breaking wave height persisted at about 0.6m in June and July and 0.4m in rest of the year. Wave period was observed between 8.0 to 10.0 sec. KREC Study Team, (1994) conducted a study on coastal erosion along Dakshina Kannada coast and observed that the ocean waves are high along coast in the months from June to September. Wave periods range from 9.0 to 10.0 seconds in monsoon. The largest single wave recorded is about 5.4m and typical South West monsoon waves are of height about 4.0m, while the wave heights are less than 1.0m during non-monsoon season and the wave periods show wide variation with the presence of long period waves. Predominant deepwater wave direction in monsoon is SW, W and NW. These waves become almost parallel to coast due to refraction as they near the shoreline. Tides are semidiurnal with a mean tidal range of 1.2m and spring tidal range of 1.8m. From the beach profile studies carried out along the D.K. coast, KREC study team concluded that beaches along D.K coast are in the state of dynamic equilibrium. It was also reported that net erosion tendency are observed at Ullal. KREC study team concluded that littoral drift along the study area is negligibly small and some of the evidence given by them are, had there been a large scale littoral drift, there would have been maximum accretion of sea borne sediments on the north of the northern NMPT breakwater and matching erosion on the south of the southern NMPT breakwater which is not visible. Also, the analysis of the siltation at the entrance channel of NMPT and the changes in the coast line adjacent to the breakwaters at NMPT indicates that the littoral drift in the study area is negligibly small. Dattatri et al. (1997) conducted sea sled survey along the D.K. Coast during 1995 and 1996, and concluded that although there are changes during monsoon, there is no net erosion or deposition and the portion of the beach considered for the study was in a state of dynamic equilibrium. Subba Rao et al (2000, 2002, 2001, 2002a, 2003a, 2003b, 2004, 2006a, 2006b) based on the beach profile and sediment trend matrix investigations also concluded that the sediment movement along D. K. coast is seasonal and there is no net littoral drift along it. Further, studies carried out by them revealed that the direction of sediment movement gets reversed along D.K. coast seasonally and also observes that littoral drift does not pose any problem in the coasts of D.K. district. Eduardo et al, (2002) calibrated and validated a numerical model developed using MIKE-21 HD (Hydrodynamics) and NSW (Nearshore spectral Wind-Wave Model) for modeling the water surface topography at the complex estuarine inlet system at Teignmouth, UK. Modelling was carried out to predict the water surface topography and its response to different tide, waves and river discharge condition. Hakeem et al., (2005) used MIKE 21 PMS (Parabolic Mild Slope) and HD flow model for simulating waves and currents in the vicinity of submerged breakwaters. PMS model was used to simulate wave transformation and calculate wave radiation stresses, while HD flow model (2- dimensional depth averaged) was used to calculate the resulting wave driven currents. It is shown that the simulated flow pattern is qualitatively similar to that observed in the experiments.

Near-Shore Data Collection:

As a part of Ministry of Earth Sciences (MoES) project, under Integrated Coastal and Marine Area Management (ICMAM, Chennai), near-shore oceanographic data were collected in the month of November 2006. State-of-the art equipments like Valeport wave and tide gauge, Aanderaa current meter, Doppler Current Profilers, Ceeducer echo sounder, RTK GPS Systems were used in the field data collection programme. The deployment locations of various instruments are shown in Fig.1.

Analysis of Field Data:

Beach Profile Study:

The main systematic variation observed in the series of beach profiles would most likely be in response to the changing wave condition. By studying and comparing the beach level changes in different time periods, the dynamic behavior of the beaches can be studied. In the present study, beach profiles were measured at 4 locations in Bengre covering a distance of 1600m at chainages 0, 200, 300 and 1600m from the Northern breakwater. The same was measured at 28 locations covering a distance of 4000m from the southern breakwater. Profiles are measured at 50m interval from 0 to 1000m and from 1000m to 4000m at interval of 500m. Beach level changes at Bengre is shown in the Fig. 2. From the analysis it was found that during monsoon season, from the northern breakwater to 200m distance towards north accretion was taking place and the remaining portion of Bengre was undergoing erosion. In the post monsoon season, from the northern breakwater to 200m distance towards north erosion was taking place and the remaining portion of Bengre was undergoing accretion. In the pre monsoon season accretion was taking place if the wave energy is low and erosion if wave energy is high. The estimation of relative changes in the volume of sediment per meter length of beach for the year of 2004 to 2005 and 2005 to 2006 at each location is shown in the Fig.3. By comparing the relative volume changes it is found that in the year 2004 to 2005 there was a net accretion of about 0.058Mm^3/year and in the year 2005 to 2006 is about 0.0927Mm^3/year. By comparing the relative volume changes for the year 2004 to 2005 and 2005 to 2006 it can be said that net accretion was about 0.035Mm^3/year, in the study area of Bengre. Fig. 4 shows the influence of seasonal erosion and accretion conditions prevailing during the southwest monsoon and fair weather period. The estimation of relative changes in the volume of sediment per meter length of beach for the year of 2004 to 2005 and 2005 to 2006 at each location is shown in the Fig. 5. By comparing the relative volume changes it is found that in the year 2004 to 2005 there was a net erosion of about 0.124Mm^3/year and in the year 2005 to 2006, it is about 0.311Mm^3/year. By comparing the relative volume changes for the year 2004 to 2005 and 2005 to 2006 it can be said net erosion was about 0.18Mm^3/year in the study area of Ullal.

Bathymetry:

Tidal corrections have been applied to the data in the post processing mode by using the simultaneously collected tide from the tide gauge at 11m water depth. Surveyed data was interpolated to get the continuous bathymetry of the study area. Hence the observed data was post processed, analyzed and interpolated using HYPACK Max survey software. Fig. 6 shows the bathymetry details of the study area. The average slope at different water depths are shown in Table 1 from which it can be inferred that Ullal was steeper than Bengre up to a water depth of 6m. Slope of Ullal and Bengre becomes nearly the same after a water depth of 6m.

Sediment Analysis:

From the grain size analysis carried out, it was observed that the grain size along the beach is in the range of 0.2mm to 1.6mm. As per the IS classification, the sand in the study area are medium grained. The near-shore sediment samples are medium sand with minor amount of silt and clay which can be observed up to a water depth of about 5 to 6m. Beyond this, the sea bed is composed of silt and clay as shown in the Fig. 7. The absence of silt and clay in the beach and at water depth of 5 to 6m indicates that these are the surf zone areas where waves break resulting in significant turbulence which brings silt and clay into suspension which are then moved offshore.

Analysis of Water Levels:

Tide data collected at the NMPT is analyzed using the Tidal Analysis of Height tool of Mike-21 (TIDHAC) to get the tidal constituents and the major constituents so obtained are given in Table 2. The mixed semidiurnal nature of the tide is shown in the typical plot presented in Fig. 8 and is also reflected from the form number which amounts to 0.937.

Analysis of Waves and Currents:

Marine structures are those which are exposed to marine environment. Major forces that these have to withstand are those due to the wave induced fluid motion or flows, apart from working loads. For a structure to be designed on an optimal basis and to be efficient in its function, a thorough understanding of wave-structure interaction is essential. Detailed information on wave climate and analysis of wave record helps in arriving at an optimum design wave height. Typical plot showing the wave height distribution corresponding to pre-monsoon, monsoon and post-monsoon are shown in the Fig. 9. Average wave direction in the monsoon season is 260^0 (W), 240^0 (SW) in the post monsoon and 280^0 (NW) in the pre monsoon season. The statistics corresponding to the current magnitude and direction obtained from the current meters installed at different locations are shown in Table 3.

River Discharge:

The river discharges were computed indirectly by measuring the cross-sectional area of flow and the magnitude of current at different time periods for both the rivers and Fig. 10 shows the variation in the river discharge for the same rivers. Discharge in the rivers were more in the monsoon season because of heavy rain in their catchment areas.

Numerical Modeling:

The standard numerical modelling procedures were applied to understand the hydrodynamics and sediment dynamics of the study area. Model was setup and with one set of field data and by fine tuning the calibration parameters, the sensitivity of the model to these parameters were studied. The model was then validated with another set of data without changing the calibration coefficients. Subsequently the validated model was used to understand the hydrodynamics and sediment dynamic of the study area. The model simulation is carried out for all the three seasons of the year 2006.

Wave (PMS) Model:

MIKE-21 PMS module is based on the parabolic approximation to the mild-slope equation and accounts for the effects of wave shoaling, refraction, diffraction, breaking, directional spreading, forward scattering and bed friction on the incident waves. The basic outputs from the model are integral wave parameters such as significant wave height, mean wave period and mean wave direction. Other outputs that can be obtained from the model are radiation stresses and instantaneous surface elevations.

Flow (HD) Model:

The hydrodynamic (HD) module is the basic module in the MIKE-21 Flow Model. This module calculates the flow field from the solution of the depth-integrated continuity and momentum equations. The bathymetry data, bed resistance coefficients, wind field, hydrodynamic boundary conditions and eddy viscosity are fed as the basic inputs. The model includes the capability to allow periodic flooding and drying in inter tidal areas. In addition to the wind and tide, the forcing terms may include the gradients in the radiation stress field as calculated by the wave module. The outputs of the simulations are water levels and fluxes (velocities) in the computational domain resulting from the tide.

Non Cohesive Sediment Transport (ST) Model:

This module computes the rates of non-cohesive sediment transport for both situations containing pure current and combined waves and current.

Setting up the Model:

This is a process which transforms real world events and data into a format which can be understood by the numerical model MIKE-21. Thus generally speaking, all the data collected have to be resolved on the spatial grid selected like a 5mX5m grid spacing for the PMS and a 25mX25m grid for HD module.

Boundary Conditions:

Different boundary conditions are to be used for different modules in MIKE-21. Thus for PMS module, the incoming wave conditions such as wave height, period and direction are specified at the offshore boundary (Model West). For the lateral boundaries (Model North and Model South), symmetrical boundary condition was adopted. Similarly for the HD module, the Model West boundary is fed with flux=0, tide data at Bengre as Model North, River discharge data at Gurupur and Netravathi rivers for these boundaries and the tide data at Ullal as the Model South boundary condition.

Calibration:

Calibration of the numerical model is a very important requirement before being put into any practical usage. However, there is no widely accepted procedure for the model calibration and validation in the modeling literature (Cheng et al., 1991). Typically, calibration or validation is accomplished by quantitative comparison of short time series of water level or velocity produced by the numerical model with the field data for the same location and for the same period of time (Cheng et al, 1993). A number of models are calibrated with time series data of surface elevation, velocity, and salinity at stations wherever they are available. Eduardo et al, (2002) calibrated the MIKE-21 model for the inlet system in Teignmouth, UK with the time series data of water level and velocity. Nicholas et al, (2004) calibrated Delft3D Terschelling model for the water levels, waves and currents. For the PMS module, the bottom friction coefficient is the basic calibration parameter and for HD module, bottom roughness (bed resistance), eddy viscosity and wind are the basic calibration parameters. From the sensitivity analysis, value of bed resistance is found to be $20m^{1/3}/s$ in terms of Chezy number and eddy viscosity is 2.

Calibration of Wave Model:

For the PMS wave analysis module, data collected at the river mouth at 11m water depth (M11) was used as offshore boundary condition and calibration of the model was done by using Bengre 8m water depth (B8) and Ullal 8m water depth (U8) wave data. For the calibration of the model, results are extracted from those locations where the instruments are deployed for collecting the field data. These extracted values are compared with the observed field data. The results are as shown in the Fig. 11 and Fig. 12 respectively. To establish the statistical relationship between the observed and the predicted values, parameters like Bias and RMS errors were used in the study.

Calibration of Flow Model:

Data collected at Ullal 8m water depth (U8), Bengre 8m water depth (B8), discharge data at Gurupur and Netravathi Rivers are used as a boundary condition. Calibration of the model is done by using the data collected at Ullal 6m water depth (U6) and River Mouth 11m water depth(M11).

Modeling by using NDBP Data:

Since the collected data is for a limited duration, 1 year data collected by NDBP at NMPT was used to simulate monsoon season parameters. Before this data is to be used for the simulation of the model, the same has been validated by comparing the predicted values (tide and currents) obtained from the model simulation using the field data with the simulation done using NDBP data. Validation results are shown in the Fig. 13.

Model Outputs:

The model output of wave height distribution for the different seasons is shown in the Fig. 14. It can be observed that the wave activity in the study region during the monsoon season is more than that during non monsoon seasons. Wave height contours show that in the monsoon season waves with higher wave heights are breaking near the coast. This reveals that erosion is mainly because of direct wave action on the coast. It can also be revealed that the hydrodynamics of the study area is very complex during the monsoon season than that during non-monsoon season. The range of current speed for the different season is shown in the Table 4.

Sediment Transport:

Net sediment transport pattern obtained from the model for the three seasons are shown in the Fig. 15. During the Monsoon and Pre-monsoon season, net sediment transport is towards South and during Post-monsoon it is towards North. It is also observed that an amount of 800m3/year of sand during monsoon is moving towards South, $70m^3$/year towards north during post-monsoon an amount of 100m3/year towards south during pre monsoon season. This shows that the sediment drift is more during monsoon and is about 11 and 8 times more than during post-monsoon and pre-monsoon seasons. This is mainly because of the high wave activity and the current in the region. During pre-monsoon, the sediment movement is more than that of post monsoon to the tune of about 1.5 times. From the grid sampling it was found that the sediments will be sand up to a water depth of about 5m to 6m from the shore. Contour lines of 5m water depth are at a distance of 100m from the shore and are considered as effective surf zone width for the calculation of net sediments. Net sediment transport rates in the monsoon, post-monsoon and pre-monsoon season are $0.08Mm^3$/year, $0.007Mm^3$/year and $0.01Mm^3$/year respectively. Net sediment drift was towards South and is about $0.063Mm^3$/year. Thus in general, the beaches are in dynamic equilibrium.

Conclusions:

An attempt has been made to collect and analyse the virgin oceanographic data with the help of various state-of-the-art scientific equipments available in the present day. The data has been used to develop a model of the study area considered and with the various parameters available in the model, the same has been fine tuned to simulate the existing field conditions. Based on such studies conducted, following conclusions can be arrived at.

- Beaches at Ullal and Bengre are generally in dynamic equilibrium even though there is net erosion of small magnitude at Ullal.
- Bathymetry survey conducted reveals that sea bed at Ullal is steeper than that at Bengre.
- Modelling results shows that the hydrodynamics of the study area becomes more complex in the monsoon season than in the non-monsoon season.
- Direct wave attack on beach is the main cause of erosion in the study area.
- Current Direction and the sediment movement are towards South in the monsoon and pre monsoon seasons and towards North in the post monsoon season.
- There appear to be a small net sediment movement towards South in the study area.

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Figure 1: *Location of Erosion and Instrument Deployment Locations*

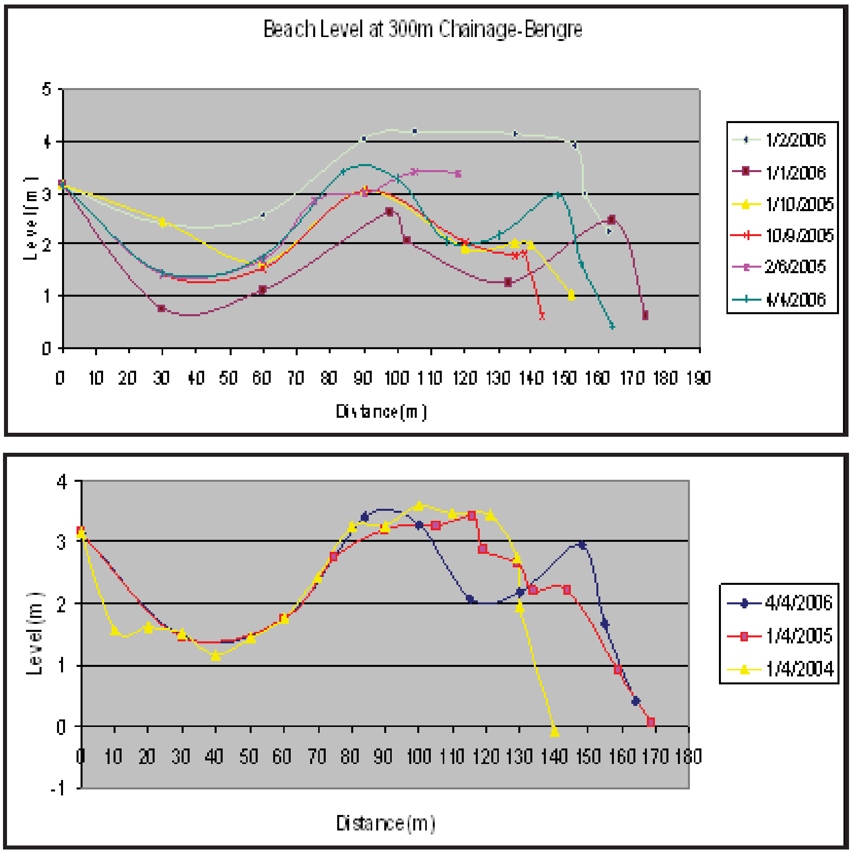

Figure 2: *Monthly and Yearly Beach Level Changes at Bengre*

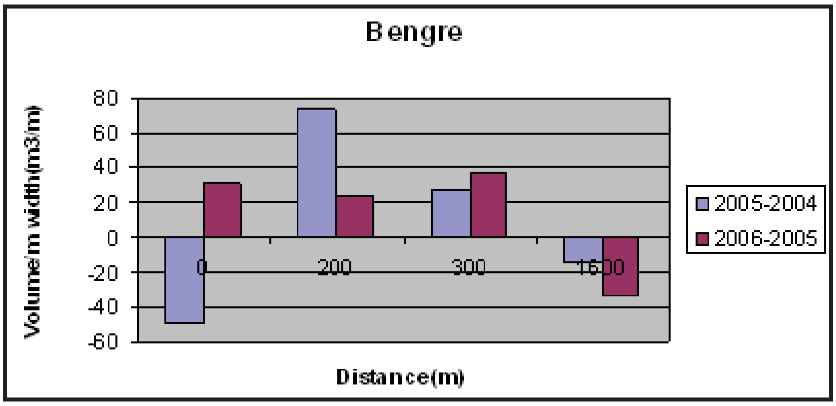

Figure 3: *Yearly Relative Beach Sediment Volume per Meter Length at Bengre*

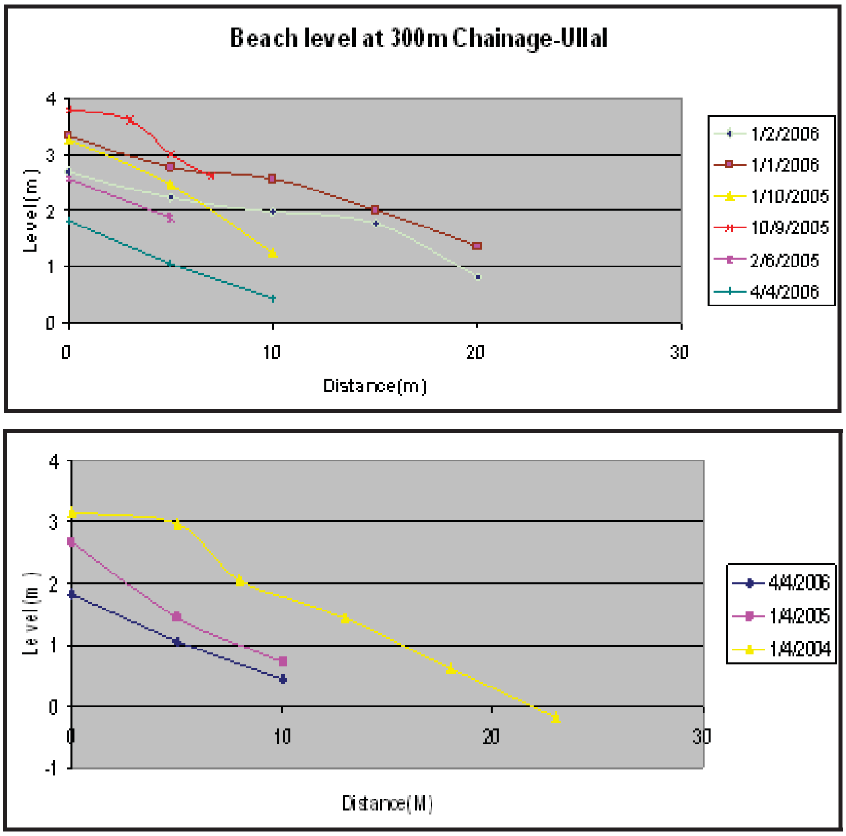

Figure 4: *Monthly and Yearly Beach Level Changes in at Ullal*

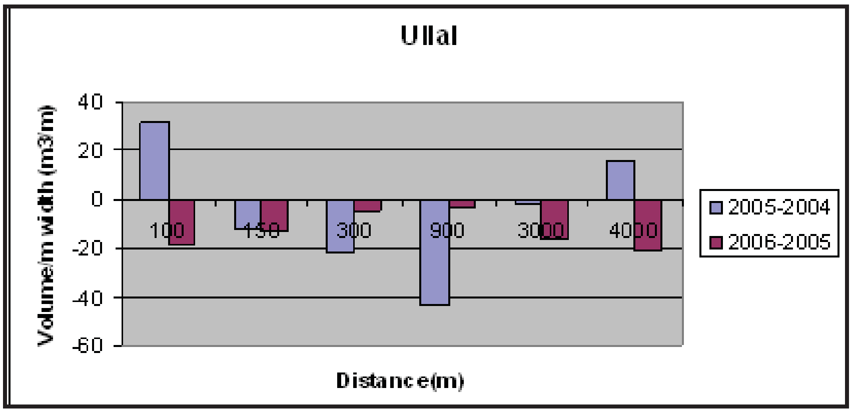

Figure 5: *Yearly Relative Beach Sediment Volume per Meter Length at Ullal*

Table 1: *Average Bed Slope off Ullal and Bengre Coast*

Water depth (m)	Ullal	Bengre
0 to 6	1:20 to 1:30	1:50 to 1:60
6 to 12	1:400 to 1:500	1:420 to 1:520
12 to 20	1:780 to 1:900	1:800 to 1:910

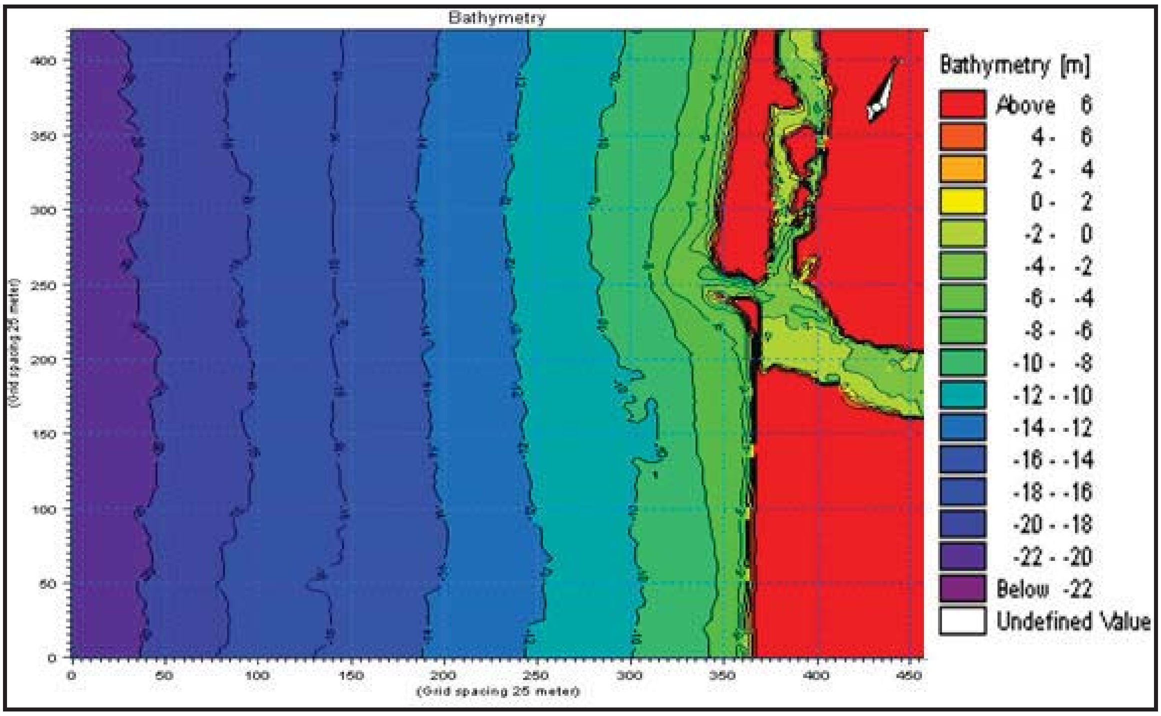

Figure 6: *Bathymetry of the Study Area*

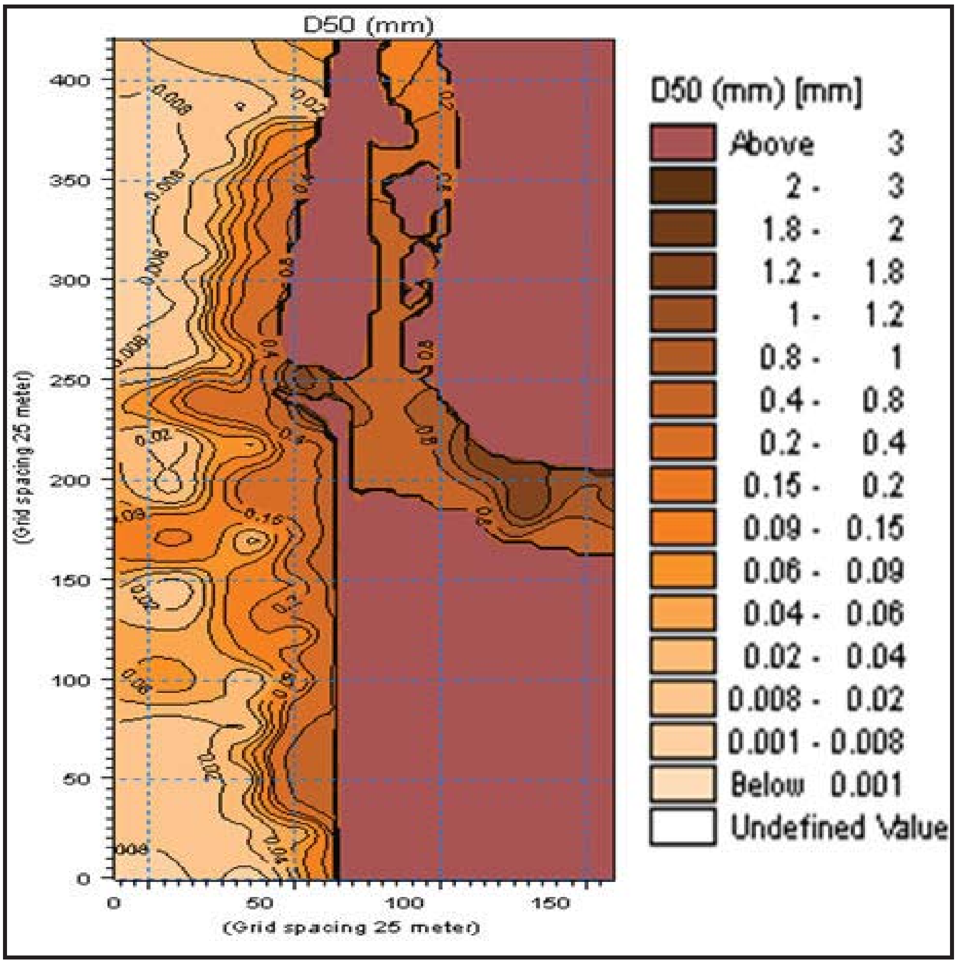

Figure 7: *Grain Size Distribution off Bengre and Ullal*

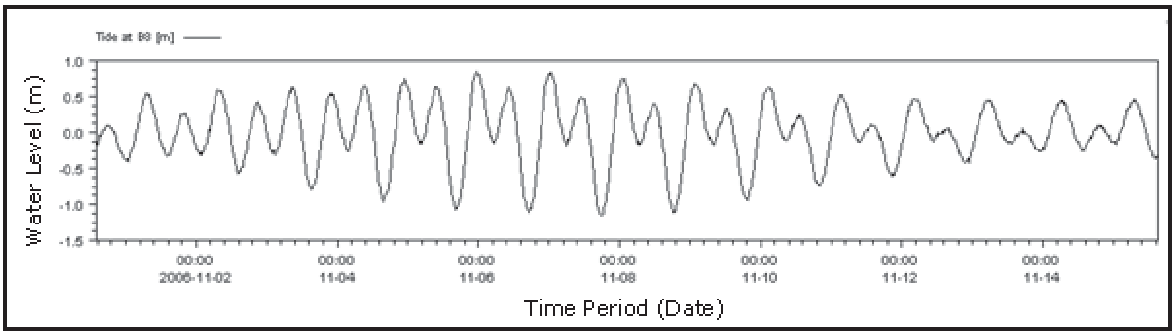

Figure 8: *Typical Plot of Water Levels at B8 Location*

Table 2: *Tidal Constituents obtained from NDBP Data*

Constituents	Amplitude	Phase
O1	0.14	57.56
K1	0.318	60.94
M2	0.405	332.14
S2	0.085	19.89

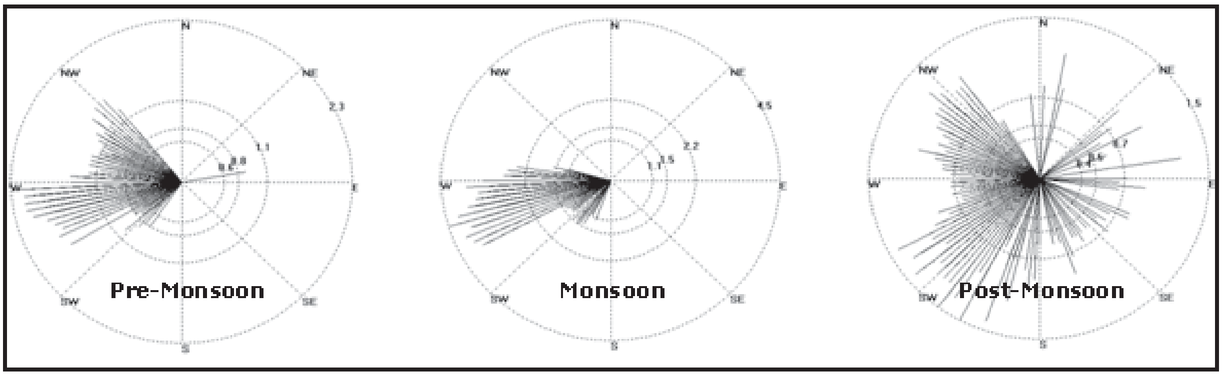

***Figure 9:** Typical Wave Height Distribution Plot from NDBP Data*

***Table 3:** Current Statistics at Various Locations*

Location	Average current speed (m/Sec)	Predominate current direction
B8	0.116	N & S
M11	0.161	-
U6	0.077	NNW & SE
U8	0.12	NNW & SSE

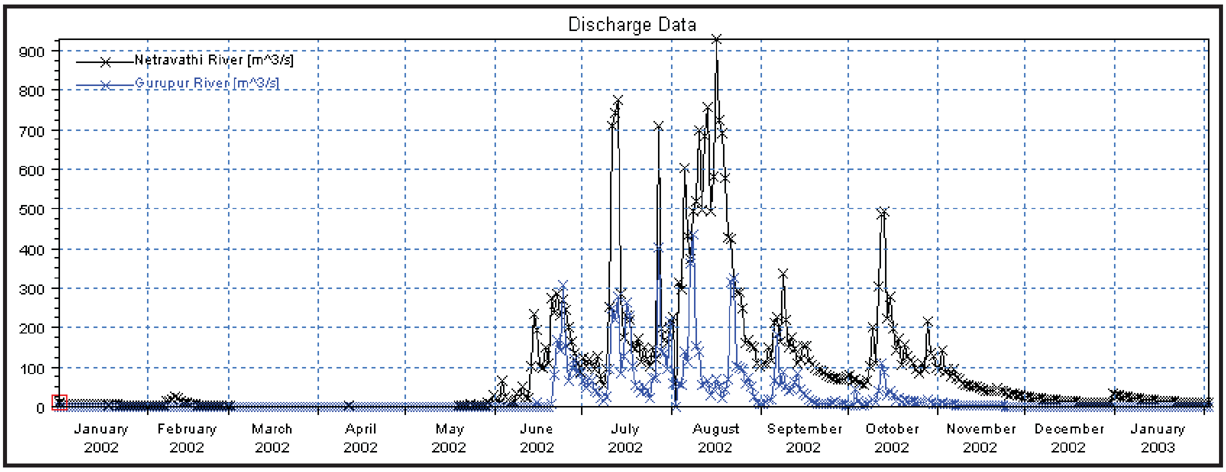

***Figure 10:** Monthly Variation of River Discharge at Netravathi and Gurupur Rivers*

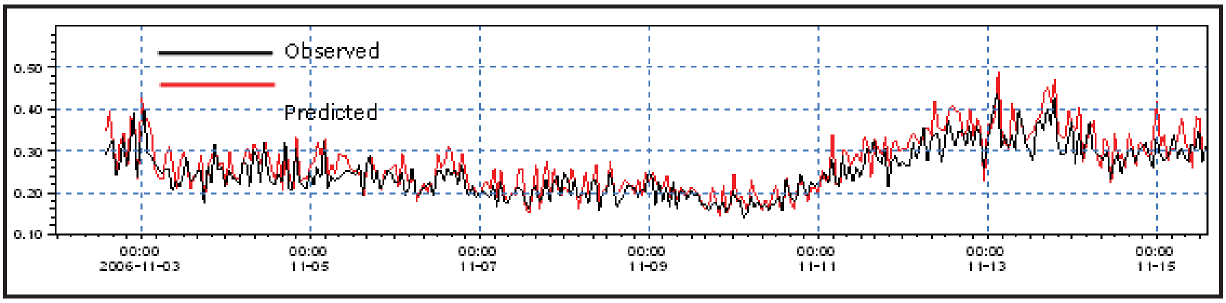

***Figure 11:** Observed and Model Simulated Wave Height at U8 Location*

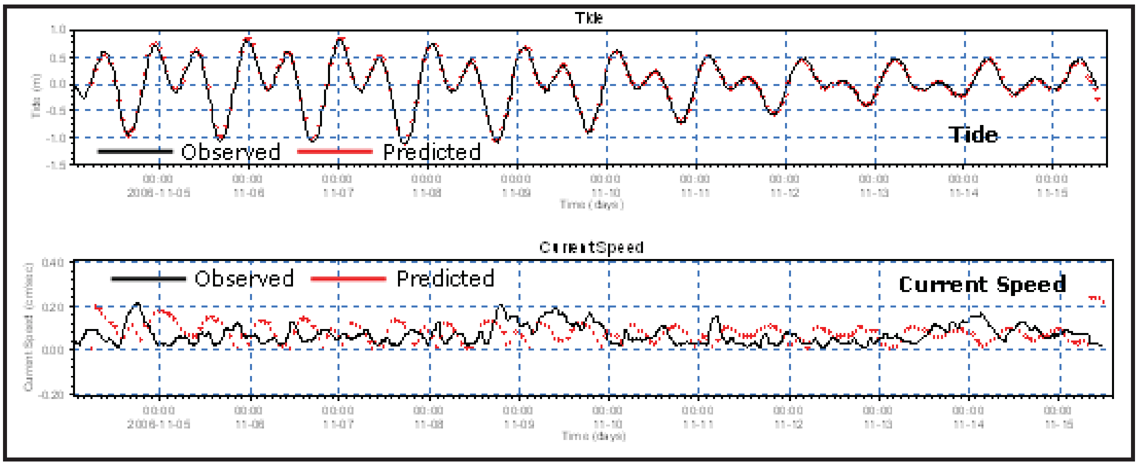

Figure 12: *Typical Plot of Observed and Model Predicted Tide and Current Speed at U6 Location*

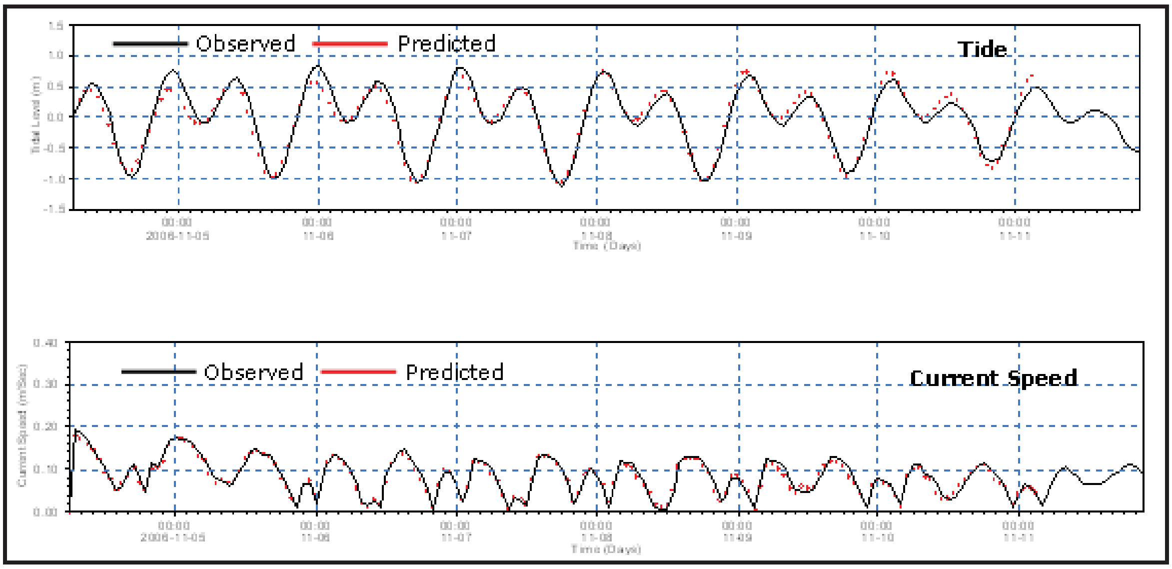

Figure 13: *Typical Plot of Observed and Model Predicted Tide and Current Speed at U6 Location from NDBP Data*

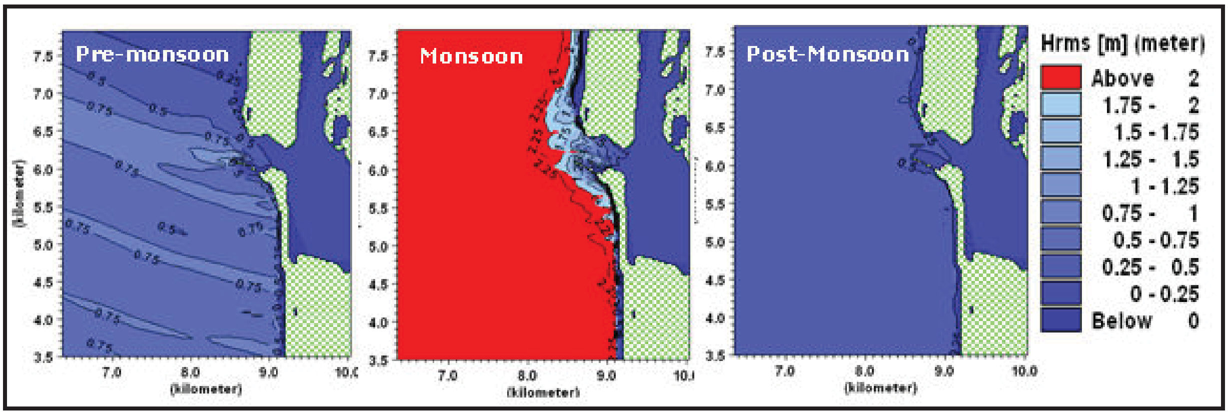

Figure 14: *Plot of Predicted Seasonal Wave Height from NDBP Data*

Table 4: *Range of Seasonal Current Speed*

Season	Current Speed (m/sec)	Direction
Monsoon	0.2 to 0.55	South
Post-monsoon	0.07 to 0.25	North
Pre-monsoon	0.09 to 0.35	South

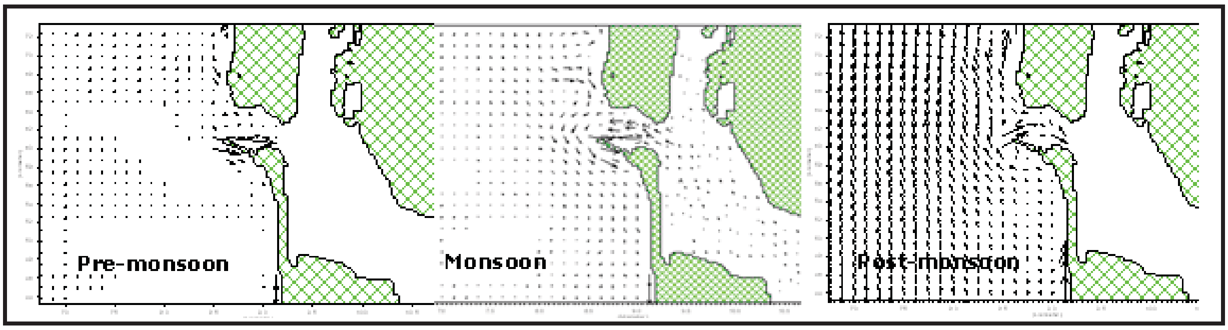

Figure 15: *Typical Seasonal Plot of Sediment Movement Patterns*