IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 19, Issue 3 Ser. I (May. – June. 2022), PP 15-31
www.iosrjournals.org

Simulation of Longshore Sediment Transport and Coastline Changing Along Kuakata Beach by Mathematical Modeling

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Abstract
This study work has been conducted for estimation of longshore sediment transport and coastline evolution as well. Dedicated hydrodynamic model using MIKE 21 FM is developed, calibrated, and validated for studying nearshore hydrodynamic analysis and hydrodynamic result is used as input in LITDRIFT and LITLINE model. Dedicated wave model has been developed using MIKE 21 SW and the simulated wave climate has been used in LITDRIFT model and LITLINE model. Simulated hydrodynamics of coupled wave-tide model are used in LITDRIFT model to estimate the rate of longshore sediment transport. It is found that overall net sediment transport occurs eastward of amount 5.94x10^5 m^3/yr and 1.46x10^5 m^3 is eroded for Lebur Char area and 2.36x10^5 m^3 deposited in Kawar Char area per year, estimated by LITDRIFT model of LITPACK module under MIKE. Coastlines have been simulated by LITLINE model, which is calibrated and validated with the real filed data of coastline extracted from the satellite images of the year 2018 and 2016. LITLINE model has been simulated over the year 2010 to 2018 for erosion prone area of Kuakata. It is observed that coastline is moving towards land with time. Future coastline position is also simulated up to the year 2024. It is predicted that western part (Lebur Char area) of Kuakata beach will further erode at a rate of 9.6 m/yr up to the year 2024.
Keywords:
Longshore sediment transport
Coastline evolution
LITDRIFT model
LITLINE model
Coastal erosion

Date of Submission: 28-04-2022 Date of Acceptance: 10-05-2022

I. Introduction

Coastal erosion is one of the big challenges in Bangladesh. Many reasons are responsible for coastal erosion, among them strong tidal current, wave action, cyclonic storm surge and human interventions are prime reasons. There has been happening erosion along the main beach of Kuakata for last decades. This study has been conducted to simulate longshore sediment transport and shoreline evolution along Kuakata beach. A few numbers of studies have been conducted so far on Kuakata beach regarding erosion issue and other aspects. Despite these existing studies, there are some research gaps and huge scopes to work with Kuakata beach and nearshore area. Under this research authors tried to address some research gap finding longshore sediment transport and simulating coastline evolution.

1.1 Study area

This study is conducted for Kukata beach area. Kuakata is in the southern part of Banaladesh and northern part of Bay of Bengal (BoB). It is situated 320 km south of capital city Dhaka and 70 km away from Patuakhali district headquarter. The area lies between latitudes 21^{0}48' and 21^{0}55' N and longitudes 90^{0}03' and 90^{0}15' E. Kuakata is under Kalapara upazila of Patuakhali district. Study area (Kuakata) is shown in the Figure 1**.** Kuakata beach is an important place for tourism and thereby plays a vital role for national economy. But beach erosion is becoming a serious problem day by day. Kuakata beach is about 24 km long stretching from

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west to east. West part of the beach, named Lebur Char which is the main attractive place of the tourists has been suffering from erosion for last few decades. Middle part, named Gangamatir Char is relatively stable. Whereas, the east part of the beach, named Cowar Char has been accreting for last few decades.

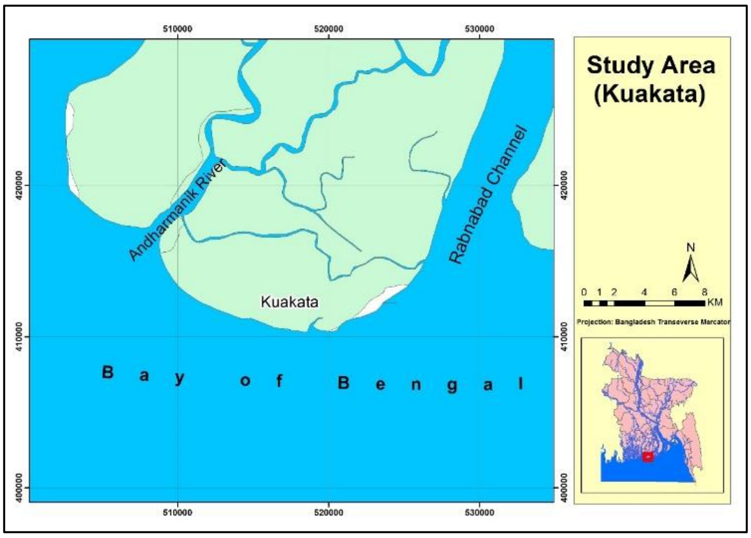

Figure 1: Map showing study area

The beach is bounded by the Andharmanik river estuary at the west and Rabnabad river estuary at the east. Longshore sediment transport has been estimated by Littoral Processes FM. Coastline evolution has been estimated and verified with satellite image coastline for a particular year. Assessment of the longshore sediment transport and simulation of shoreline changes along Kuakata beach are the main output of this research work which will help coast management authority to take necessary protection measures.

II. Materials and method

Four models (i.e., Hydrodynamic, wave, littoral drift, and coastline evolution) are used in this study. Both Hydrodynamic and wave model are setup, calibrated and validated. Ultimately using HD result file and wave result file sediment budget is estimated from LITDRIFT model and coastline evolution is seen by LITLINE model for Kuakata beach.

2.1 Data collection

Various types of data have been collected for this study purpose like water level, discharge, wind data, sentinel satellite imageries (10x10m) ,1D hydrodynamic result file for the year 2010 to 2018, wave data for the year 2010 to 2018 and wind field for the same period from different authentic sources (i.e., IWM, BWDB, ECMWF, USGS).

2.2 Mathematical model

Mathematical model is a great science for decision making in water resources sector. Now a days software developed based on mathematical model are widely used in coastal engineering. And mathematical model is more advantageous over physical model. Most of the cases physical model can't be done because of plenty of restraints. Though in this research four models were simulated, here only LITDRIFT and LITLINE model are discussed in detail. As this paper focuses on longshore sediment transport estimation and coastline evolution so only key models are described briefly.

2.2.1 LITDRIFT model

LITDRIFT simulates the littoral drift or shore parallel sediment transport, and it is a part of the software package LITPACK developed by DHI Water & Environment. The output from the model is the littoral transport for the individual wave situations and the total sediment budget for any time span. LITDRIFT consists mainly of two calculation parts which are longshore current calculation and sediment transport calculation.

The sediment transport is calculated by the Sediment Transport Program (STP) of DHI based on the local wave, current and sediment conditions. STP is a detailed intra-wave-period model which describes the time-varying distribution of both suspended load and bed load within the wave period in combined wave and current motion, including the effect of wave breaking when relevant. The transport rates are found directly by calls to STP. As a result, LITDRIFT can give a deterministic description of the cross-shore distribution of longshore sediment transport for an arbitrary, non-uniform, bathymetry, and sediment profile, as well as a detailed description of the sediment budget. The structure of LITDRIFT is shown in Figure 2.

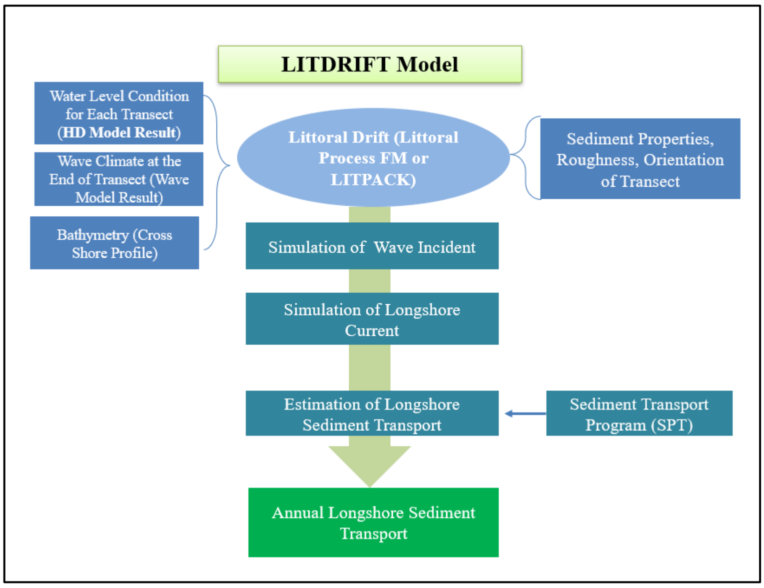

Figure 2: Structure of LITDRIFT model

2.2.1.1 Governing Equations of LITDRIFT Model

The Littoral Processes FM module is an integrated modeling system that simulates non-cohesive transport in points and along quasi-stationary coastlines using an n-line approach. The system of numerical models available in Littoral Processes FM (popularly known as LITPACK) enables one to determine longshore current and distribution of sediment concentration in vertical direction which ultimately determines sediment transport. LITDRIFT model is one of the modules under Littoral Process of FM (LITPACK) by which longshore drift can be estimated. Longshore sediment transport primely depends on wave climate, sediment characteristics and orientation of coastline.

The littoral current computation in LITPACK is based on the equation,

$$-\frac{1}{\rho}\frac{\partial S_{xy}}{\partial x}+\frac{1}{\rho}\tau_w sin\theta + gDI = \frac{V^2}{C^2} - \frac{\delta}{\delta x}\left(E_c D\frac{\delta v}{\delta x}\right) \qquad (1)$$

Where, ρ is the density of sea water, D is the water depth, V is mean velocity over depth, c is the resistance factor, S_{xy} is shear stress due to radiation, τ_w is the wind stress, I is longshore slope of water surface, θ is angle between wind direction and coast normal, E_c is momentum exchange coefficient, G is the acceleration due to gravity, x is the longitudinal coordinate along the coastline

Sediment concentration is determined by vertical turbulent diffusion equation as mentioned below:

$$\frac{\delta c}{\delta t} = \frac{\delta}{\delta x}\left(\epsilon_s\frac{\delta c}{\delta z}\right) + W\frac{\delta c}{\delta x} \qquad (2)$$

Where, c is the sediment concentration, t is the time, z is the vertical coordinate, ε_s is the turbulent diffusion coefficient, w is fall velocity of the sediment, x is longitudinal coordinate.

Total sediment load (q_T) is computed by adding bed load(q_b) and suspended load (q_s). Bed load is determined by deterministic approach of Engelund Fredsoe (1976) model while suspend load is calculated by the following equation

$$q_s = \frac{1}{T}\int_0^T\int_{2d}^D (uc)dzdt \qquad (3)$$

Where, q_s is the suspended load, u is the velocity, x is the vertical coordinate, T is the wave period, D is the local depth, c is the reference concentration, t is the time and d is the sediment size.

The annual drift is found by the contribution of transport from each of the wave incidents occurring during the year.When calculating the annual drift, the wave climate in the calculations is described in a time series file where each set of items describe the characteristics of one wave incident and the bathymetric conditions at that time. In addition, the duration of the individual wave incident considered. Thus, the total annual drift Q_{annual} is found as the sum of the contributions from all wave incidents.

$$Q_{annual} = \sum_{i=1}^{NSETS} Qs(i).Duration(i) \qquad (4)$$

Where NSETS is the total number of wave incidents and Duration(i) is the duration of the wave incident. The definition of annual drift Q_{annual} is provided that the total duration in the wave climate file is one year. Otherwise, the total drift is found per design period (i.e., total duration in simulation).

2.2.1.2 LITDRIFT model development

The LITDRIFT model for the study area covers the coastline of Kuakata beach. Total of six transects are selected to obtain the longshore sediment transport in the shoreline stretching from Lebur Char to Kawar Char, as shown in Figure 3. The six transects are established by taking into account the wave climate, shoreline orientation and the erosion and deposition pattern of the shoreline. The cross-sectional profile along the above mentioned six transects are shown in the Figure 4.

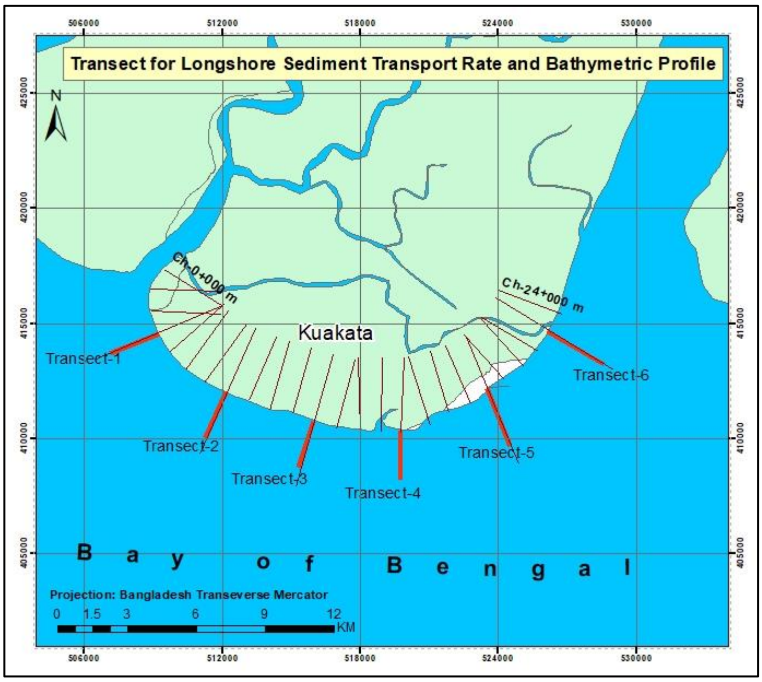

Figure 3: Transects perpendicular to the shoreline

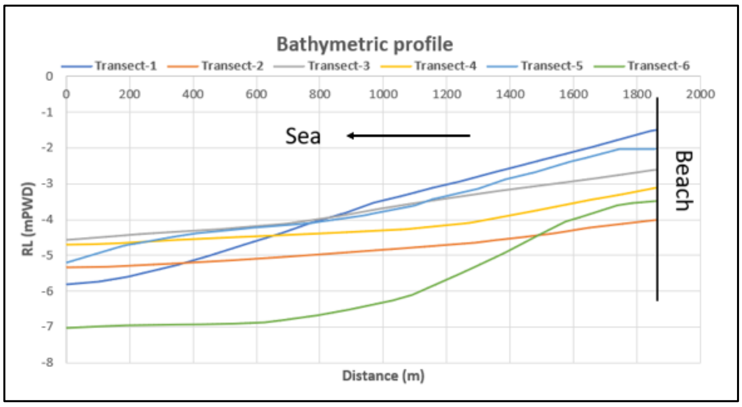

Figure 4: Cross-sectional profiles along the transects

The characteristics of the individual computation profiles are illustrated by Table 1. Length of the transect depends on the location of depth of closure. Depth of closure is that depth in the offshore of the sea, beyond which literally no littoral transport occurs. So, over the time no significant change in bottom elevation of the sea beyond depth of closure. Length of the transect should be equal or greater than the distance of depth of closure from coastline. There are several formulae exists to find the depth of closure. For Kuakata nearshore area, it is seen that depth of closure located within 2000 m. So, the length of the transect in this study is reasonable and appropriate.

Table 1: Overview of profiles used for computation of littoral transport

Profile ID	Δx (m)	Number of grid points in the transect	Position for wave climate extraction at the tip of the transect			Shore normal orientation (degrees)	Length (m)
			Easting	Northing	Depth (m)		
Transect-1	5	400	507116	413688	-5.8	250	2000
Transect-2	5	400	511205	410176	-5.3	210	2000
Transect-3	5	400	514909	408928	-4.5	203	2000
Transect-4	5	400	519677	408287	-4.7	182	2000
Transect-5	5	400	524490	409822	-5.2	157	2000
Transect-6	5	400	528617	413274	-7.0	120	2000

Sediment Characteristics and Bed Roughness:
Bed samples should be collected from different location in intertidal zone but in this study, it could not be done for limitation. So, bed parameters have been collected from previous literature.

Table 2: Bed parameters applied for all transects

Parameter	Value
Median Grain Size (d_{50})	0.2 mm
Geometrical spreading for grain sizes $\left(\sigma = \sqrt{\frac{d_{84}}{d_{16}}}\right)$	1.5
Nikuradse roughness coefficient	4 mm

After giving all necessary inputs (i.e., transects position and dimension, cross-sectional profiles, grid size, beachline orientation and transect orientation and sediment characteristics) in the LITDRIFT model, timeseries of longshore sediment transport has been simulated. Minimum 4/5 years' simulation needs to run for getting better result for LITDRIFT model.

2.2.2 LITLINE model

This model type will calculate the movements of the coastline position with respect to a straight baseline. The model is, with minor modifications, based on a one-line theory, in which the cross-shore profile is assumed to remain unchanged during erosion or accretion. Thus, the coastal morphology is solely described by the coastline position (cross-shore direction) and eventual changes of dune geometry at a given long-shore position. The sediment transport information is derived from information in pre generated littoral drift transport tables. Figure 5 represents the simple flow chart of LITLINE or coast evolution model.

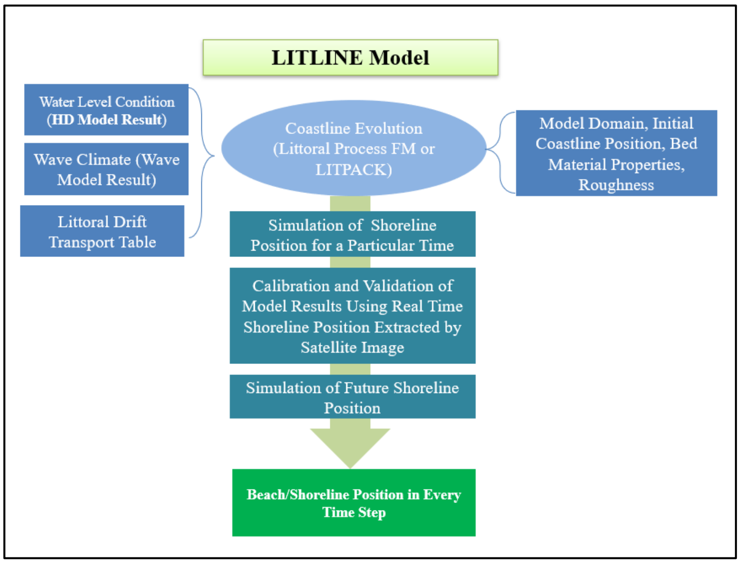

Figure 5: Simple Flow chart of LITLINE model

The coastline evolution calculations are based on a co-ordinate system in which the x-axis is a baseline that runs parallel to the primary coastline orientation, while the y-axis runs from the baseline in offshore direction (Figure 6) $y_c(x)$ is the distance from the baseline to the coastline. Coastline profile is used to denote the variation of y_c in the longshore(x) direction, while the cross-shore profile denotes the water depth (bottom position) as a function of the cross-shore position relative to the coastline position y_c.

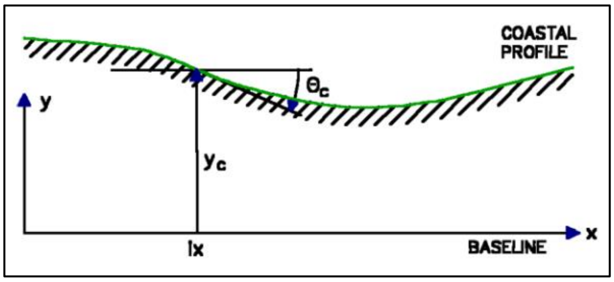

Figure 6: Coordinate system in coastline evolution calculation

2.2.2.1 Governing Equation for LITLINE Model

The main equation in the coastline evolution model is the continuity equation for sediment volumes:

$$\frac{\partial yc(x)}{\partial t} = -\frac{1}{h_{act}(x)}\frac{\partial Q(x)}{\partial x} + \frac{Q_{sou}(x)}{h_{act}(x)\Delta x} \qquad (5)$$

Where, $Y_c(x)$ is distance from the baseline to the coastline, t is time, $h_{act}(x)$ is height of the active cross-shore profile, Q(x) is longshore transport of sediment expressed in volume, x is longshore position, Δx is longshore discretization, $Q_{sou}(x)$ is source/sink term expressed in volume. $h_{act}(x)$ and $Q_{sou}(x)$ are calculated based on user specifications while longshore transport rate Q(x) is determined from tables relating the transport rate to the hydrodynamic condition at breaking. Δx is user specified, while the internal timestep, Δt is determined from stability criteria. From an initial coastline position $y_{init}(x)$, the evolution in time is determined by solving equation using an implicit Crank-Ncholson scheme.
The continuity equation for sediment volumes, equation 5, is solved through an implicit Crank-Nicholson Scheme. The discretization in longshore direction is sketched in Figure 7.

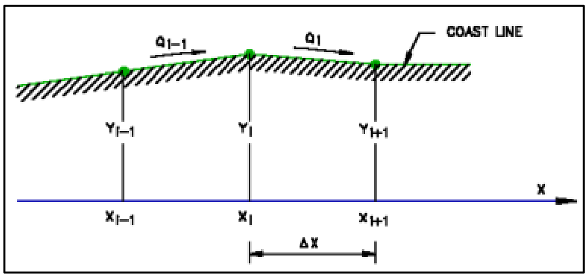

Figure 7: Longshore discretization

Qi denotes the transport rate between x_i and x_{i+1} while dQ_i denotes the change in the transport rate with respect to change in coastline orientation (for values of **θ** close the local orientation **θ_0).**

$$dQ(x) = \frac{\partial Q}{\delta\theta}(x, \theta_0) \qquad (6)$$

A subscript "t" denotes(known) values of the present time step, while subscript "t+1" denotes unknown values of the next time step. Transport rates corresponding to time step t+1 are estimated through:
Based on a crank-Nicholson scheme of the continuity equation can be written as

$$a_i y_{i-1,t+1} + b_i y_{i,t+1} + c y_{i+1,t+1} = d_i \qquad (7)$$

in which

$$a_i = (1-\propto)dQ_{i-1} \qquad (8)$$

$$b_i = \frac{\Delta x^2 . h}{\Delta t} - a_i - c_i \qquad (9)$$

$$d_i = a_i y_{i-1,t} + b_i y_{i,t} + c y_{i+1,t} - \Delta x.(Q_{i,t} - Q_{i-1,t} - QS_i) \qquad (10)$$

Where QS_i is the contribution from possible sources. a_i, b_i, c_i, and d_i can be found for the present time step and with two boundary conditions, the system of equation for all longshore positions can be solved by Gausselimination method. The boundary conditions applied assuming a zero-transport gradient through each boundary. This causes the coastline orientation at the boundaries to be constant. The parameter **α** is the Crank-Ncholson factor.

2.2.2.2 LITLINE Model Development

Model domain can be provided in two ways. Either we can set a mesh file of our interested area (i.e., Kuakata) giving domain type as 2D bathymetry or we can set domain type as work area providing lower left corner and upper right co-ordinates. Here dedicated HD model bathymetry (.mesh file) is used to set model domain.Under littoral processes module model definition is set as coastline evolution which is also known as LITLINE model. Time is set according to user and model requirement. In case of current research study coastline evolution model was run from year 2008 to year 2018. Constant roughness height (0.00040) is used for Bed Resistance for each profile in the model.Water level condition needs to provide in the model. Model can be run without providing water level condition but for more accurate prediction (converging result with actual scenario in faster rate) it is necessary to incorporate water level condition of the study area. In this current study water level is extracted for the year 2008 to year 2018 in somewhere in the middle portion of Kuakata beach from BoB model and used in the model accordingly.

2.2.2.3 Baseline and Initial Coastline Preparation

A coastline under Bathymetry needs to be provided as dfs1 file (i.e., line series) which will be regarded as initial coastline. For this from satellite image of year 2010 the coastline of Kuakata is digitized by ArcGIS tool. Then shapefile is imported in AutoCAD. A baseline is set from which distance of the ordinates of the coastline is calculated with 50-meter interval. Again these 50-meter interval lines are imported in GIS again and length of those lines are calculated. Eventually a dfs1 file is created by MIKE using these values. As the concern is about the erosion of Kuakata beach so only the segment, vulnerable to erosion, is considered for LITLINE model. Moreover, the orientation of beach is bidirectional so by a single baseline (i.e., one orientation angle) it is difficult to represent a coastline. Initial coastline is represented by Figure 8.

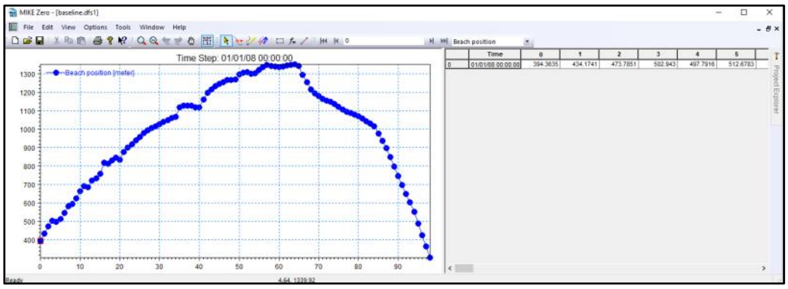

Figure 8: Beach position from baseline (Initial Coastline)

2.2.2.4 Wave Climate Input

Wave climate is derived from the dedicated wave model of Kuakata. Varying in time and space a representative dfs1 file is extracted from dedicated wave model result file and ultimately given as input to the LITLINE model. The components of wave climates are wave height, wave period, mean wave direction and reduction factor. Here reduction factor is assumed to be 1 which means all incident waves are effective (i.e., the strength of wave is not reduced). Wave climate is shown in the following Figure 9.

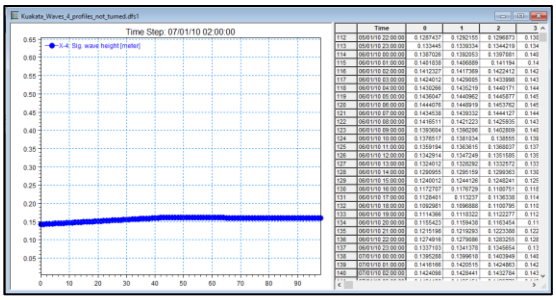

Figure 9: A dfs1 file represents wave climate

2.2.2.5 Littoral Drift Table Generation

A .val file is required to run LITLINE model. To create a .val file we use littoral drift table generation. Under bathymetry predefined cross-shore profiles (i.e., transect-1 to transect-6) are added. Bed resistance for each profile is given as 0.0040. grain diameter and fall velocity for each profile are set as 0.2000 mm and 0.0220 m/s respectively. Bed parameters and sediment calculation are set as default value. In Table Mode under Transport output_table.val file is saved in specified location. If we run this setup we will get .val file which is required for coastline evolution model. If the .val file is opened by notepad, it shows the following data as like Figure 10.

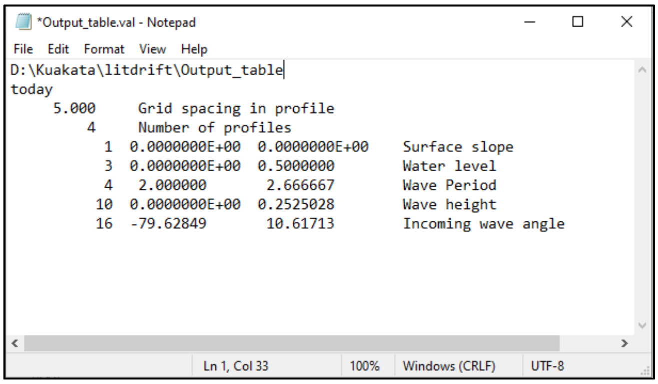

Figure 10: Output_table.val file required for LITLINE Model

Providing all essential inputs in the LITLINE model, time series of beach position is simulated. Future shoreline can also be predicted by this model adopting special technique which is described in the following chapter.

III. Result

Manual calculation of longshore sediment transport, transport from bathymetry data and detailed results from LITDRIFT model and LITLINE model are explained in the following sections. This result will help us to understand coastal morphology and take necessary interventions/measures if it is required.

3.1 Assessment of Longshore Sediment Transport

The littoral transport has been calculated by the model LITDRIFT for several coastal profiles distributed along the coast which is described in the previous section. The littoral drift has been determined for the actual orientation of the coastline and for a range of different coastline orientations to find the sensitivity of the transport to variations in the coastline orientation and the dominant wave direction estimated from the wave simulations by MIKE21 SW. The calculations have also determined the ‘equilibrium orientation’ of the coastline for each profile, which indicates how much the coastline will change its orientation if the transport rate is to be reduced considerably by coastal protection structures like groins, and thereby make it possible to make an estimate of how long and/or how closely spaced protection structures would have to be for being effective.

Littoral drift model is simulated for four years (from 01/01/2015 to 31/12/2018). For getting better result LITDRIFT model should be simulated at least for 4 years which is a prerequisite. Timeseries of wave climate at the end of a transect is extracted from the wave model result and given as input in the LITDRIFT model which is essentially a dfso file. Sediment properties (D50) is given as 0.2 mm and other sediment properties are assumed based previous literature. By data extraction tool of MIKE cross-shore profile is generated along the transect which given in the input in the LITDRIFT model as dfs1 file. Cross-shore profile, sediment properties, coastline orientation and model development are illustrated in the previous section.

The main results from the sediment transport estimation are shown in the Figure 11. It is observed that for transect-1, transect-2, transect-3 and transect-4 longshore sediment transport is toward east direction and found different value for each transect. And for transect-5 and transect-6 longshore sediment transport is toward west direction and here also found different value for each transect. The westward sediment transport is very low compared to eastward sediment transport. As eastward transport higher than the westward transport, the net sediment transport will be from western side to eastern side along the beach through the transect. Maximum erosion occurs in between transect-2 and transect-3 amounts 73,001 m^3 and maximum deposition occurs in between transect-4 and transect-5 amounts 226,094 m^3 which is explained in the Figure 11. Maximum littoral transport is found in transect-4 amounts 216,136 m^3/year. It is also evident that total amount of sediment that eroding from Lebur Char area is depositing in the eastern side and apart from that some sediment flow from the upstream also enters the system and being deposited in the eastern side of Kuakata.

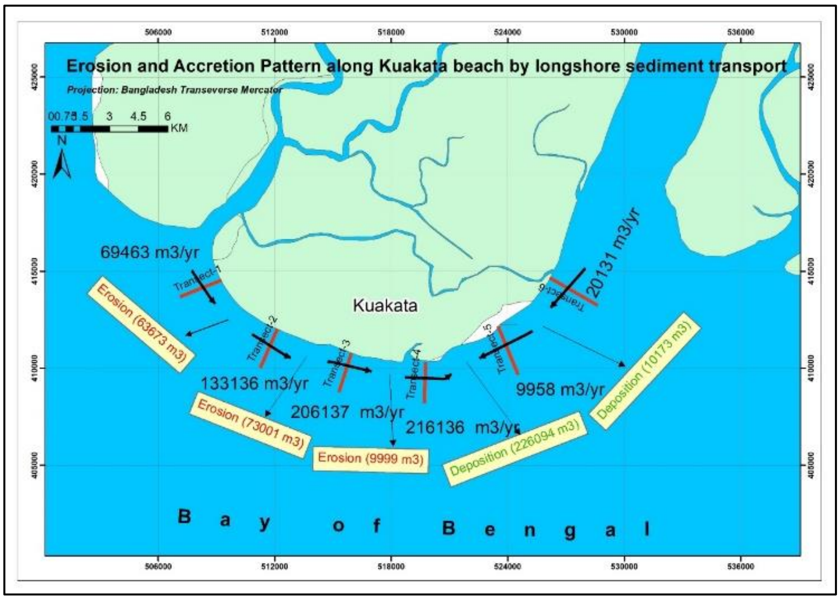

Figure 11: Erosion and accretion pattern by annual littoral transport along Kuakata beach

3.1.1 Calculation of Longshore Sediment Transport Using Empirical Equation

Several empirical formulas have developed by different authors and organizations like CERC (1984), Kamphuis (1991), Van Rijn (1993) and many others. Among them CERC and Kamphuis formula are popular. Here longshore sediment transport is estimated manually using these two formulas and comparison is made with model result.

CERC Formula:

The CERC formula provides an estimate of the instantaneous (gross) sediment transport, ignoring the effects of currents and onshore-offshore processes. It should be noted that longshore sediment transport rates derived using the CERC formulation provide at best an order-of-magnitude estimate of the sediment transport, as there is considerable scatter in reported estimates of the dimensionless K value and as the formulation does not take the effect of wave period into account in the calculations.

The CERC formula is given by:

$$Q = \frac{K}{(\rho_s - \rho)ga'} P_{ls} \qquad (11)$$

Where, Q = Longshore sediment transport rate, K = dimensionless empirical coefficient, related to sediment grain size, ρ_s = sediment density, ρ = water density, g = acceleration due to gravity, a' = solids fraction of the in-situ sediment deposit (1-porosity) and the longshore component of energy flux in the surf zone is given by:

$$P_{ls} = \frac{\rho g}{16} H_{sb}^2 C_{gb} \sin(2\theta_b) \qquad (12)$$

Where, H_{sb} = nearshore breaking height of significant wave, C_{gb} = wave group speed at breaking, θ_b = angle breaking wave crest makes with shoreline

In shallow water,

$$C_{gb} = \sqrt{g d_b} \qquad (13)$$

Where, d_b = depth of wave breaking, which is assumed to be related to the wave breaking height $H_b = 0.78\ d_b$

The values for the parameters in the CERC formula are given below:

The median grain size of sediment (D_{50}) in the surf zone at Kuakata beach from previous literature is found to be 0.20 mm. From Coastal Engineering Manual (2003), an empirically based value for K is around 0.9, based on the median grain size D_{50} = 0.20 mm using coastal engineering manual, 2003. ρ_s is assumed 2650 kg/m^3**,** g is the acceleration due to gravity take as 9.81 m^2/s and a = 1- porosity, Porosity of a typical beach berm is around 40% so a = 0.6.

It is seen from model or wave rose analysis, Lebur Char to Gangamatir Char (i.e., transect 1, 2, 3 and 4) and Kawar Char to Gangamatir Char (i.e., transect 5 & 6) has opposite pattern of longshore sediment transport. From the wave model result file wave climate is extracted near transect 2. Breaking wave height can be calculated giving some input data by Surf Wave Calculator (https://swellbeat.com/wave-calculator/).

Water depth is given from 2D hydrodynamic result file near transect 2. Thus, H_{sb} is found out.

C_{gb} = wave group speed at breaking, which varies with the wave height in accordance with above equation and θ_b = angle breaking wave crest makes with the shoreline. Longshore sediment transport is found using CERC formula is 142,327 m^3/yr.

Kamphuis Formula:

For comparison purposes, the sediment transport direction and relative magnitude is also evaluated using the Kamphuis (1991) expression. This expression is based on an extensive series of hydraulic model tests and depends on breaking wave height, wave period, grain size, nearshore beach slope and nearshore wave approach angle. The expression is given by:

$$Q_k = (6.4x10^4)H_{sb}^2 T_{op}^{1.5} m_b^{0.75} D^{-0.25} sin(2\alpha_b)^{0.6} \quad (14)$$

Where, Q_k = sediment transport rate, m^3/year, H_{sb} = breaking wave height, T_{op} = wave period, M_b = nearshore beach gradient, D = sediment grainsize (i.e., 0.20 mm according to previous literature), α_b = angle breaking wave crest makes with the shoreline.

If data used for the same location in the domain, longshore sediment transport found using above equation is 127,227 m^3/yr.

Kamphuis (1991) method also shows that the main potential is for sediment transport from west to east direction. It is noted that the Kamphuis equation takes into account wave period, which is not a parameter used by the CERC equation.Kamphuis formula estimates lower littoral drift compared to CERC formula. Values are close to net sediment transport estimated from the model which validates the model result to some extent.

3.1.2 Comparison of Longshore Sediment Transport Obtained by Various Methods

So, we can compute longshore sediment transport for a coastline by different methods but data requirement to find out littoral transport varies method wise. CERC or Kamphuis does not provide us the accurate estimation for littoral drift always, but it can be helpful to have an idea. Using bathymetry comparison in nearshore area or the area up to the transect end (depth of closure) longshore sediment transport can be found out with promising result. Based on bathymetry comparison result LITDRIFT model is calibrated to some extent. But most of the time bathymetry is not available for different year then we have to rely on manual calculation. The comparison of longshore sediment transport by different methods are illustrated by the bar chart in following Figure 12.

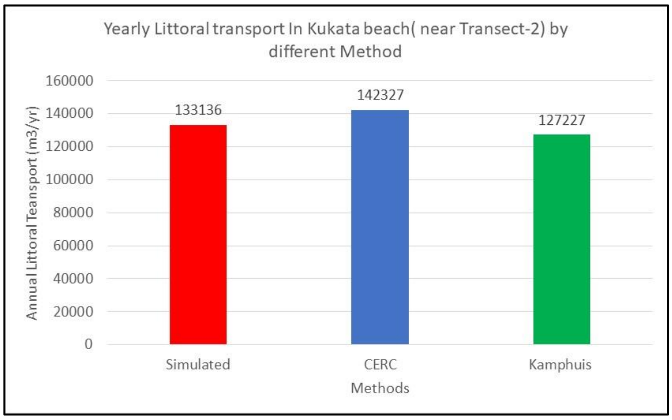

Figure 12: Comparison of simulated longshore sediment transport along Kukata beach with empirical method

So, it can be concluded that there is a significant longshore sediment transport along Kuakata beach which is the prime cause of erosion. Series of groyne can be constructed to arrest this transport, thus combat erosion. As tourism is very important for Kuakata beach, from aesthetic point of view any hard structure like groyne or breakwater might not be permissible. As a result, soft measurement could be undertaken rather than hard structure. In that case beach nourishment can be a good idea to protect the beach from erosion. Estimated annual longshore drift can give idea about the requirement of beach nourishment for the beach.

3.1.3 Longshore Sediment Transport by Bathymetry Data

In practical case it is difficult job to measure the actual longshore sediment transport through a cross-shore profile or a transect. But techniques or technologies are available to measure the transport which is very time consuming and high cost is also involved which can be found in literature review. Another way is there to verify the model estimated littoral transport or longshore sediment transport by comparing two set of bathymetry data (if available) of different time span in the nearshore area up to the depth of closure. This method is widely used to verify the LITDRIFT model. In this study, volume of erosion and accretion have been calculated by GIS tool using bathymetry of 2007 known as C-map and the bathymetry of 2014 downloaded from GEBCO. So, the erosion and accretion volume in 7 years are found 1.3 Mm^3 and 1.5 Mm^3 respectively. From the model we get the net sediment transport transect-2 is 133,136 m^3/year. Total erosion and accretion are found from littoral transport model is 146,673 m^3/year and 236,267 m^3/year. So, in 7 years, erosion and deposition will be 1.03 Mm^3 and 1.65 Mm^3. Thus, the littoral drift model can be verified. Erosion-deposition volume is shown in the Figure 13.

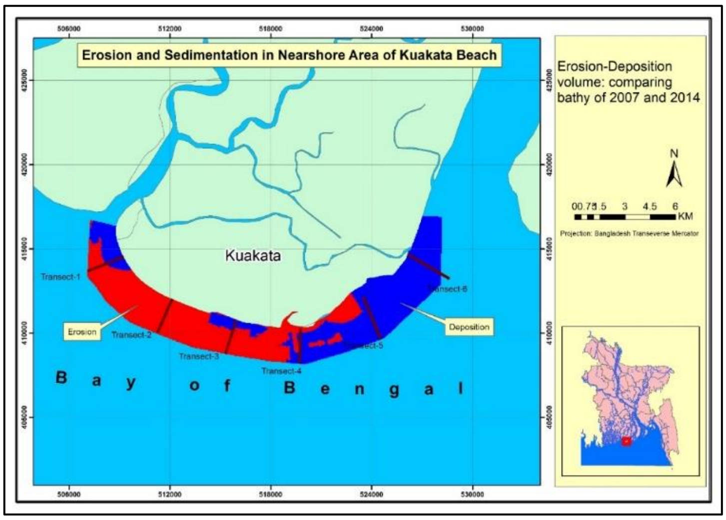

Figure 13: Volume calculation by bathymetry comparison in nearshore area of Kuakata beach using GEBCO bathy data of the year 2007 and 2014

3.1.4 Seasonal Variation of Longshore Sediment Transport

One hydrological year is divided into three seasons for convenience. These are pre-monsoon (January-May), post-monsoon (June-September), and Post-monsoon (October-December). There must be upstream flow variation for different season. There is also impact of seasons in wave climate in the near shore which is the prime reason for longshore sediment transport. The simulation period of LITDRIFT model is 01/01/2015 to 31/12/2018 (i.e., 4 years). Output of the LITDRIFT model provides us timeseries of longshore sediment transport so we get the littoral transport in every time step, and we get accumulation of longshore sediment transport as well. Copying the result from the output (dfso file) into excel, the analysis of seasonal variation of longshore sediment transport.

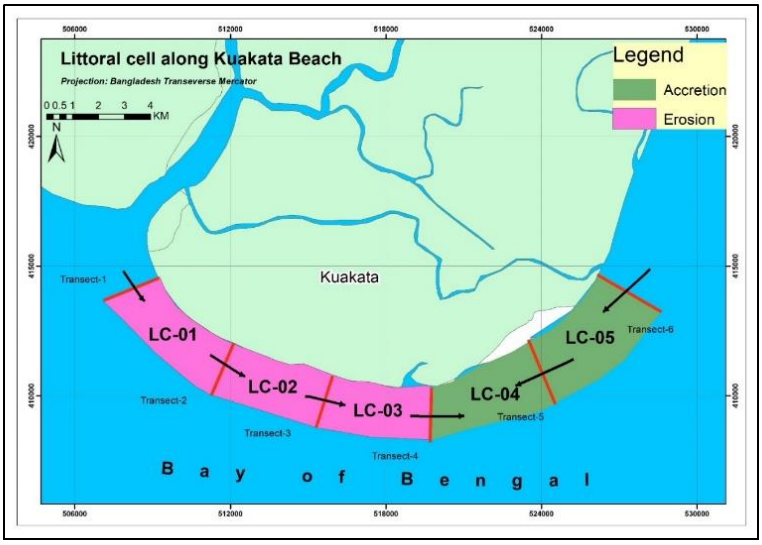

Figure 14: Littoral cell along Kuakata beach

As it is mentioned earlier that, here in Kuakata beach 6 transects are considered. In each transect littoral annual longshore sediment transport is estimated from the model and erosion-accretion pattern are observed and verified with bathymetry and empirical methods of estimating longshore sediment transport. Segment in between 2 transects is called littoral cell. There are total 5 littoral cells (i.e., LC-01 to LC-05) as we see in the Figure 14. Litttoral cell are the portion or segment in between 2 transects where erosion or accretion will be dominant based on the water level condition, wave climate, tidal current and upstream flow. Littoral cell 01 to 03 (red marked) are located on the western side of Kuakata whereas in Littoral cell 04 and 05 are accretion dominant cell. Maximum erosion occurs per year at LC-02 (73,001 m^3) and Maximum accretion occurs per year at LC-04 (226,094 m^3). The amount of erosion-accretion volume is found from Figure 11.

Month wise longshore sediment transport for each transect have been calculated from LITDRIFT result file which is illustrated by

Table 3 and Figure 15. It is evident that considering all 6 transects, there is maximum net longshore sediment transport occurs in June (i.e., 138,087 m^3/month) whereas minimum net longshore sediment transport (1552 m^3/month) occurs in January. Total net LSTR is from west to east direction and estimated value is 5.94 x 10^5 m^3/year.

Table 3: Month wise variation of longshore sediment transport

Station	Longshore sediment transport rate (LSTR) in m^3/month												Net LSTR (m^3/year)	Gross LSTR (m^3/yr)
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec		
Transect-1	214	632	4371	10065	6640	15947	14900	9497	4360	1695	823	319	69463	76409
Transect-2	410	1212	8378	19291	12726	30565	28557	18202	8357	3249	1578	611	133136	141124
Transect-3	634	1876	12972	29868	19704	47325	44216	28183	12939	5030	2443	946	206137	218505
Transect-4	665	1967	13601	31317	20660	49620	46361	29550	13567	5274	2562	992	216136	216136
Transect-5	-123	-364	-1010	-1530	-1046	-1777	-1421	-1066	-187	-721	-370	-343	-9958	9958
Transect-6	-249	-736	-2042	-3092	-2114	-3593	-2873	-2156	-378	-1457	-748	-693	-20131	21741
Net (m3)	1552	4589	36271	85919	56570	138087	129739	82209	38658	13069	6289	1832	594783	683874

Yearly longshore sediment transport is shown in the Figure 16. The highest transport occurs at transect no. 4 (i.e., 216,136 m^3/year). Figure 17 reveals the seasonal variation of longshore sediment transport. It is observed that there is huge impact of season in the longshore sediment transport.

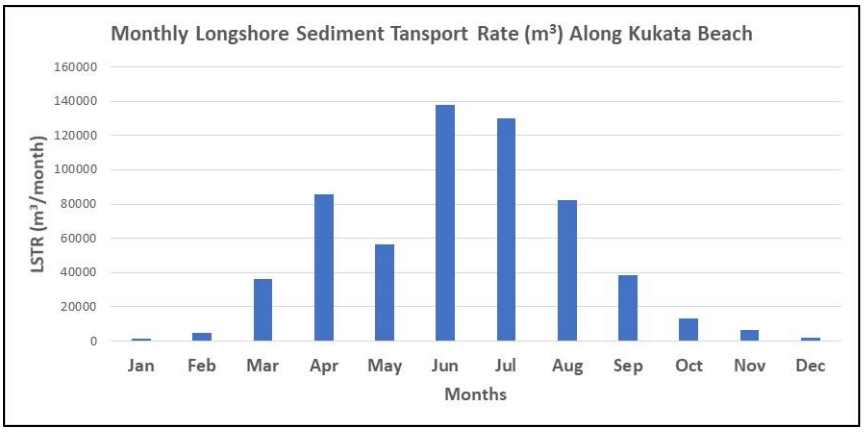

Figure 15: Monthly longshore sediment transport rate along Kuakata beach

Yearly longshore sediment transport is shown in the Figure 16. The highest transport occurs at transect no. 4 (i.e., 216,136 m^3/year). Figure 17 reveals the seasonal variation of longshore sediment transport. It is observed that there is huge impact of season in the longshore sediment transport. From the Figure 17, it is seen that maximum transport occurs at monsoon season, minimum transport occurs at post-monsoon and moderate amount of transport occurs at pre monsoon season. Seasonal longshore sediment transport for pre monsoon, monsoon and post monsoon are 184,900 m^3; 388,693 m^3 and 21,189 m^3 are respectively. So, it can be concluded

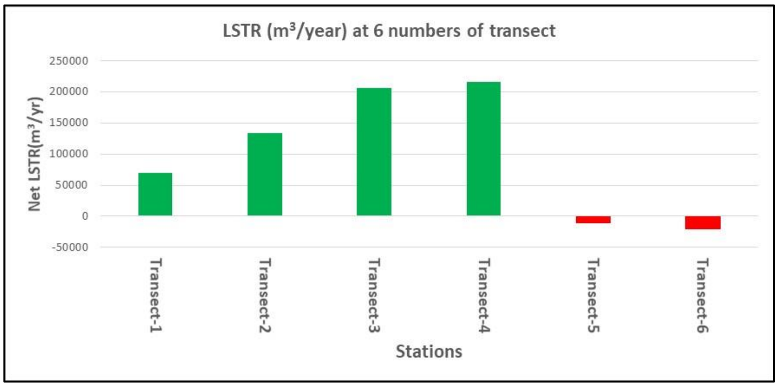

Figure 16: Net longshore sediment transport rate at each transect

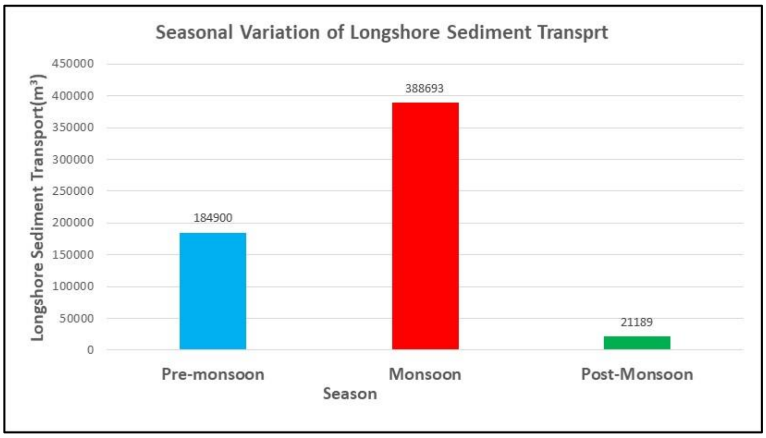

Figure 17: Seasonal variation of longshore sediment transport

that during monsoon nearshore is more susceptible to longshore sediment transport, hence beach will likely be eroded in monsoon.

3.2 Shoreline Evolution Using LITLINE Model Simulation

Coastline evolution or LITLINE model is simulated over the time span 02-01-2010 to 01-01-2019 (i.e., for 9 years). Time step interval is considered as 3600 sec or 1 hour and real time formulation is checked. Under morphology module **Include morphology calculation** is check marked. Update scheme is given as update continuously. Under active profile section height of the active beach is assumed to be 3 m. For active depth baseline.dfs1 is given and active depth is shown accordingly.

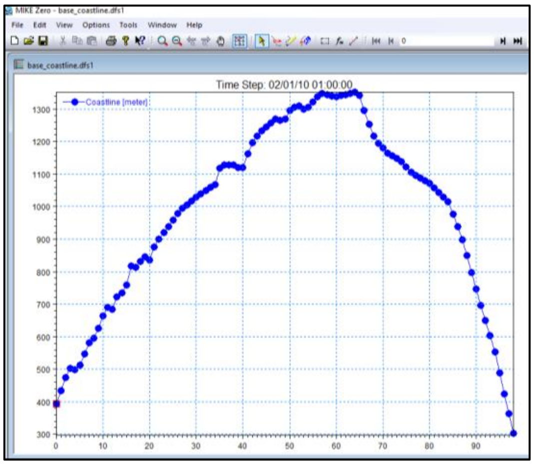

Figure 18: Simulated beach position (output of LITLINE model)

A dfs1 file is obtained as output of the model which indicate the beach position from the baseline at each time step. The output or result file is shown in the Figure 18. Baseline, initial coastline, and simulated coastline are illustrated in the Figure 19. It is observed that coastline is moving landward causing significant amount erosion in eastern side (Lebur Char area). The movement of coastline in the middle portion is not that prominent as like Lebur Char area. Erosion-accretion analysis by satellite images also confirms this phenomenon. From LITLINE model result file it is possible to observe the beach position at any time step of any year whereas it could be done by analyzing satellite images with the aid of GIS tool also which is more accurate but cumbersome job.

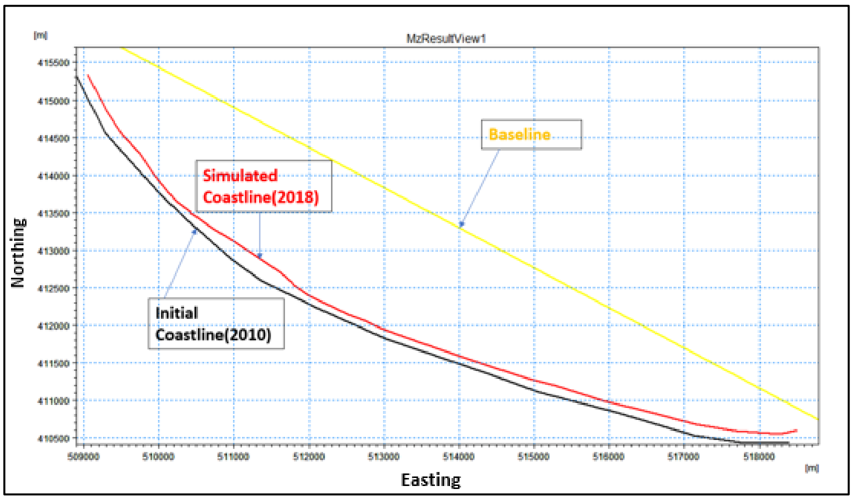

Figure 19: Baseline, initial coastline, and simulated coastline

3.2.1 Verification of LITLINE Model

The LITLINE model is calibrated for the year 2018 and validated for the year 2016 by Sentinel-2 satellite imageries. Sentinal-2 satellite images are found from year 2016 with high resolution (10 x10 m) compared to LANDSAT satellite images. It is good have high resolution images for calibration and validation purpose of LITLINE model. From USGS Sentinel-2 satellite images for dry season (clear image found for the month March) of mentioned year have been downloaded.

To calibrate and validate the coastline evolution model or LITLINE model, actual shoreline of Kuakata beach is digitized from satellite image of the year 2018 and 2016 by ArcGIS tool. Then it is superimposed in the Result Viewer of MIKE Zero with the simulated coastline by the model.

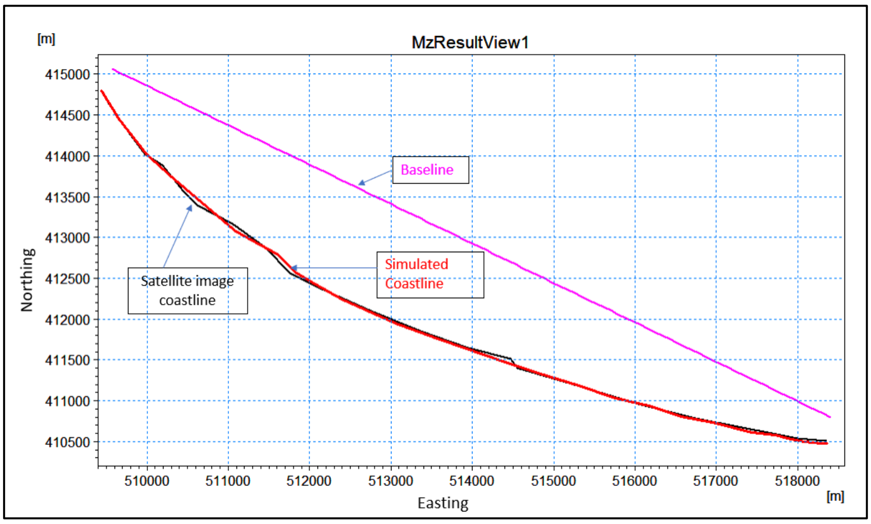

Figure 20: Calibration of LITLINE model for the year 2018

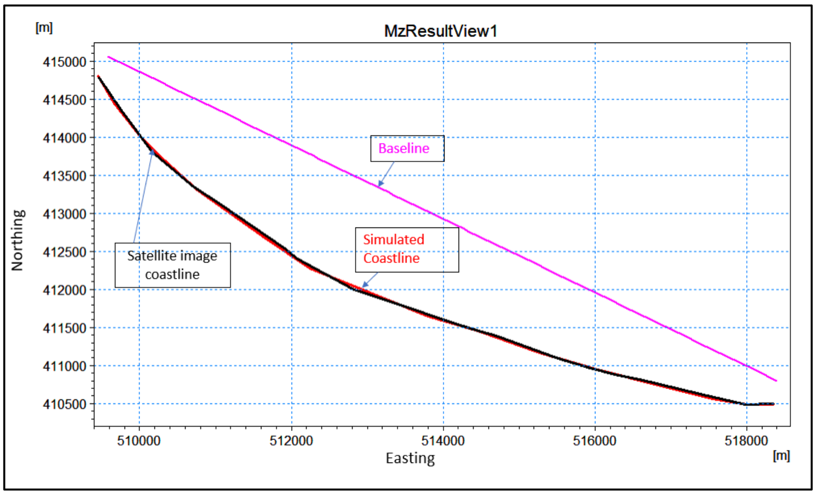

Figure 21: Validation of LITLINE model for the year 2016

The calibration and validation of the LITLINE model are shown in the following Figure 20 and Figure 21 which imply quite satisfactory model result. After calibration and validation of LITLINE model. A long-term simulation (i.e., 9 years) of beach position is conducted for erosion prone area only, the simulated beach position is shown in the Figure 18. It is observed from the simulation result that maximum erosion occurs 240 m in 9 years shown by circle on the map and other places erosion varies 100 to 145 m over simulation period.

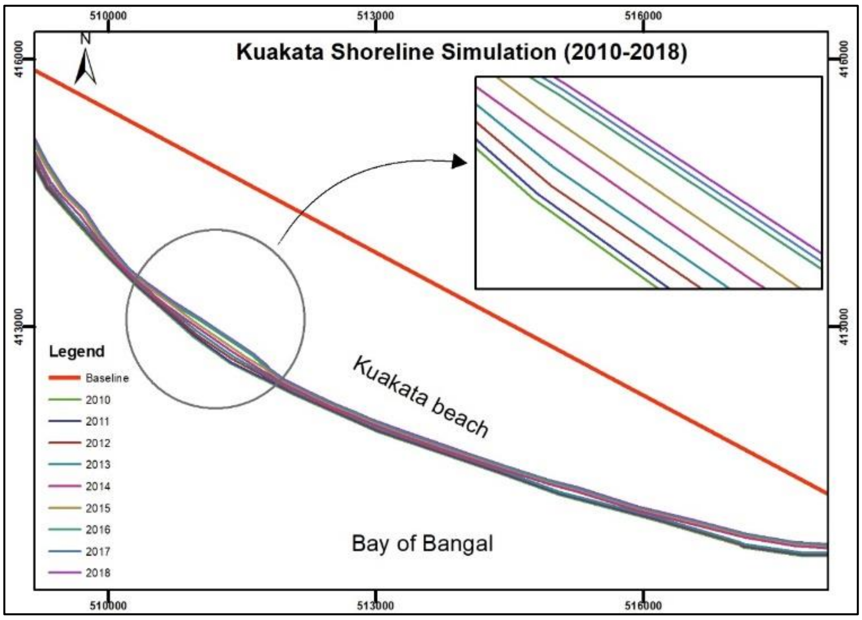

Figure 22: Simulated shoreline position along Kuakata beach using LITLINE model for period 2010 to 2018

3.2.2 Prediction of future shoreline in eroding zone

To predict or simulate future shoreline we require future wave climate data. And to have future wave climate data we require future wave field, wind field and tide level. Global tide model provides tide level at any geographical point on the sea at any time based on the tidal constituents.

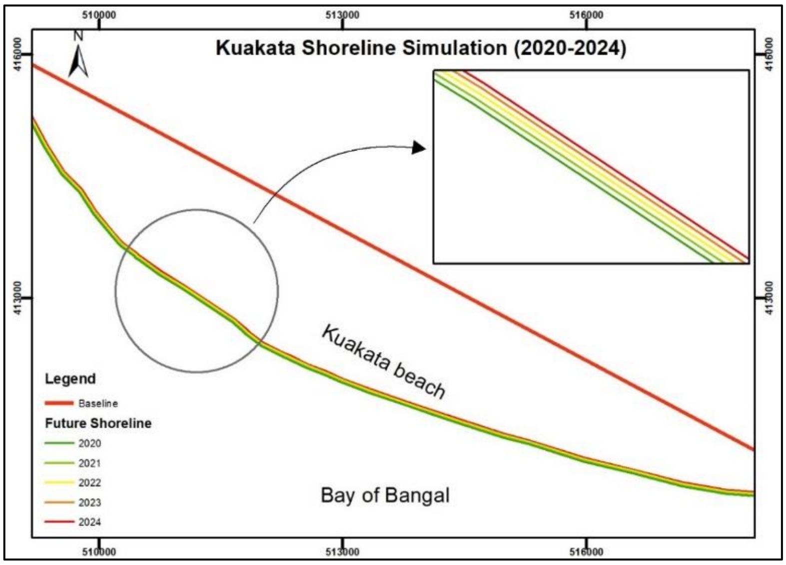

Figure 23: Future shoreline simulation (2020-2024)

But for future wave field and wind field data, it is not possible to have. If we make assumption that last 5 years wave climate will prevail for next 5 years in the study area, then changing the time series of wave climate to future we can predict future shoreline for next five years.

Shoreline evolution model can be used more effectively beach morphology study incorporating structures in the model (i.e., groyne and breakwater). Special technique is to be adopted to predict or simulate future shoreline. It is estimated for future shoreline simulation that shoreline will move further 9.6 m/year in next 5 years.

IV. Discussion

LITDRIFT model was calibrated in different ways (i.e., by bathymetric data and empirical equations) and results are reasonable and promising. On the other hand, LITILINE model is also calibrated and validated with satellite images. Wave climate and hydrodynamic result derived from wave model and hydrodynamic model, also calibrated, and validated as well.Result from the wave model is used in LITDRIFT model. Longshore sediment transport is calculated from LITDRIFT model which is shown in previous chapter. The overall net sediment transport or resultant transport is eastward. 5.94×10^5 m^3/yr sediment transport is seen eastward. Total amount of erosion and accretion are 1.46×10^5 m^3 and 2.36×10^5 m^3 per year which is justified with bathymetry data of Kukata beach area.By coastline evolution model, it is also observed that up to chainage 13 km shoreline is eroding with time and it is verified with real satellite images coastline where same wave climate is used as in littoral drift model which confirms the accuracy of longshore sediment transport estimation. Shorelines of Kuakata are simulated from the year 2020 to 2024. During this period further migrating of shoreline is predicted as 48 m towards the land.

It is evident that significant erosion is taking place along Kuakata beach. Coast management authority can take decision to combat the sever erosion either by hard or soft structural measures. Series of groin could help in this regard for better outcomes. Beach nourishment could be another way to protect but needs to be done recurrently which eventually increases the maintenance cost.

V. Conclusion

Result from wave and hydrodynamic model is used in littoral drift model and LITLINE model. Eventually from littoral drift model sediment budget is estimated and from LITLINE model shoreline changes along beach are observed. Following major findings have been found from this study:

1. Longshore sediment transport is estimated from LITDRIFT model. It is seen that overall net longshore sediment transport is 5.94×10^5 m^3/yr towards east. Erosion occurs at Lebur Char area is 1.46×10^5 m^3/yr and deposition occurs at Kawar Char area is 2.36×10^5 m^3/yr.
2. Coastline evolution model simulated for eroding western side of Kuakata beach and it is verified with real satellite images coastline where same wave climate is used as in littoral drift model which conforms the accuracy of longshore sediment transport estimation. At the same time future shoreline simulation is done where it is seen that eroding beach will erode further at 9.6 m/yr.

Based on this study some recommendations have been summarized below:

1. Kuakata beach morphology study can be done incorporating series of groynes in the coastline evolution model (LITLINE) and different options or scenarios can be analyzed with further studies.
2. Beach nourishment study can further be enhanced using littoral drift model result of this thesis work.
3. Coarser bathymetry is used from C-map and GEBCO in the vicinity of Kuakata beach. Better result can be expected if fine bathymetry would be used. Further study can be carried out using fine bathymetry (if available) and compared with present result.

Acknowledgement

This research work was conducted during M.Sc. Engineering study of corresponding author from Department of Water Resources Engineering of BUET under the supervision Prof. Dr. Md. Ataur Rahman. Modeling software and required data were supported by Institute of Water Modelling (IWM). Authors would also like to be thankful to Prof. Dr. A T M Hasan Zobeyer and Dr. K.M. Ahtesham Hossain, Assistant Professor from department of Water Resources Engineering of BUET and Mr. Rubayat Alam, Director, Coast port and Estuary Division, IWM for their valuable suggestions during the study period.

References

[1]. Appendini, C.M., Salles, P., Mendoza, E.T., and Lopez, J. (2012), "Longshore sediment transport on the Northern Coast of the Yucatan Peninsula", *Journal of Coastal Research,* Vol. 28 (6), pp. 1404–1417.

[2]. Ariya, D.S., Kori, S., and Vaidya, A.M. (2013), "Simulation of shoreline changes along Muthalapozhy Harbour, India", *11th International Conference on Hydroinformatics.*

[3]. Corbella, S. and Stretch, D. D. (2012), "Predicting coastal erosion trends using non-stationary statistics and process-based models", *Coastal Engineering,* Vol. 70, pp. 40-49.

[4]. DHI. (2017), *Scientific document and user guide on Littoral Process FM,* Danish Hydraulic Institute, Denmark.

[5]. DHI. (2017), *Scientific document and user guide on MIKE 21 FM, Danish Hydraulic Institute,* Denmark.

[6]. DHI. (2017), *Scientific document and user guide on MIKE 21 SW, Danish Hydraulic Institute*, Denmark.

[7]. Haque, A. (2018), "A mathematical model study on the hydraulics for the design and construction of a closure in a tidal channel", *M.Sc. Engg. Thesis*, Department of Water Resources Engineering, BUET, Dhaka, Bangladesh.

[8]. Hendriyono, W., Wibowo, M., Hakim, B.A., and Istiyanto, D.C. (2015), "Modeling of sediment transport affecting the coastline changes due to infrastructures in Batang - Central Java, Procedia", *Earth and Planetary Science*, Vol. 14, pp. 166-178.

[9]. Hossain, S. (2015), "Assessment of sediment movement pattern along nearshore coastal water of cox's bazar", *M.Sc. Engg. Thesis,* Department of Water Resources Engineering, BUET, Dhaka, Bangladesh.

[10]. IWM. (2014), *Coastal hydraulic and morphological study and design of protection measures for marine drive road, Institute of water modeling*, Dhaka, Bangladesh.

[11]. José, M., Cáceres, A.I., Brocchini, V. M. and Baldock, T. E. (2012), "An experimental study on sediment transport and bed evolution under different swash zone morphological conditions", *Coastal Engineering*, Vol. 68, pp. 31- 43.

[12]. Nahiduzzaman, S. (2018), "Simulation of storm surge level at a tidal channel due to coastal cyclone along the Bangladesh coast", *M.Sc. Engg. Thesis*, Department of Water Resources Engineering, BUET**,** Dhaka, Bangadesh.

[13]. Noujas,V., and Thomas, K.V.(2018), "Shoreline management plan for a medium energy coast along west coast of India" *Journal of Coastal Conservation*, Vol. 22, pp. 695-707.

[14]. Paul, B. K. (2009), "Human injuries caused by Bangladesh's cyclone sidr: an empirical study", *Natural Hazards*, Vol. 54(2), pp. 483-495.

[15]. Kobayashi, N., Agarwal, A. and Johnson, B. (2007), "Longshore current and sediment transport on beaches", *Journal of Waterway, Port, Coastal and Ocean Engineering*, Vol. 133(4), pp. 296-304.

[16]. Rajab, P.M., and Thiruvenkatasamy, K. (2017), "Estimation of Longshore Sediment Transport Along Puducherry Coast, Eastcoast of India; Based on Empirical Methods and Surf Zone Model." *Indian Journal of Geo Marine Science*, Vol. 46(07), pp. 1307-1319.

[17]. Safak, I. (2006), "Numerical modeling of wind wave induced longshore sediment transport", *M.Sc. Engg. Thesis*, Department of Civil Engineering, Middle East Technical Universitsy, Turkey.

[18]. Sarwar, M., and Woodroffe, C.D. (2013), "Rates of shoreline change along the coast of Bangladesh", *Journal of Coastal Conservation*, Vol. 17(3), pp. 515-526.

[19]. Shetty, A. and Jayappa, K.S. (2020), "Seasonal variation in longshore sediment transport rate and its impact on sediment budget along the wave-dominated Karnataka coast, India*", Journal of Earth Syst. Science*, Vol. 2020, pp. 129-234.

[20]. Thach, N.N., Truc, N.N., and Hau, L.P. (2007)," Studying shoreline change by using LITPACK mathematical model (case study in Cat Hai Island, Hai Phong City, Vietnam)", *VNU Journal of Science*, Vol. 23 (2007), pp. 244-252.

[21]. Yadav, A.K., Dodamani, B.M., and Dwarakish, G.S. (2016), "Estimation of Longshore Sediment Transport Rate: A Review ", *Proceedings of International Conference on Hydraulics*, Water Resources and Coastal Engineering (Hydro2016), CWPRS Pune, India.

Dipen Saha, et. al. "Simulation of Longshore Sediment Transport and Coastline Changing Along Kuakata Beach by Mathematical Modeling". *IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)*, 19(3), 2022, pp. 15-31.