ASSESSMENT OF SEDIMENT MOVEMENT PATTERN ALONG NEARSHORE COASTAL WATER OF COX'S BAZAR

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CERTIFICATE OF APPROVAL

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It is hereby declared that this thesis work “Assessment of Sediment Movement Pattern Along Nearshore Coastal water of Cox‟s Bazar” has been done by me. Neither of the thesis nor any part of it has been submitted elsewhere for the award of any degree or diploma.

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D_*	Characteristics Particle Diameter
G	Soil Density
I	Nodal points along X-axis
J	Nodal points along Y-axis
γ	Specific weight of water
γ_s	Specific weight of sediment
γ_s'	Specific weight of submerged sediment
λ	Characteristic sediment coefficient
τ_0	Bed shear stress
τ_c	Critical shear stress
υ	Kinematic Viscosity
S_a	Reference concentration
S_e	Fall Velocity
T	Transport Stage Parameter
U_*	Shear Velocity
U_{*cr}	Critical Shear Velocity

LIST OF ABBREVIATIONS

ADI	Alternating Direction Implicit
BOB	Bay of Bengal
BTM	Bangladesh Transverse Mercator
CDS	Coastal Development Strategy
CEGIS	Centre for Environmental and Geographic Information Services
CEM	Coastal Engineering Manual
CZPo	Coastal zone policy
DIVAST	Depth Integrated Velocity and Solute Transport Model
ERDDAP	Environmental Research Division's Data Access Program
GBM	Ganges-Brahmputra-Meghna
ICZMP	Integrated Coastal Zone Management Plan
IPCC	Inter-Governmental Panel of Climate Change
IWM	Institute of Water Modeling
LGM	Last Glacial Maximum
MS	Magnetic Susceptibility
SPM	Shore Protection Manual
UTM	Universal Transverse Mercator

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ABSTRACT

Cox‟s Bazar is the most important Coastal district of Bangladesh. Coastal resources provide here the opportunities to use the coast in different ways within the hazard-prone environment. The shape and orientation of the coastal landforms near Cox‟s Bazar is primarily based on sediment transport. Mathematical model can be used successfully to forecast this sediment movement pattern in nearshore coastal water of Cox‟s Bazar. Validity of forecast in sediment transport depends on both mathematical modeling technique and boundary conditions.

In this research a numerical two dimensional hydrodynamic Depth Integrated Velocity and Solute Transport Model (DIVAST) has been set up at nearshore coastal water of Cox‟s Bazar to assess the sediment movement pattern. An observation was made on the condition of suspended sediment and bed load along the study area by changing wave angle for 2 cases, one is for the boundary condition generated within the study area (case 1) and another is for the boundary condition generated outside of the study area from deep sea (case 2). The model output for both suspended and bed load is representing here one by one plotting them in surfer software to visualize and assess the sediment movement pattern in nearshore coastal water of Cox‟s bazar covering three very important beach of Bangladesh, kolaboti beach, Laboni beach and Inanibeach and the adjacent area of Moheshkhali channel. At first, the model was run for the wave angle 230^{o}. Gradually it was changed for every 10^{o} and the model output is presented here up to wave angle 290^{o}. Some selected model output for wave height and radiation stress is also presented in this thesis paper.

The wave angle 230^{o} for case 1 and 240^{o} for case 2 were found most critical because of a considerable amount of suspended and bed load movements occur with these wave angles. The amount of sediment concentration has found to be negligible for incoming wave angle of 260^{o}, 270^{o} and 280^{o}. After 290^{o} the suspended sediment movement and after 270^{o} the bed load movement was found insignificant. The sediment concentration is higher along the shore line than the other point of the study area.

CHAPTER 1
INTRODUCTION

1.1 General

The Bay of Bengal, a shallow ocean is at the northeastern part of the Indian Ocean. It is characterized by a broad U-shaped basin and occupies an area of about 2,173,000 square km, located between latitudes 5° and 22°N and longitudes 80° and 100°E. It is about 2090 km long and 1610 km wide, with an average depth of more than 2600m and the maximum depth is 5258m and bordered by Sri Lanka and India to the west, Bangladesh to the north, Myanmar and the northern part of the Malay Peninsula to the east. The Bay of Bengal receives a great amount of sediments from various sources including the Himalaya, Trans–Himalayan plutonic belt, Indo-Burma Ranges and the Peninsular India through the major rivers, the Ganga, Brahmaputra, Irrawaddy etc. (Tripathy et al., 2011).

Figure 1.1: Bangladesh and Bay of Bengal (Source: Wikipedia).

Coastal zone is always on the forefront of civilization and has been by far the most exploited geomorphologic unit of earth. Its easy access and resourcefulness have always attracted human activities. A study of IPCC in 2001 reveals that 20 percent and 40 percent of the world‟s population live within 30 kilometers and 100 kilometers of the coast respectively. Coastal zones are continually changing because of dynamic interaction between the ocean and land. Tides, waves and winds are responsible for depositing sediment on a continuous basis along such zones (Komol, 2011). The coastline of Bangladesh is of around 734 km and the Cox‟s Bazar beach lies at the northeastern stretch of the Bay of Bengal (Banglapedia, 2014). The beach of Cox‟s Bazar is sandy, gently sloped and it fronts a range of dunes. The dunes, spit and beach have been built up over hundreds of year through a combination of wave action and deposition of sediment from the Bay of Bengal (Alam et al, 1999). The shape and orientation of the coastal landforms near Cox‟s Bazar is primarily based on sediment transport. Mathematical model can be used successfully to forecast this sediment movement pattern in nearshore coastal water of Cox‟s Bazar.

1.2 Background of the Study

Coastal plains are one of the key focal points of human interests. In Bangladesh, coastal areas are being used for a wide variety of purposes such as settlement, agriculture, fishing and communication. Over the last two to three decades rapid population expansion on the coastal plains has exerted tremendous pressure on the fragile coastal resource base (Alam et al., 1999). The coastal zone of Bangladesh is often perceived as a zone of multiple vulnerabilities. But it has much potentials and opportunities.

The coastal zone of Bangladesh covers 47,201 square km land area, which is 32 percent of total landmass of the country. Total population living in the coastal zone is 35.1 million that represent 28 percent of total population of the country (Islam, 2004). The coastal areas of Bangladesh are different from rest of the country due to its unique geo-physical characteristics and vulnerability to several natural disasters like cyclones, storm surges, erosion and sea level rise (Komol, 2011). It has been identified as one of the 27 countries which are most vulnerable to the impacts of coastal region mainly on drainage congestion, fresh water abundance in monsoon, fresh water scarcity in dry season, inundation of land, unsteady morphological processes and extreme events (IWM and CEGIS, 2007). The shape of the coastal zone is quite unstable and changing time to time due to erosion and accretion (Sarwar, 2005). Different combinations of wave and current interaction causes complicated patterns of grain transport that are not always reflected by the bedform configurations. In these areas, the use of bedforms for current and sediment transport analysis is restricted (Oertel, 1972). In such cases mathematical modeling is very effective for studying the processes and pattern of sediment transport.

Sediment transport is the mechanism by which coastal erosion or deposition proceeds. It is one of the important fields of knowledge which is used to determine whether erosion or deposition will occur in future. It also determines the magnitude of erosion and deposition and the time and distance over which it will occur (Wikipedia, 2014). Coastal sediment transport takes place in near shore environments due to the motions of wave and currents. It results in the formation of characteristic coastal landforms such as beaches, barrier and capes (Ashton et al., 2001). The Study of sediment transport plays an important role in determining areas of coastal erosion and accretion. It can provide vital information for the direction of sediment movement, quantity and also the processes that governs the transportation (Kunte et al., 2013).

In system with boundaries that are subject to deposition or scour, it is necessary to model the movement of the sediment particles with the flow to study all these phenomena mentioned above. These models are also used to improve the understanding of different morphological processes in different areas. Although sediment transport modeling is a complex topic and is subject to much uncertainty, mathematical modeling is comparatively effective in studying sediment transport including yield, distribution and management of sediment (Tan, 2005). To develop and understand the physical processes responsible for shaping the ongoing evolution of the coast and to develop the management strategies to deal the impact of human activities on the coastal zone and as well as for adapting to the hazards associated with the people living on the coast, knowledge of the mechanism, processes and the pattern of sediment transportation in the nearshore zone is the key component.

This study is important because here the mathematical modeling is very effectively used to assess the sediment movement pattern in nearshore coastal water of Cox"s Bazar which is the most important part of the coastal zone of Bangladesh.

1.3 Objectives of the Study

This research is undertaken to assess the sediment movement pattern in nearshore water of Cox"s Bazar with the help of a mathematical model based on FORTRAN-IV language using the bathymetry data, wave height, wave period and wave direction**.** More specifically, the overall objective of the study is as following.

1. To set up the morphological model for Cox's Bazar coastline to assess the sediment movement pattern.
2. To assess the suspended and bed load concentrations at different locations.
3. To assess the sediment movement due to the change in wave directions.

Possible Outcome

In this research a numerical two dimensional hydrodynamic Depth Integrated Velocity and Solute Transport Model (DIVAST) has been set up at nearshore coastal water of Cox"s Bazar to assess the sediment movement pattern. An observation was made on the condition of suspended sediment and bed load along the study area by changing wave angle for 2 cases, one is for the boundary condition generated within the study area (case 1) and another is for the boundary condition generated outside of the study area from deep sea (case 2). The model output for both suspended and bed load is representing here one by one plotting them in surfer software to visualize and assess the sediment movement pattern in nearshore coastal area of Cox"s bazar covering the three very important beach of Bangladesh, kolaboti beach, Laboni beach and Inani beach and the adjacent area of Moheshkhali channel. At first, the model was run for the wave angle 230^{o}. Gradually it was changed for every 10^{o} and the model output is presented here up to 290^{o}. Some selected model output for wave height and radiation stress is also presented in this thesis paper.

1.4 Organization of the Thesis

This thesis paper consists of five chapters. Outlines for each chapter are given bellow.

Chapter 1 which is the introductory part of this paper highlights the background, the objectives and the possible outcome of the study.

Chapter 2 of this thesis paper is Literature Review. It describes the zoning at the Coastal Part of Bay of Bengal and zoning of coastal area in Bangladesh. It also highlights the Morphology of the Cox"s Bazar Coastal Plain. This chapter contains Previous Sediment Related Studies on Bay of Bengal and Previous studies on Coastal Area of Bangladesh. At last it focuses on the scope of this research work and related terminologies and summery of this research work.

Chapter 3 is Theory and Research Methodology. This chapter discusses about the hydrodynamic of nearshore zone, radiation stress, types of sedimentation, process of sedimentation, pattern of sedimentation, modes of sediment transport and related theories. It highlights the necessity of Mathematical Model and Data Requirements and describes the DIVAST model. IT also describes the study area where the research work is carried out. It also contains the important equations which are related with the research work. The details about data collection, data organization and processing of data to set up the bathymetry, select the boundary conditions and create all necessary file to run the mathematical model is represented here step by step to describe the methodology of this research work.

Chapter 4 describes how the model is calibrated and validated. Then represents different maps for different output of suspended sediment and bed load for case 1 and case 2. Some selected model output for wave height and radiation stress is also represented at the end of this chapter. This chapter also contains some discussion based on the comparison of those maps.

Chapter 5 is Conclusions and Recommendations which provides the overall conclusion of the study and some recommendations for the future study.

CHAPTER 2
REVIEW OF LITERATURE

2.1 General

Coastal zone means the coastal waters (including the lands therein and thereunder) and the adjacent shorelands (including the waters therein and thereunder), strongly influenced by each other and in proximity to the shorelines of the several coastal states, and includes islands, transitional and intertidal areas, wetlands, and beaches. The zone extends inland from the shorelines only to the extent necessary to control shorelands, the uses of which have a direct and significant impact on the coastal waters, and to control those geographical areas which are likely to be affected by or vulnerable to sea level rise. Coastal zones are continually changing because of the dynamic interaction between the oceans and the land. Tides, waves and winds are responsible for depositing sediment on a continuous basis and rates of erosion and deposition vary considerably from day to day along such zones (Rochette, 2010).

2.2 Zoning at the Coastal Part of Bay of Bengal

Bay of Bengal is the largest bay of the world [Wikipedia, 2014]. The coastal part of the bay can be divided into 3 parts: Central coast, West coast, and East coast.

The Central coast, associated with Indian and Bangladesh boarder, revealed a decreasing gradient towards the north. The Upper Bengal fan, situated at this part along with Swatch of no ground is one of the world largest canyons of the world. Continental shelf of the central coast has been found to be more flat and extended around 150 to 200 km in width. Continental slope was found to be extended in between 100m to 2000m with the depth increasing gently towards southwest part.

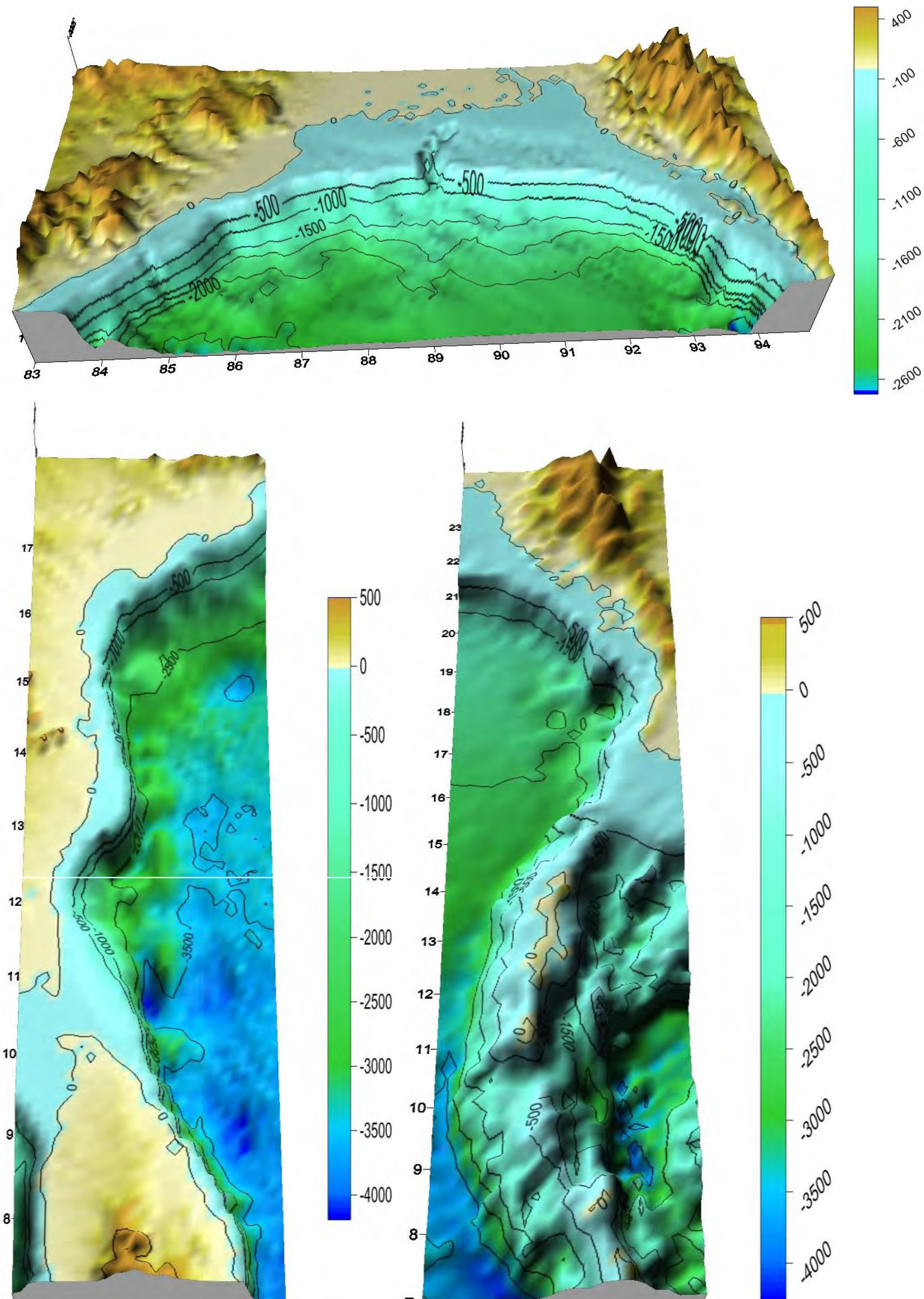


Figure 2.1: Central coast (upper one), West coast (left one) and East coast (right one) of Bay of Bengal (Source: Kader et al., 2013).

The West coast has been found to be associated with the Indian and Sri Lankan country boundary. The Palk Strait bay separated Sri Lanka from India while both countries are found to be situated at the same crustal plate. Sri Lankan continental slope has been found to be steeper than the Indian part. Depth was found to be increased from north to south direction with abrupt changes in the sea floor features.

The East coast bordered by Bangladesh, Myanmar and Andaman Islands. The continental shelf of this part has been found to be broader in comparison to the west part. Andaman Islands are situated at the south portion of the region. All Andaman Islands, situated at the same crustal plate, have been found in this portion of the region (Figure 2.1) (Kader et al., 2013).

2.3 Zoning of Coastal Area in Bangladesh

Bangladesh is a flood plain delta, sloping gently from the north to the south and meets the Bay of Bengal at the Southern end. The coastal region of Bangladesh is marked by morphologically dynamic river network, sandy beaches and estuarine system. The whole coast runs parallel to the Bay of Bengal. According to the coastal zone policy (CZPo, 2005) of the Government of Bangladesh, 19 districts out of 64 are in the coastal zone covering a total of 147 upazillas of the country (figure 2.2).

The southern part of Bangladesh falls under coastal zone that receives discharge of numerous rivers, including Ganges-Brahmputra-Meghna (GBM) river system, creating one of the most productive ecosystems of the world. Except Chittagong-Cox‟s Bazar, all parts of the coastal zone are plain land with extensive river networks and accreted land, which is known in Bangladesh as char land. India is at the west of the zone whereas Myanmar is at the east of the coast. The coastal zone of Bangladesh has been divided into three regions namely eastern, central and western coastal region.

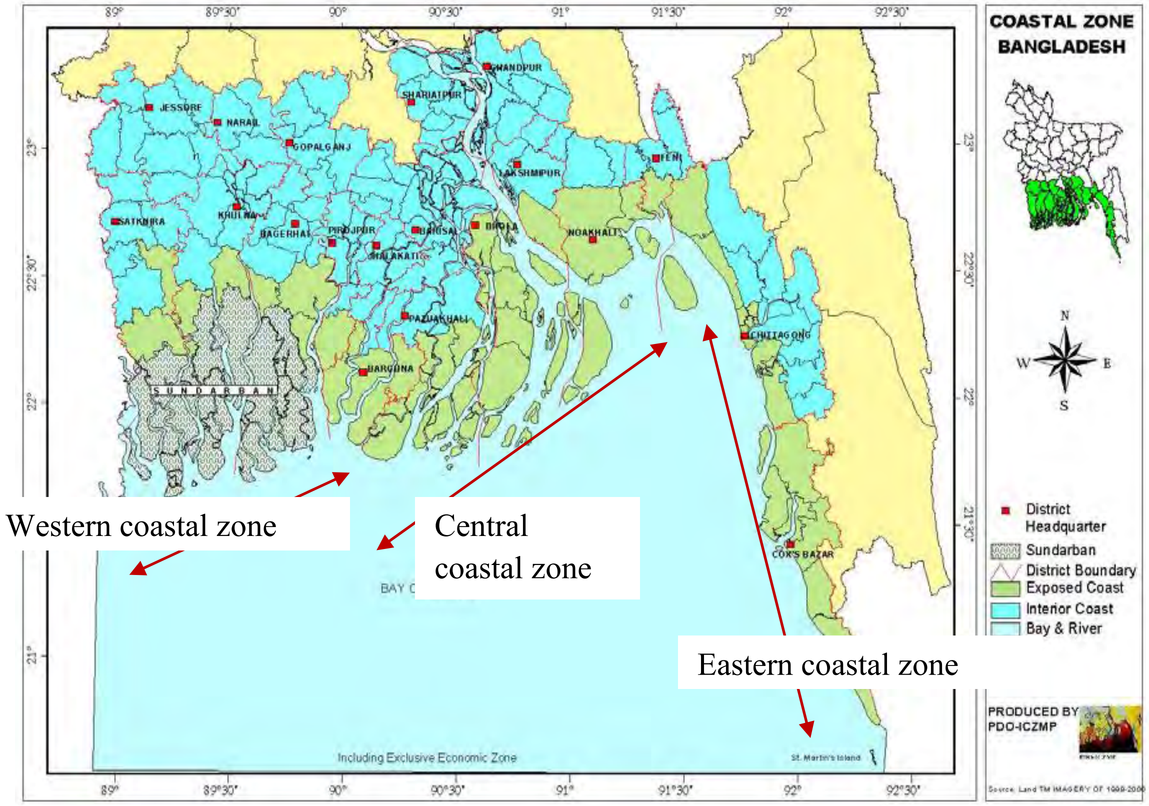


Figure 2.2: Map of the coastal zone of Bangladesh (Source: ICZMP, 2006)

Eastern coastal zone

The eastern coastal zone starts from Bodormokam, the southern tip of mainland to the Feni river estuary. This zone is very narrow. A series of small hills are run parallel to this zone. Karnafully, Sangu and Matamuhury river falls into the Bay of Bengal in this area. The Naf river falls to the Bay of Bengal dividing Bangladesh from Myanmar. Soil characteristics of the eastern coastal zone are dominated by submerged sands and mudflats. The submerged sand of the zone has formed a long sandy beach of 145 km from Cox‟s Bazar towards Teknaf. Two of the country‟s most important sandy beaches from tourists‟ perspective, namely Patenga and Cox‟s Bazar are located in this coastal zone. Fish farming, fishing in the bay, salt production and tourism are main economic activities of the zone.

Central coastal zone

Central coastal zone extends from Feni river estuary to the eastern corner of the Sundarbans, covering Noakhali, Barisal, Bhola and Patuakhali districts. The zone receives a large volume of discharge from the Ganges-Bhrahmputra-Meghna river system, forming high volume of silty deposition. More than 70% of the sediment load of the region is silt; with an additional 10% sand. Because of the sediment discharge and strong current, the morphology of the zone is very dynamic and thus erosion and accretion rates in the area are very high. Numerous islands are located in the area including the country‟s only island district Bhola. Many islands have been formed in last few years in the area by the process of land accretion. At the same time many have been eroded or disappeared. Kuakata, an attractive sandy beach is located at the zone under Khepupara upazilla of Patuakhali district

Western coastal zone

The western coastal zone is covered by the Sundarbans mangrove forest, covering greater Khulna and part of Patuakhali district. Because of presence of mangrove forest, the zone is relatively stable in terms of soil erosion. Mangrove swamps, tidal flats, natural levees and tidal creeks are characteristics of the zone. Mangroves of the area support feeding and breeding grounds for fish and shrimps species, enriching the area in fisheries bio-diversity. The area lies at 0.9 to 2.1 metre above mean sea level. Soil characteristics of the western coastal zone are silty loams or alluvium. The mangrove dominated coastal areas have developed on soil formations of recent origin consisting of alluvium washed down from the Himalayas. The zone also has tourist attraction in the Sundarbans (Komol, 2011).

2.4 Morphology of the Cox's Bazar Coastal Plain

Cox‟s Bazar is the most important Coastal district and tourist area of Bangladesh. It is bound on the east by low hill ranges, on the west by the Bay of Bengal, on the north by the Bakkhali estuary and Moheshkhali channel and on the south by the headlands.

The area of Cox‟s Bazar changes to bigger or smaller due to erosion resulting in the formation of islands or char (Banglapedia, 2014). The coast of Cox‟s Bazar has land forms of two distinct origins: fluvial and Marine. Beach and dunes are the two most prominent features of the coast.

The beach of Cox‟s Bazar appears with a wide base of 20km in a north-south direction and gradually narrows down to about 3km at the seaward end. The area is directly exposed to the long shore current and periodic tidal oscillatory wave with occasional flood due to the cyclonic storm surges. The floodplain of Cox‟s bazar is elongated in shape and covers an area of 9.30 square km. The area lies at lower elevation than the dunes of the beach plain and gently slopes towards the Bay of Bengal. The floodplain is connected to the sea by narrow outlets of the coastal channels and tidal creeks. The beach plain covers an area of 2.60 square km which is also an elongated shape of land and the width of the beach is 200-300 m at the mean sea level. It is elevated at their landward parts and gradually slopes towards the Bay of Bengal. The elevation of the marginal parts of beach plain is of the order of 2 to 3 m above the mean sea level and the area is covered by dunes. The beach is a flat land tilted in the direction of the Bay of Bengal. There is an accumulation of varied types of sediment, usually of sand size or above at the land-water interface. In most parts of the beach plain, dunes and beach are located side by side but in few cases these two units are separated by tidal creeks. Tidal creeks are shallow and wide channels with variable depths and widths ranging from 1-1.5 and 50-100m respectively. The area covered by dunes is about 1.60 square km, with a maximum width of approximately 200 m. it lies in a north-south direction and almost parallel to the beach plain. Dunes are highly susceptible to coastal hazards such as storm surge, spring tide, cyclone etc. But they can recover in 3 to 6 months when yields to these hazards.

The sedimentation and its evolutionary sequence of the coastal plains indicates an infilling of a sheltered basin within a relatively high wave and micro to meso tidal conditions. Sediments of the Cox's Bazar beach plain are mostly coarse while those of the flood plain are fine. Beach plain sediments are also better sorted than those of the floodplain deposits (Alam et al., 1999).

2.5 Previous Sediment Related Studies on Bay of Bengal

Kolla and Rao (1990) made a study on Sedimentary Sources in the Surface and Near-surface Sediments of the Bay of Bengal. Fine fraction (< 2μ) mineralogy and heavy minerals in sand suggest that sediment of the Western Bengal Fan have been derived from Peninsular Indian rivers; sediments of the rest of the fan are derived from Himalayan rivers. The sediments on the Ninety East ridge and in the deep southerly areas beyond the reach of fan deposition result from the in situ alteration of volcanics (Kolla et al., 1990).

Curray, (1994) describes about Sediment Volume and Mass Beneath the Bay of Bengal. The objective of this study was to put on record the best estimates which are possible with existing data of the volume and mass of sediments, sedimentary rock and meta-sedimentary rock beneath the sea floor of the Bay of Bengal (Curray, 1994).

The Bay of Bengal receives large volume of sediments discharged through seven major rivers, the largest of them being the Ganga and the Brahmaputra river system (G-B). These sediments preserve records of the sediment discharged from these rivers. Sediment composition of the Bay appears to be mainly governed by three processes viz. detrital, biogenic and diagenetic, with detrital being the dominant in this region. Their input reveals physical and chemical erosion of the terrain over which they flow and is strongly dependent on the monsoon intensity, especially the southwest or summer monsoon. The sedimentation rate for 4032 varied significantly with a faster rate at ~20 Ka consistent to that reported from the southeastern Arabian Sea with enhanced sedimentation rates by a factor of 3-4 high during Last Glacial Maximum (LGM) compared to other periods during the past ~30 ka. During the last LGM, the Bay of Bengal experienced enhanced sedimentation due to significant detrital flux. The sedimentation rate remained constant at 1.7cm/ka in 4040 at the top of 90^{o}E ridge. Paleoclimatic Studies from Sediments in the Bay of Bengal was made by Bhushan et al. (2007). This study reports results from the two gravity cores (4032; ~13.36^{o}N; 88.9^{o}E and 4040; 6.03^{o}N; 89.94^{o}E) collected from the central and southern Bay of Bengal respectively (Bhushan et al., 2007).

Sediment dispersion in the Bay of Bengal has been studied by Mohanty et al. (2008). This study showed how the different issues affect the dispersal pattern in the Bay of Bengal. This unique semi-enclosed basin experiences seasonally reversing monsoon and dispersions, severe cyclonic storms and consequently receives a large amount of rainfall and river run-off. It also encounters the largest seasonal sea level fluctuations. The circulation and Hydrography of the Bay of Bengal is complex due to the interplay of semi-annually reversing monsoonal winds and the associated heat and fresh water fluxes. Apart from this, the inflow of warm high saline waters of the Arabian sea, the persian Gulf and thered sea origin and a number of synoptic disturbances originating during both pre and post monsoon period affect the dispersal pattern of sediment (Mohanty et al., 2008).

A temporal high-resolution analysis of Sr–Nd isotopic composition, Fe, Al and V concentration and magnetic susceptibility (MS) has been carried out in a sediment core from the western Bay of Bengal to trace sediment sources was done by Tripathy et al. (2010). Significant variations in the Sr and Nd isotopic composition and corresponding

MS and elemental Fe/Al and V/Al ratios are observed in the sediment core with depth (time) indicating variable contributions from sources. The observed changes in the sediment provenance correlate well with the climatic record of the region, highlighting the important influence of climate over erosion. Relatively lower 87Sr/86Sr and higher εNd corresponding to the Last Glacial Maximum (LGM) suggests proportionally reduced sediment contribution from the Himalaya. Erosion rate over the Himalaya decreased during LGM due to combined influence of reduced intensity of the southwest monsoon and larger extent of glaciations over the Higher Himalaya, the main source of sediments to the Bay of Bengal (Tripathy et al., 2010)..

Kader et al. (2013) studied the bathymetry of the Bay of Bengal based on open source satellite and sounding data. An attempt has been taken to produce a bottom topographic 3D map using open source sounding and satellite data available for the Bay of Bengal area. Topographic data has been collected from the Environmental Research Division's Data Access Program (ERDDAP) live server under griddap protocol. Swatch of no ground, found at the northern part of the bay was most probably due to the heavy sedimentation load from the upper streams of the mighty river systems. Likewise, except the uneven features have been observed at 85°E longitude in between 14°N to 7°N known as 85°E ridge, rest part of the ridge was found to be buried under the huge sediment load. An unidentified bathymetric positive elevation in between86.0°E to 86.4°E and 6.2°N to 6.7°N with a height of 250 m suggested some tectonic or geophysical activities around the elevation. The Ninety East Ridge, most prominent and important feature, was found to be headed at the Bay of Bengal with height variation of 1000 to 1500m (Kader et al., 2013)

2.6 Previous Studies on Coastal Area of Bangladesh

Ahmed (1998) researched on residual tidal and sediment volume, their circulation patterns and land cover changes in the Meghna estuary. Here the tidal and sediment volume computed from hourly measurement and their residual direction in the estuary of the lower Meghna have been studied based upon an analysis of tidal velocity and sediment concentration measurements during full tidal cycles mostly at the time of premonsoon and postmonsoon for the period 1986- 1994 (Ahmed, 1998)

Alam et al. (1999) studied the morphology and sediments characteristics of the Cox's Bazar coastal plain. The paper highlights the broad hydrogeomorphological characteristics of the Cox's Bazar coast of Bangladesh. High resolution air photographs of 1:20000 were interpreted for delineating the geomorphological boundaries of the coastal plain. Sediment samples collected from the each geomorphic unit s were analysed to understand the sedimentary environments. Based on the location and characteristics of the geomorphic units and types and spatial distribution of sediments, evolutionary history of the coast was developed. Finally,a weighted matrix was prepared for assessing the exposure of the geomorphic units to geohazards e.g., storm surges, flash flood (Alam et al., 1999).

A Depth Integrated Two-Dimensional Numerical Modeling was carried out to study the sediment dynamics within the Meghna Estuary by Ali (2007). Both cohesive and noncohesive sediment transport formulation were used to estimate the total sediment transport. An interactive morphological computation was used here to verify the bed level changes over 2 years. Sediment transport of both monsoon and dry seasons were modeled. Land reclamation dams were tested by the model and found to be effective in enhancing the accretion in its vicinity (Ali, 2007).

Komol (2011) set up a two dimensional hydrodynamic Depth Integrated Velocity and Solute Transport Model (DIVAST) for Bay of Bengal for simulation of tidal level at selected coastal area of Bangladesh. The bathymetry of the Bay of Bengal has been generated based on the data of Meghna Estuary Study (MES) phase I and phase II. the simulated tidal levels of the bay of bengal model have been calibrated and verified with the observed tidal levels of tidal gauge stations located at Daulatkhan, Tazumuddin, Hatiya, Sandwip, Feni river, Rangadia and Hiron point locations (Komol, 2011).

2.7 Scope of the Research Work

Coastal sediment transport is the interaction of coastal land forms to various complex interactions of physical processes. Wind generated waves play a vital role in the transfer of energy from the open ocean to the coastlines (Komar, 1983). In case of coastal sediment transport the primary agent is wave activity followed by tides, storm surges and nearshore currents. The cox‟s bazar beach is the subject of wind wave and also faces storm surges, cyclones etc.

Other than the interactions between coastal land forms and physical processes there is also the addition of modification of these landforms through anthropogenic sources. In terms of population concentration and infrastructural development, most of the Cox‟s Bazar town has been developed on the flood plain because of its topographic advantages, easy and cheaper to develop. Mud flat of Cox‟s Bazar is mainly used for shrimp culture and for salt bed (Islam, 2004).

The stability and transport of sediments is central to the analysis and prediction of environmental quality and impact, habitat stability, public health risks, as well as to marine hazards such as ship grounding, access to ports, seabed scouring, siltation of harbors, infill of reservoirs and artificial lakes. Studies of sediment transport in the near shore coastal area is of utmost importance for coastal protection strategies, designing and maintaining port and harbors, fisheries, marine recreation and land reclamation (Kunte et al., 2013).

In Cox‟s Bazar, the coastal resources provide the opportunities to use the coast in different ways within the hazard-prone environment. Fish farming, fishing in the bay, salt production and tourism are the main economic activities of the zone of Cox‟s Bazar (Sarwar, 2005). Day by day the risk has been increased considerably in the interactive zone of human activities and coastal hazards. People of Cox‟s Bazar are more vulnerable to cyclones than they had ever been before as more as people are now living within the hazard zone of the coastal plain. Engineering structures adopted in the shore face to protect or minimize the coastal erosion will be a risk. The sea beach of Cox‟s Bazar at present is being eroded with the site of sedimentation shifting back to inland and the coastal plain streams have started filling their own valleys with sand. The beach is flattened by storm and associated wave related phenomenon. Sediment Mobilization is also very significant along the passage of cyclones. This research work may have the scope to work with this entire phenomenon by predicting and analyzing the sediment movement pattern along the near shore water in Cox‟s Bazar coastline including the area of Laboni beach, Kolaboti Beach, Inani beach, moheshkhali channel etc.

2.8 Related Terminologies with the Research Work

Long shore sediment transport: Long shore sediment transport is defined as the movement of sand in the surf zone parallel to the shoreline by long shore currents.

Cross shore sediment transport: Cross shore sediment transport is the displacement of sediment perpendicular to the shore (onshore or offshore)

Mathematical model: A mathematical model is a description of a system using mathematical concepts and language. It is a method of simulating real-life situations with mathematical equations to forecast their future behavior. A model may help to explain a system and to study the effects of different components, and to make predictions about behavior.

Numerical Analysis: It is the study of algorithms that use the numerical approximation for the problems of mathematical analysis. The overall goal of the field of numerical analysis is the design and analysis of techniques to give approximate but accurate solutions to hard problem.

Suspended Sediment Load: Suspended sediment load is the portion of the sediment that is carried by a fluid flow which settles slowly enough such that it almost never touches the bed. It is maintained in suspension by the turbulence in the flowing water and consists of particles generally of the fine sand, silt and clay size. it is carried in the lower to middle parts of the flow and moves at a large fraction of the mean flow velocity in the stream.

Bed Load: The term bed load describes particles in a flowing fluid that are transported along the bed. The sand, gravel, boulders or other debris transported by rolling, sliding and hopping along the bottom of a stream are bed load. It is generally thought to constitute 5 to 10% of the total sediment load in a stream.

Bathymetry: Bathymetry is the study of the beds or floors of water bodies including the ocean, rivers, streams and lakes. The term bathymetry originally referred to the ocean"s depth relative to sea level, although it has come to mean "submarine topography" or the depths or shapes of underwater terrain.

Boundary Condition: A condition which a quantity that varies throughout a given space or enclosure must fulfill at every point on the boundary of that space. It can also be defined as a condition that is required to be satisfied at all or part of the boundary of a region in which a set of differential equations is to be solved.

Grain Size Distribution: It is a list of values or a mathematical function that defines the relative amount, typically by mass, of particles present according to size.

Wave Direction: Wave direction is the direction from which a wave approaches. Because of the random nature of natural waves a statistical description of the wave is normally always used. The most commonly used variables in coastal engineering are described below.

D50: the sediment size, D50, is defined as the grain diameter at which 50% of the sediment sample is.

D90: the sediment size, D90, is defined as the grain diameter at which 90% of the sediment sample is.

Fall velocity: The constant maximum velocity reached by a body falling under gravity through a fluid. Sediment deposition is proportional to the fall velocity of the particles.

2.9 Summary

Assessment of sediment movement pattern is an important factor and key component for different sector of coastal engineering. Now a days it is very common and comfortable practice to set up a mathematical model to assess the sedimentation pattern in nearshore coastal water. This technique has already proved very effective and reliable. But there is no significant research work at Cox‟s Bazar coastal area to set up any mathematical model which can predict the sediment movement pattern. As Cox‟s Bazar is the most important coastal district of Bangladesh, in this research work a initiative was taken and done successfully to set up a numerical model for nearshore coastal water of Cox‟s Bazar and represent the sediment movement pattern in this area. The condition of wave height and radiation stress along the study area is also represented here which is important for different Coastal related studies.

CHAPTER 3
THEORY AND RESEARCH METHODOLOGY

3.1 General

Mathematical model is very effective for studying the processes and pattern of sediment transportation. Validity of forecast in sediment transport depends on both mathematical modeling technique and boundary conditions. Reliable field data and in-depth understanding of mechanism of sediment transport are essential for verification and improvement of mathematical modeling (Tan, 2005). In this research work a numerical two dimensional hydrodynamic Depth Integrated Velocity and Solute Transport Model (DIVAST) has been set up for nearshore coastal water of Cox"s Bazar to assess the sediment movement pattern from Bay of Bengal.

3.2 Hydrodynamics of Nearshore zone

The nearshore zone extends from the low tide line out to a water depth where wave motion ceases to affect the sea floor. On steeply sloping coasts the nearshore zone may be less than 100m wide.in case of gentle slopes the nearshore zone is usually wide, more than 5 km. Here wave breaking will generally occur some distance offshore and there will be a wide surf zones. On many coasts the nearshore zone is 0.5 – 2.5 km in width and extends into water depth greater than 40 km. Nearshore zone is divided into three sub zones, Consisting of shore breaker zone, surf zone and bar breaker zone. The nearshore acts as a link between the coast and the inner continental shelf and materials can move in both direction across it. It is a very active area, where a series of dynamic processes occurs. These processes involve the action of waves, breaking of waves, currents, turbulence, wave-current interaction and different dynamic processes. Here the sediment transport is driven by the combined motions of water waves and currents. As wave travels from the deep water of the nearshore zone towards the shoreline, they are increasingly affected by the bed friction and the process of wave shoaling and eventually the wave breaks. In addition to the orbital motion associated with the waves, wave breaking generates strong unidirectional currents within the surf zone close to the beach and this is responsible for both in cross shore and long shore sediment transport (Sierra et al., 1993).

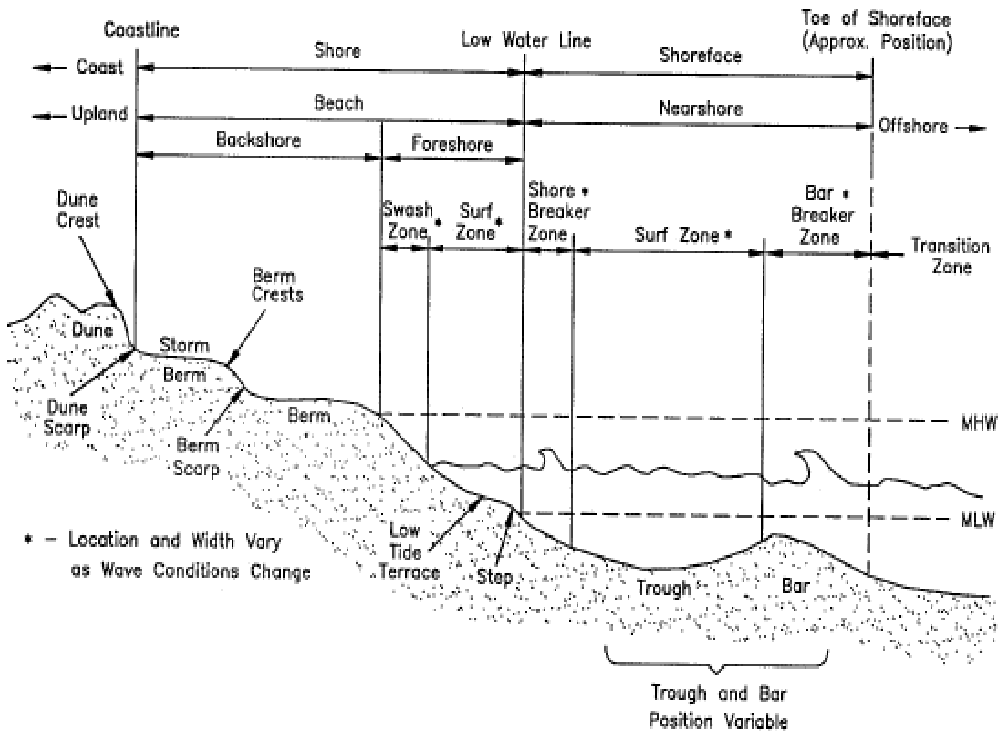


Figure 3.1: Typical profile of a beach (Source: SPM, Volume I).

Wind, tidal and wave-induced currents act in the nearshore zone shaping morphology and determining sediment textures by interaction and performing jointly a flexible dynamical equilibrium. During large wave events, the sediment gets transported off the beach face a offshore deposition generating a sandbar. Once the significant wave event has diminished, the sediment then gets slowly transported back onshore (Dean et al., 2002). Tide and wind driven currents can remove fine sediments and pollutants offshore and coarse sand can be transported offshore beyond the normal wave base by intense storms. Wave refraction around seaward extending shoals results in a concentration of wave energy, which generally causes headland erosion and the landward displacements of a portion of the shoal. However, in some nearshore areas the interactions of wave surge with river flow and tidal currents produce concentrations of sand which nourish the shoals and inhibit the erosional effects of wave attack (Oertel et al., 1972).

3.3 Radiation Stress

It is well known that electromagnetic radiation impinging on a surface or originating on a surface produces a force referred to as the „radiation pressure". The similar phenomenon occurs in the case of acoustic waves and of waves on the surface of the fluid. In each case the force is principally in the direction of wave propagation. It is therefore not an isotropic one unless the waves themselves are isotropically distributed. In fluid mechanics it has become customary to use the term „pressure" for the isotropic stress which figures in the equation of state. It is therefore considered to coin the term „radiation stress" as a more general one which does not carry any implication of isotropy.Breaking waves on beaches induce variations in radiation stress driving long shore currents and the resulting long shore sediment transport shapes the beaches and may result in beach erosion or accretion. The long shore sediment transport rate is calculated by using one-dimensional momentum equations for both velocity components and the turbulent diffusion equation for sediment concentration. The driving force in the momentum equations is the radiation stress induced by wave breaking. In fluid dynamics, radiation stress plays an important role in a variety of oceanographic phenomena, such as generation of surf-beats, changing mean sea level due to storm waves, interaction of waves with steady current and the steepening of short gravity waves on the crest of longer waves. For oblique incidence of waves on a beach, the reduction in wave height inside the surf zone introduces a variation of the shear stress component of the radiation stress over the width of the surf zone. This provides the forcing of a wave driven long shore current, which is important for sediment transport and resulting coastal morphology (Higgins et al., 1964).

3.4 Sediment Transportation Processes

When there is sufficient wave energy, a system of sediment erosion, deposition, and transport is established as shown in Fig: 3.2. This diagram depicts the distribution of sediments for an uninterrupted length (no shoreline structures) of natural coastline. A finite amount of sediment S_{Tin} is transported by longshore currents into a section of the coast (nearshore zone). Wave action at the shore erodes the beach and dune-bluff sediment (S_B) and carries it into the longshore current. This same wave action lifts sediment from the bottom (S_w) for potential transport by the longshore current. Finally, wave action and cross-shore currents at the offshore boundary move sediment onshore or offshore (S_{on} and S_{off}) depending on wave and bottom conditions. This transport at the outer limit of the nearshore zone can usually be assumed negligible with respect to the other transports. The summation of these various transports over time provide a measure of the net sediment budget for a section of coast.

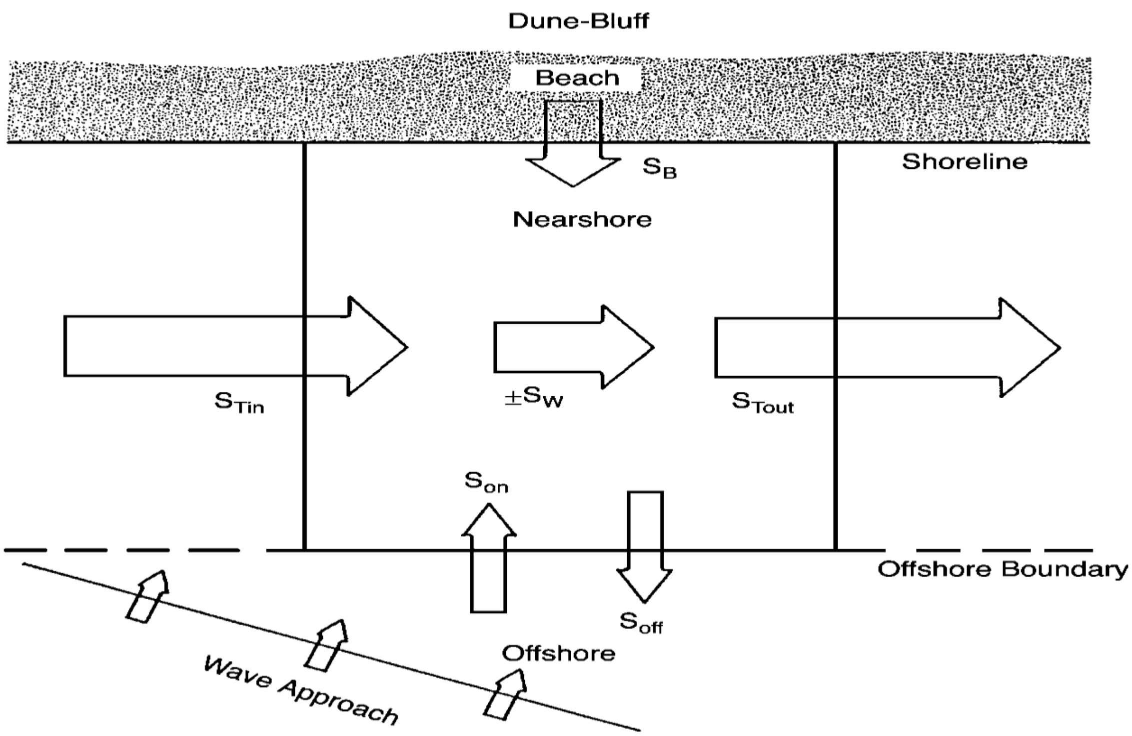


Figure 3.2**:** Box diagram of sediment transport components at the coast (Source: CEM, 2002).

Sediment transportations are of several types. Physical processes dominate at ocean margins, where they transfer particles eroded from the land to the sea floor. Active sedimentation processes occur where the sediment modifies the properties and behavior of the suspension include mass wasting and density currents. Such deposition tends to mask other sedimentary processes. The active sedimentation depends on gravitational energy, so that it does not extend seaward of the trenches along convergent plate boundaries but can affect the entire ocean basin of passive margins. Passive sedimentation processes are those in which the sediment is carried by but does not modify the normal thermohaline circulation. Such as Hemipelagic sedimentation where it appears that fine sediment moves along isopycnal surfaces high in the water column. Drift deposition along the path of bottom currents and the Eolian sedimentation prominent where major wind systems cross semi-arid source areas or active ash-generating volcanoes. passive sedimentation process record the history of deep currents, volcanism, aridity, wind trajectories and iceberg abundance. Chemical sedimentation processes dominate sedimentation only in deep, low productivity areas. Again Biological sedimentation processes dominate sediment formation in areas of high productivity.

Longshore and cross-shore sediment transports are one of the most widely studied processes in the nearshore zone by waves and currents. It is of fundamental importance to the long-term sediment budget of a stretch of coast and plays a key role in shaping coastline (Cartier et al., 2011). Sediment transport at a point in the nearshore zone is a vector with both longshore and cross-shore components (Figure 3-1). It appears that under a number of coastal engineering scenarios of interest, transport is dominated by either the longshore or cross-shore component.

Cross-shore Sediment Transport

Cross-shore sediment transport encompasses both offshore transport, such as occurs during storms and onshore transport, which dominates during mild wave activity.

Transport in these two directions appears to occur in significantly distinct modes and with markedly disparate time scales; as a result, the difficulties in predictive capabilities differ substantially. Offshore transport is the simpler of the two and tends to occur with greater rapidity and as a more regular process with transport more or less in phase over the entire active profile. This is fortunate since there is considerably greater engineering relevance and interest in offshore transport due to the potential for damage to structures and loss of land. Onshore sediment transport within the region delineated by the offshore bar often occurs in "wave-like" motions referred to as "ridge-and-runnel" systems in which individual packets of sand move toward, merge onto, and widen the dry beach. A complete understanding of cross-shore sediment transport is complicated by the contributions of both bed and suspended load transport (CEM, 2002).

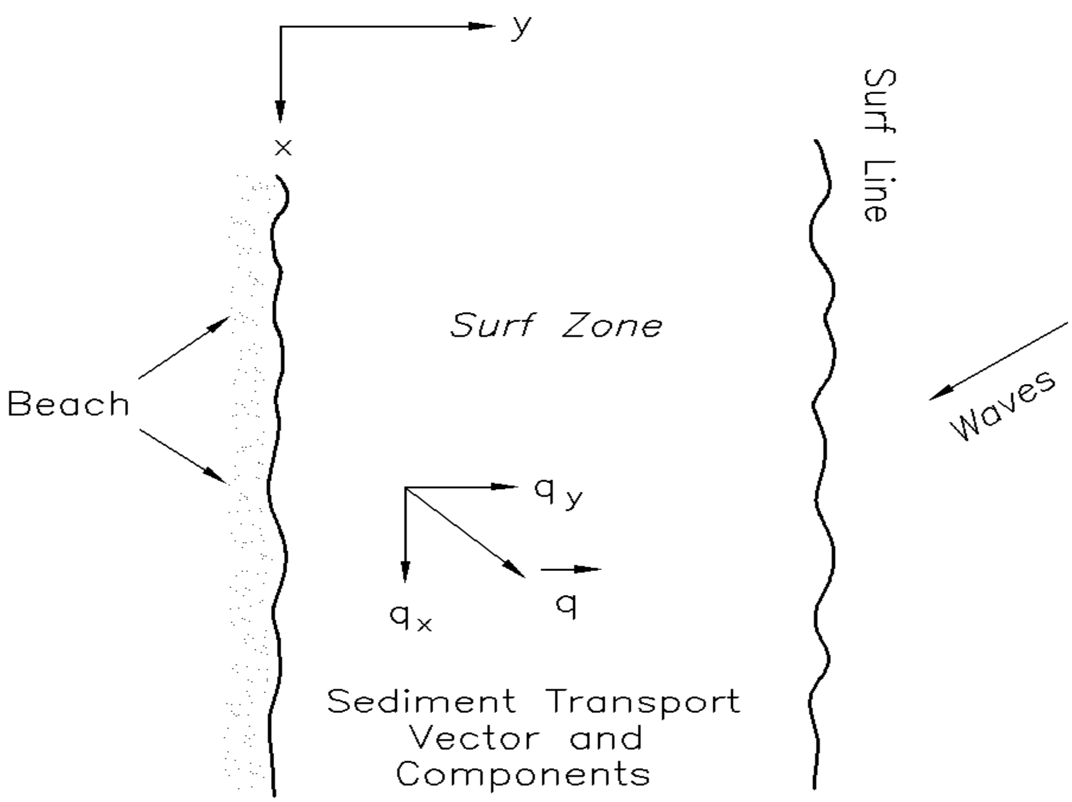


Figure 3.3: Longshore (q_x) and cross-shore (q_y) sediment transport components (Source: CEM, 2002).

Longshore Sediment Transport

The longshore sediment transport is defined to occur primarily within the surf zone, directed parallel to the coast. This transport is among the most important nearshore processes that control the beach morphology. An understanding of longshore sediment transport is essential to sound coastal engineering design practice.

On most coasts, waves reach the beach from different quadrants, producing day-to-day and seasonal reversals in transport direction. At a particular beach site, transport may be to the right (looking seaward) during part of the year and to the left during the remainder of the year. If the left and right transports are denoted respectively $Ql\ L$ and $Ql\ R$, with $Ql\ R$ being assigned a positive quantity and $Ql\ L$ assigned a negative value for transport direction clarification purposes, then the net annual transport is defined as $Ql\ NET = Ql\ R + Ql\ L$. The net longshore sediment transport rate is therefore directed right and positive if $Ql\ R > Ql\ L$, and to the left and negative if $Ql\ R < /\ Ql\ L\ /$. The net annual transport can range from essentially zero to a large magnitude, estimated at a million cubic meters of sand per year for some coastal sites. The gross annual longshore transport is defined as $Ql\ GROSS = Ql\ R + /\ Ql\ L\ /$, the sum of the temporal magnitudes of littoral transport irrespective of direction (CEM, 2002).

Modes of Sediment Transport

A distinction is made between two modes of sediment transport: suspended sediment transport, in which sediment is carried above the bottom by the turbulent eddies of the water, and bed-load sediment transport, in which the grains remain close to the bed and move by rolling and saltation. Although this distinction may be made conceptually, it is difficult to separately measure these two modes of transport on prototype beaches. Considerable uncertainty remains and differences of opinion exist on their relative contributions to the total transport rate.Because it is more readily measured than the bed-load transport, suspended load transport has been the subject of considerable study. It has been demonstrated that suspension concentrations decrease with height above the bottom. The highest concentrations typically are found in the breaker and swash zones, with lower concentrations at midsurf positions. On reflective beaches, at which a portion of the wave energy is reflected back to sea, individual suspension events are correlated with the incident breaking wave period. In contrast, on dissipative beaches, at which effectively all of the arriving wave energy is dissipated in the nearshore, long-period water motions have been found to account for significant sediment suspension. For dissipative beaches, the suspension concentrations due to long-period (low-frequency) waves have been measured as 3 to 4 times larger than those associated with the short-period high-frequency incident waves (CEM, 2002).

3.5 Theory and Related Equations

The underlying physics of how water moves sediment is not well understood. This is, perhaps, one reason for the large number of formulas which have been proposed to predict transport rates. These formulas are usually functions of fluid properties, flow condition properties, and sediment properties. Sediment properties commonly used include: grain size, grain density, fall velocity, angle of repose, and volume concentration. Sediment size distribution and grain shape are also important.

Generally for fluid flow, the mathematical model for sediment transport is usually based on conservation laws. A number of additional auxiliary equations are needed such as for the bed material sorting, bed resistance, sediment transport capacity etc. (Francisco, 2006).

From the remote past men have been concerned with the problem of sediment transport. The study of sediment transport began as an art until it became part of the field of mechanics about 200 years ago. Many researchers attempted to predict the rate of bed load transport.

The first successful development was proposed by Du Boys in 1879. Although his model of sediment transport was incomplete, the proposed relationship for bed- load transport rate proved to be in good agreement with a large amount of experimental measurements. The Du Boys formula may be written as

For Bed Load, $q_{bv} = \lambda \tau_0 (\tau_0 - \tau_c)$ (3.1)

λ was called the characteristic sediment coefficient, τ_0 is the bed shear stress, τ_c is the critical shear stress at which sediment movement begins.

Shields (1936) proposed from his experimental results a dimensionally homogenous transport function for bed load of the form

$$\frac{q_{bv} * \gamma_s}{q\, S\, \gamma} = 10\ \frac{\tau_0 - \tau_c}{(\gamma_s - \gamma) Ds} \quad (3.2)$$

Here, q is water discharge per unit width, S is slope, γ_s is specific weight of sediment, γ is specific weight of water, Ds is diameter of sediment.

Kalinske (1942) developed a dimensionless bed load equation as

$$\frac{q_{bv}}{U_* \, Ds} = f\ \frac{\tau_0}{\tau_c} \quad (3.3)$$

$$\tau_c = 0.12\ \gamma_s'\ Ds \quad (3.4)$$

Here, U_* is shear velocity near the bed, γ_s' is specific weight of submerged sediment.

The bed load equation developed by Einstein (1942) is given below

$$\frac{q_s}{\sqrt{((s-1) g D_s^3)}} = 2.15 \exp\left(-0.391\ \frac{\rho\,(s-1) g D_s}{\tau_0}\right) \quad (3.5)$$

Lane and Kalinske (1941) gave the following relation for suspended material discharge

$$q_{sw} = q\ C_a\ P_L \exp\left(\frac{15\ w\ a}{U_*\ D}\right) \quad (3.6)$$

Here w is the fall velocity, a is the level of reference above bed, q is the water discharge and at last q_{sw} is the suspended sediment discharge.

Brooks (1963) derived a sediment transport model in which he takes the half-logarithmic velocity distribution in to account and also determined that suspended sediment discharge depends on suspended sediment concentration. The suspended sediment rate can be calculated using the below formula

$$\frac{q_{sw}}{C_{md}q} = T_B\left(K\frac{U}{U_*}, Z_1, E\right) \quad (3.7)$$

Where Z_1 is a function of

$$z_i = \frac{w_i}{C_z RS} U \quad (3.8)$$

In which i is the fall velocity, U is the water velocity, R is the hydraulic radius, S is the bed slope and Cz is the factor which depends on temperature. E=e-(kv/U*)-1 and C md is the suspended sediment concentration in y=D/2 numbers, q is assumed as the water discharge. K is the Van-Karman coefficient equal with 0.4 mean velocities and at last q_{sm} is the sediment discharge.

Bagnold (1966) derived a stream-based sediment transport model. In that model, Bagnold assumes the sediment is transported in two modes, i.e., the bed load transport and the suspended transport. The bed load sediment is transported by the flow via grain to grain interactions; the suspended sediment transport is supported by fluid flow through turbulent diffusion. The suspended sediment rate can be calculated using the below formula

$$g(Sg - 1)qsm = 0.01\ (u\ /\ s\ ) \quad (3.9)$$

Where *s*, is the fall velocity of sediment, Sg is assumed as the ratio of water density by sediment density. is the mean velocity, is the shear stress and at last q_{sm} is the sediment discharge.

The equation solved in this mathematical model to assess the suspended and the bed load is very popular Van Rijn equation.

For Suspended Load,

$$q_s = F\, V_s\, H\, S_a \tag{3.10}$$

Fall Velocity, $s_s = \frac{q_s}{q}$ (3.11)

Here, Depth-integrated fluid speed, q = V_S H, Factor „F", Reference concentration „S_a".

For Bed Load, $q_b = \frac{[0.053\, T^{2.1}\ (\Delta G)^{0.5}\, D_{50}{}^{1.5}]}{D_*{}^{0.3}}$ (3.12)

Transport Stage Parameter, $T = \frac{(U_*')^2 - (U_{*cr})^2}{(U_{*cr})^2}$ (3.13)

Characteristics Particle Diameter, $D_* = D_{50}[\frac{(s_s-1)}{v^2}]^{1/3}$ (3.14)

Total Load = Suspended Load + Bed Load

3.6 Research Methodology

The development of closed form solutions to the governing equations that describe the mechanical behavior of fluid and solid-fluid mixture, have complexity with flow movement and its interaction with its boundaries, which are themselves deformable. As a result, alternative techniques have been developed to provide quantitative predictions of these phenomena (Francisco, 2006). Modeling is one such technique. The term „model" refers to the ensemble of the set of governing equations, their numeric solution technique, their implementation in a computer programme and the data that defines the prototype.

There are two types of models: Mathematical models and physical models. Mathematical and numerical modeling is based on computing techniques as opposed to physical modeling which is based on traditional laboratory techniques and measurement.

Numerical modeling has become very popular in the past few decades, mainly due to the increasing availability of more powerful and affordable computing platforms. Much progress has been made, particularly in the fields of sediment transport, water quality, and multidimensional fluid flow and turbulence. Many computer models are now available for users to purchase. Some of the models are in public domain and can be obtained free of charge. In this research work a numerical two dimensional hydrodynamic Depth Integrated Velocity and Solute Transport Model (DIVAST) has been set up for Cox"s Bazar to assess the sediment movement pattern at nearshore coastal water.

However, data collection and preparation are no less important than the computer model itself and often play the dominant role in determining the accuracy and applicability of the final numerical solutions generated by computer. In general the basic data requirements for loose boundary hydraulic models can be grouped in three broad categories: geometric data, hydraulic data and sediment data. These data establish the boundary conditions necessary to solve the governing equations and are an integral part of a model (Francisco, 2006). In this research some geometric and hydraulic data is used to run the mathematical model to assess the sediment movement pattern.

The total process of this research work has been organized in the following steps

1. Data collection
2. Data organization
3. Setting up the Bathymetry of study area
4. Setting up the Boundary condition
5. Preparing Model input data
6. Model run
7. Model development
8. Calibration and validation of the model
9. Model Output

3.6.1 Data Collection

Data was collected in two phases for this research work. All those data used for this research is secondary data and collected by Institute of Water Modeling (IWM). In first phase, bathymetry data was collected which contains longitude, latitude and adjusted bathymetry of 14645 points of the study area. In second phase, the data from sixteen points along the study area was collected which contains wave height, wave period and wave direction related data from 2004 to 2013.

3.6.2 Data Organization

To run the mathematical model the prerequisite was to keep the secondary data in the same pattern as per the command used in the FORTRAN based mathematical model. So, at the very beginning of this research work data organization was the first and foremost concern.

Data organization was done by the following processes

1. Orientation of data
2. Google Earth plotting
3. Processing of data

1. Orientation of Data

At first some points from the14645 data of the first phase collection was plotted in Google earth. After that plotting it was noted that the data change their orientation after every 145 points and the 146^{th} point is at same orientation as the 1^{st} one. So, all the 14645data was reorganized in a excel sheet as per their orientation which consists of 145 X 101 grid squares.

2. **Google Earth Plotting**

The latitude and longitudes of the points after every 145 data from the first phase collection was identified and plotted in Google earth map. In this way the study area of this research work was brought out. Then the ΔX and ΔY were measured from the Google earth and both were found nearly constant and it was approximately 600km.

From the second phase collection the data collected are of 16 points along the study area. These data was in BTM co-ordinate system. After converting it at UTM co-ordinate system and again transformed to corresponding latitude and longitude, these 16 points were plotted in Google earth. Thus their locations were observed and the suitable points were selected for preparing the necessary input data to finally run the model.

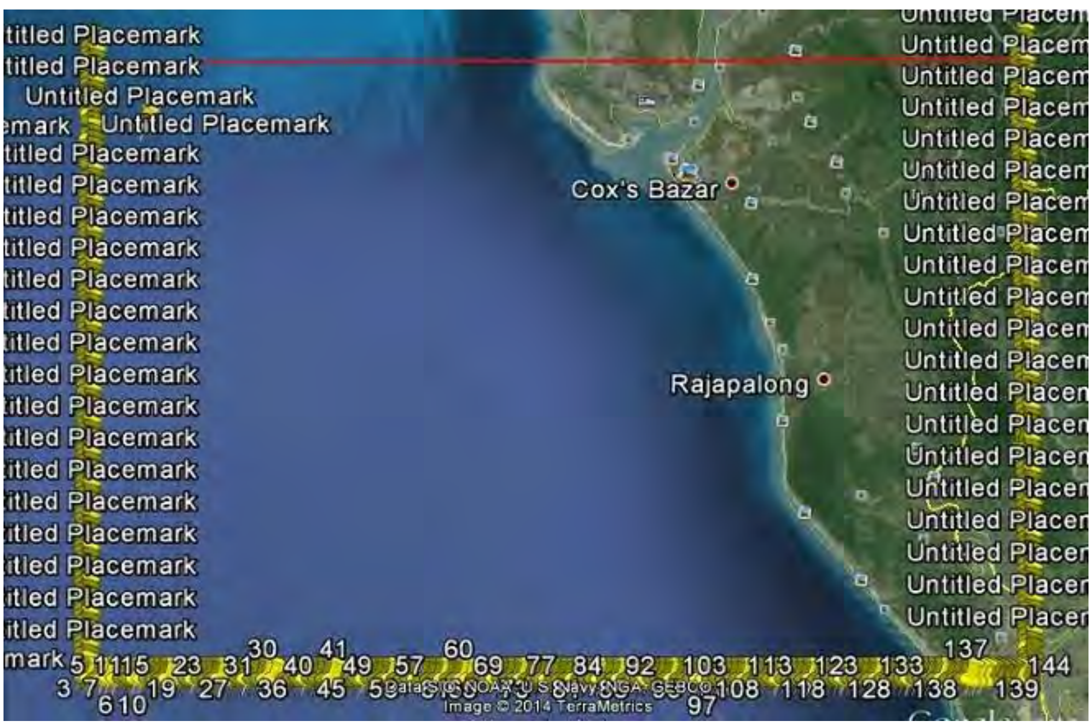


Figure 3.4: Google Earth plotting for 1st phase data (Source: Google Earth).

Figure 3.5: Google Earth plotting for 2nd phase data (Source: Google Earth).

3. Processing of Data

The reorganized data was cross checked by plotting contour map in excel to keep the data in the same orientation as per the command used in the FORTRAN based mathematical model. This raw data contains both positive and negative values according to the datum level as the study area contains both land and water area. But the model cannot run for any negative values. So, the negative values were converted to positive values adjusted the comparative depth at all those points. To run the model this bathymetry data was transferred from the excel sheet to the notepad to create the file named „out.grd".

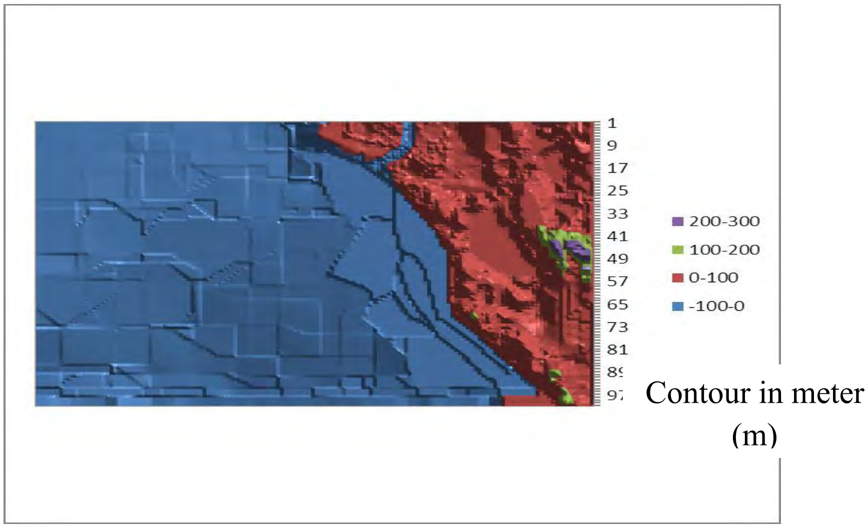


Figure 3.6: Contour Map of the Study Area.

From the second phase collection two suitable points B1 and B11 were selected. Data for B1 was taken to generate boundary conditions within the study area to observe the suspended and bed load movement pattern for different wave angle. In this research this phenomenon is remarked by case: 1. Again, The point B11 selected to generate boundary conditions from deep sea which is outside of the study area and thus observed the suspended and bed load movement pattern by changing the wave angle. In this research this phenomenon is remarked by case: 2.

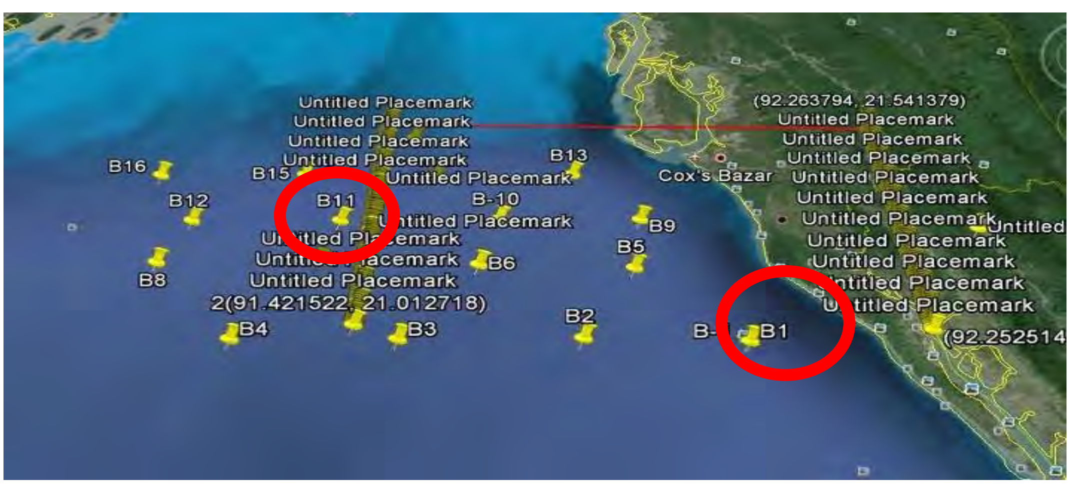


Figure 3.7: Location of B1 and B11(Source: Google Earth)

3.7 The Numerical Model DIVAST

DIVAST is a two dimensional, hydrodynamic, time variant Depth Integrated Velocity and Solute Transport Model which has been developed for estuarine and coastal modeling. DIVAST has a number of modules for different purposes and each module has different sets of equations. The hydrodynamic module of the DIVAST model is used for this research work to assess the sediment movement pattern in the nearshore Coastal water of Cox"s Bazar.

DIVAST was at first developed using FORTRAN 77 programming language by Prof. Roger Falconer and Dr. Binliang Lin, both of them from Cardiff School of Engineering, Cardiff University, UK. DIVAST is continually updated and improved by both Prof. Falconer"s team in Cardiff University. It is suitable for water bodies that are dominated by horizontal, unsteady flow and do not display significant vertical stratification. The model simulates two dimensional distributions of currents, water surface elevations and various water quality parameters within a modeling domain as functions of time, taking into account the Hydraulic Characteristics governed by the bed topography and the Boundary conditions.

The DIVAST model is based on the solution of the depth-integrated Navier-stokes equations and includes the effects of: local and advective accelerations, the earth"s rotation, free surface pressure gradients, wind action, bed resistance and a simple mixing lenth turbulence model. The differential equations are written in their pure differential form and thereby allowing momentum conservation in the finite-difference sense. Particular emphasis has been focused in the development of the model on the treatment of the advective accelerations, a surface wind stress and the complex hydrodynamic phenomenon of flooding and drying (Navera, 2004).

The governing differential equations are solved using the finite difference technique and using a scheme based on the Alternating Direction Implicit (ADI) formulation. The advective accelerations are written in a time centered form for stability, with these terms and the turbulent diffusion terms being centered by iteration. Whilst the model has no stability constraints but there is a courant number restriction for accuracy in the hydrodynamic module. The finite difference equations are formulated on a space staggered grid scheme, with the water surface elevations and the X-direction velocity components being initially solved for during the first half time step by using Gaussian elimination and back substitution (Komol, 2011).

3.8 Surfer Software

Surfer is a powerful Contour and 3D surface plotting and mapping software for scientists and engineer that runs under Microsoft windows. It is a versatile software and used extensively for terrain modeling, bathymetric modeling, landscape visualization, surface analysis, contour mapping, gridding volumetric and much more. Surfer‟s sophisticate interpolation engine transforms XYZ data into publication quality map. It provides more gridding methods and more control over gridding parameters. Surfer can display the grid as outstanding contour, 3D surface, 3D wireframe, water shade, vector, image, shaded relief and post maps. Virtually all aspects of a map can be customized here to produce Excellency in a presentation quickly and easily.

3.9 Study Area

The study area is located along the Cox‟s bazar Coastline. This research is undertaken of 5272.2 square km area from Cox‟s Bazar beach and the adjacent nearshore water of Bay of Bengal. Among them about 375 square km area is land area and 4897 square km area from Bay of Bengal. The 1st corner point of the study area is located near the area named Chowdhurypara at latitude 20.99968°N and longitude 92.252514°E, the 2nd point is located near the idgarh reserved forest at latitude 21.541379°N and longitude 92.263794°E. The last two points is located at the nearshore water of Bay of Bengal. The location of 3rd one is at latitude 21.554686°N and longitude 91.554686E and The 4th

one is at latitude 21.012718°N and longitude 91.421522°E. The area included the Laboni beach, Kolaboti Beach, Inani beach and a part of Moheshkhali channel.

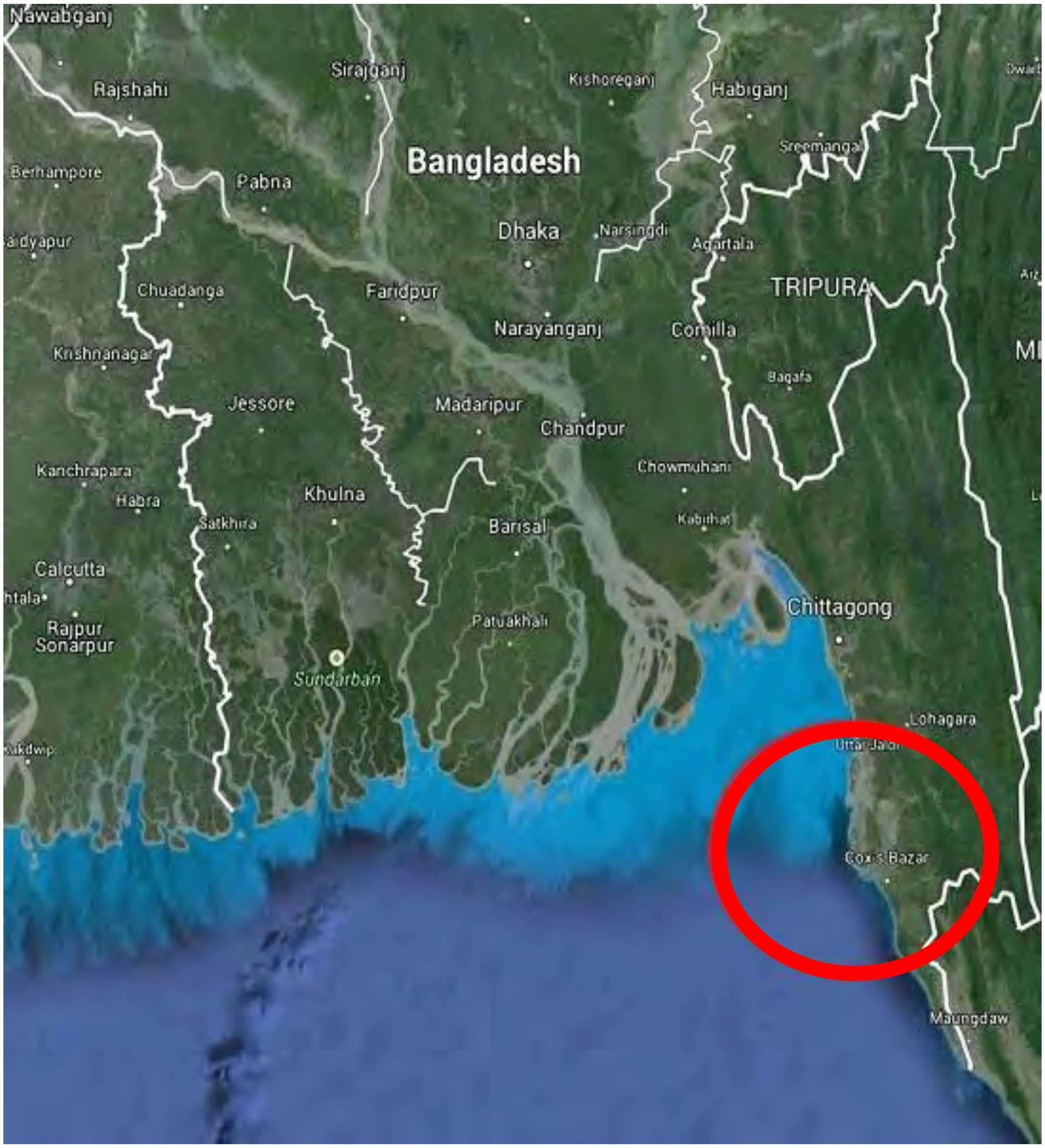


Figure 3.8: Study area (Source: Google Earth)

Figure 3.9: Study area (Source: Banglapedia)

3.9.1 Creating Bathymetry Map of the Study Area

The data of latitude, longitude and depth of the study area was organized in a excel sheet to keep the X-axis, Y-axis and the origin of the study area at the same orientation as used in the input file to run the model. After this, all those data was plotted in software named surfer to create the grid file and the map of the bathymetry. This grid file and the map were used furthermore to visualize the sedimentation pattern along the study area.

Surfer is a full function 3D and 2D visualization, contouring and surface modeling software. Using surfer the most informative display can be possible to create by adding base map and combine other map types. In this research work the bathymetry map presented below is used as a base map to assess the suspended and bed load movement pattern along the study area.

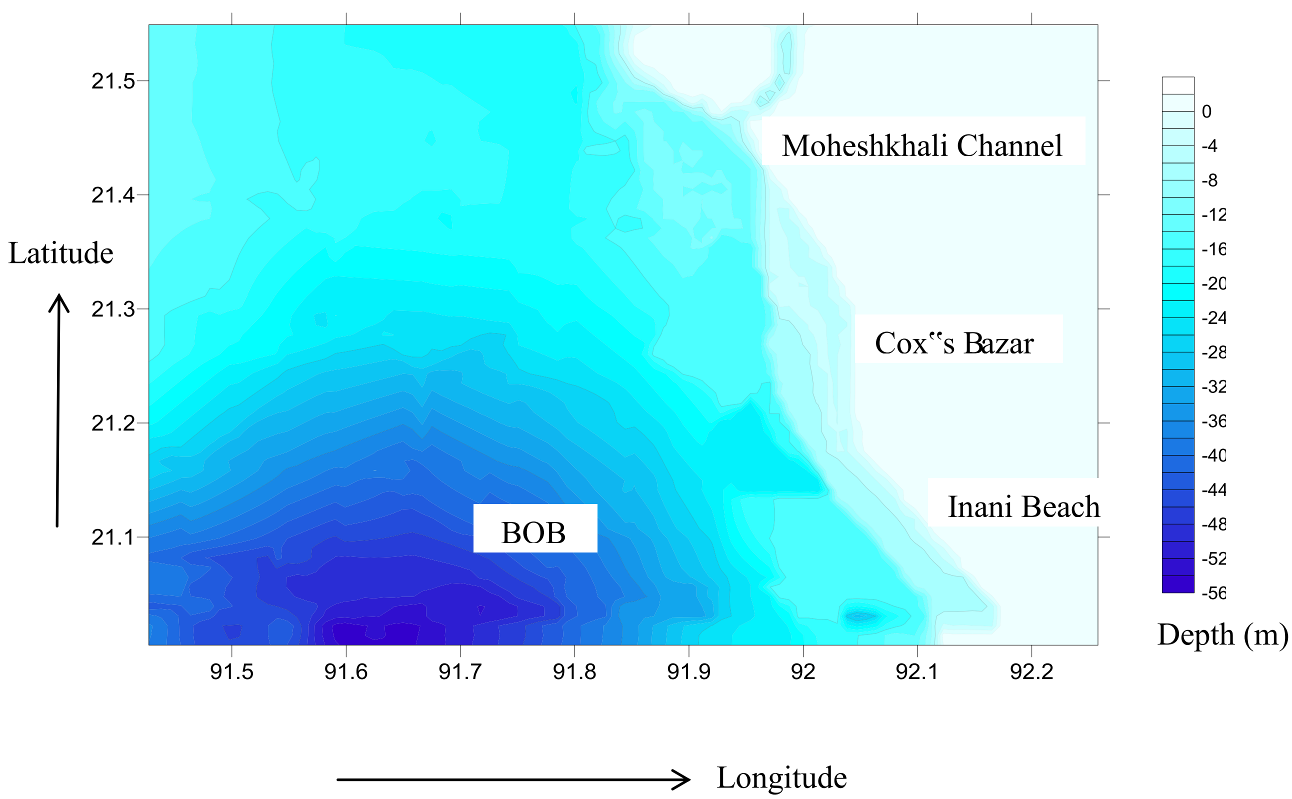


Figure 3.10: Bathymetry of the Study Area.

3.9.2 Setting up The Boundary Condition of the Study Area

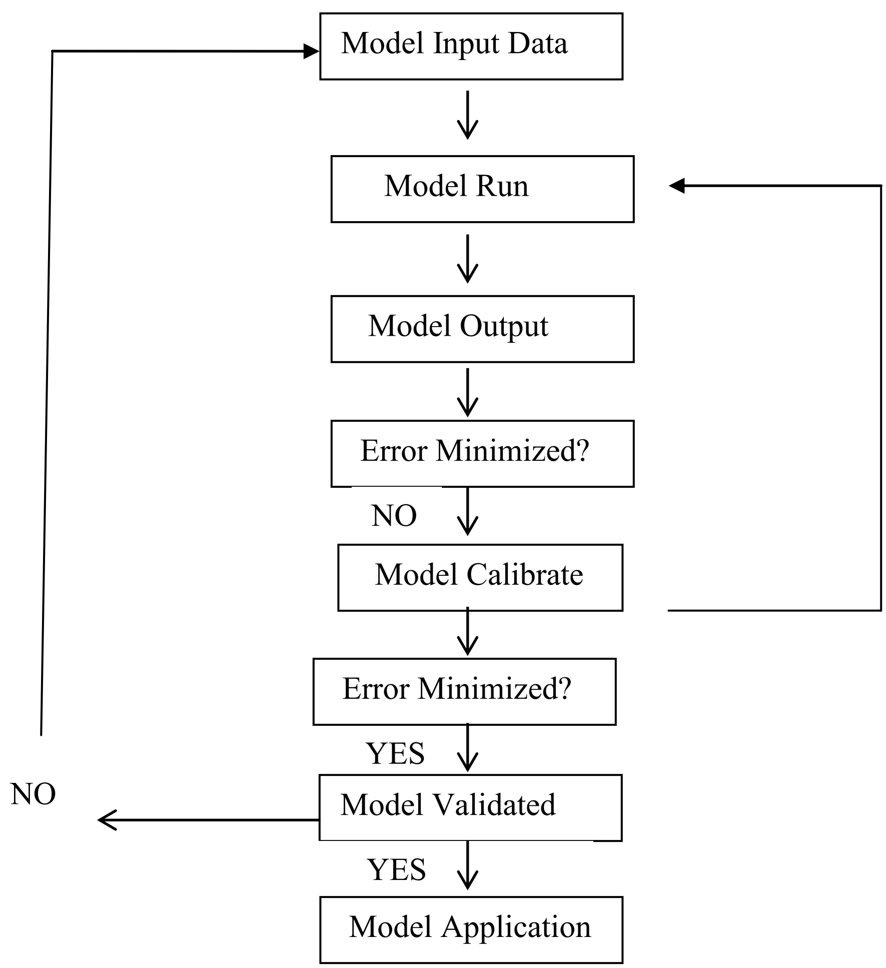
There are three open boundaries in our study area, only one is closed. Among these three open boundaries one is totally open and the other two is partially open. By using Google Earth the adjacent point of the land and water were identified to set up the boundary condition of the semi-open boundaries. The Maheshkhali channel was set up properly in this boundary condition which is inclusive in the study area. The study area which was at first selected in Google earth had total 145 points in X-axis and 101 points in Y-axis. But, in input file named „test.dat" the I value was given 72 and the J value was given 50 as boundary condition. Because the command used in the mathematical model can convert the node points along the X-axis as 2x+1 and along the Y-axis as 2y+1,where x and y are random input variables. As a result there were total 3600 nodal points from which the wet nodes were marked by „1"and the dry nodes were marked by „0".

3.9.3 Preparing Input Data and Run the Model

The mathematical model used for this research work based on FORTRAN-IV programming. Some parameters such as water density, viscosity of water, $D_{50,}$ D_{90}, breaking index, bed friction, Chezzy"s C etc. were specified correctly to get the better output from the model. The wave height and wave period for specific wave direction which were processed from the 2nd phase collection for case: 1 and case: 2, was used in the file named „wave.dat". Another input file named „test.dat" was prepared for the boundary condition and here the different parameters were specified for the Cox"s bazar coastline. The semidurenal tidal condition of Bay of Bengal takes 12hours and 24 minutes for one tidal cycle. For this thesis work, model analysed the data for every 3hours and 30 minutes in boundary for a tidal cycle. The „Out.grd" file contains the bathymetry information which was processed from the data of first phase collection. There are another two input files named „current.cmn" and „wave.cmn". Among these five input files the „wave.dat" file was changed for different condition of wave direction to predict the sedimentation pattern for suspended and bed load along the study area after 30 minutes of starting a tidal cycle.

3.9.4 Flow Chart of Mathematical Model

The numerical model is a long, tedious and iterative procedure, although model development is an important criterion for the better output. The important steps of different DIVAST model activities are schematically shown in the figure given below (Hossain, 2012).



Flow Chart of Model Developement

CHAPTER 4
RESULTS AND DISCUSSIONS

4.1 General

At first the calibration and validation of the model is represented in this Chapter. The model Output for the suspended sediment and bed load is represented by using the surfer software to assess the sediment movement pattern in the nearshore coastal water of Cox‟s Bazar and also to assess the suspended and bed load concentrations at different locations of the study area. An observation was made with the sedimentation pattern due to the change in wave directions. Some selected model output for wave height and radiation stress is also represented at the end of this chapter.

4.2 Calibration and Validation of the Model

Calibration means iterative adjustment of the model parameters so that simulated and observed responses of the system match within the desired level of accuracy. In this research the model was calibrated with the output of maximum wave height from the model against the data of maximum wave height of the year 2011 for the point B12. At first the maximum value of wave height for every month of the year 2011 was sorted out from the data of second phase collection. Then the model was run for the boundary condition generated for the point B12. Next a graph was plotted with the observed value and the model output value of maximum wave height and found that both are almost in the symmetric pattern and following approximately the same range. Thus the model calibration was accomplished for this research work.

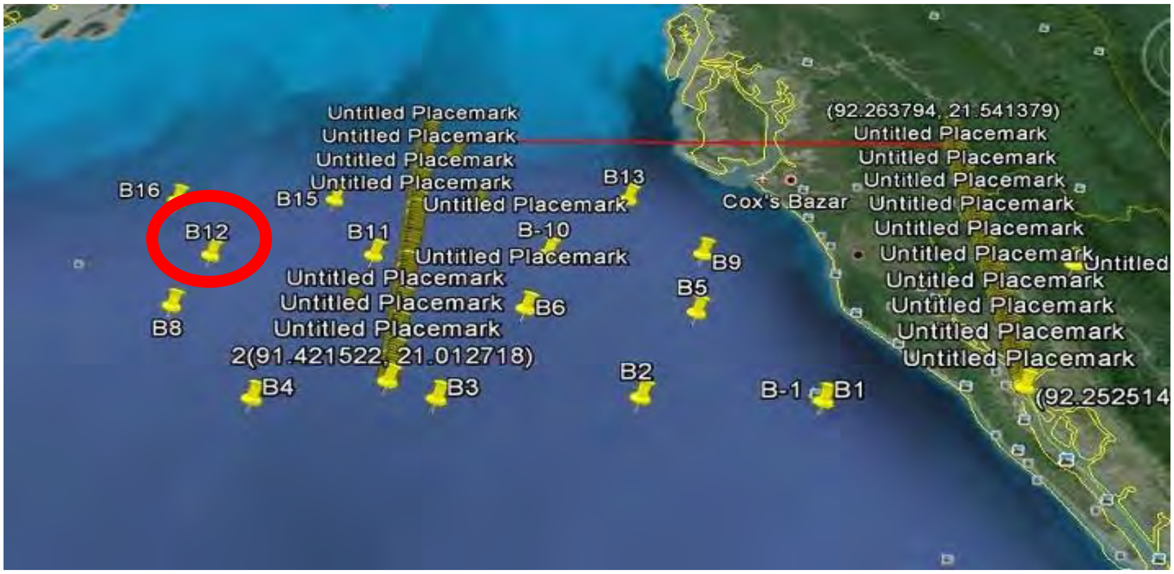


Figure 4.1: Location of B12 (Source: Google Earth)

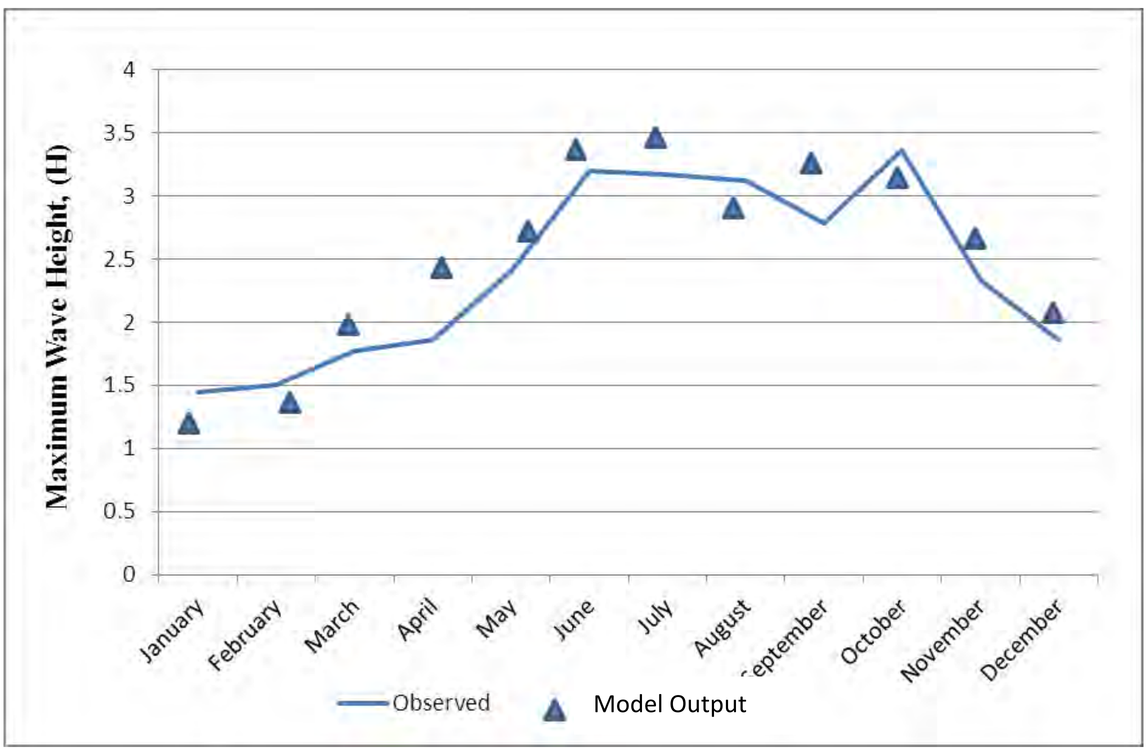


Figure 4.2: Calibration of the Model with the Data of Maximum Wave Height.

A simulation model should be tested to show how well it can perform the task for which it is intended. Performance characteristics derived from the calibration data set are insufficient as evidence of satisfactory model operation. Thus the verified or validated data must not be the same as those used for calibration but must represent a situation similar to that to which the model will be applied operationally (Klemes, 1986)

The validation of this model was accomplished by plotted the data of maximum wave height from the model output against the data of maximum wave height of the year 2012 for the point B13 and found that both are almost in the symmetric pattern and following approximately the same range.

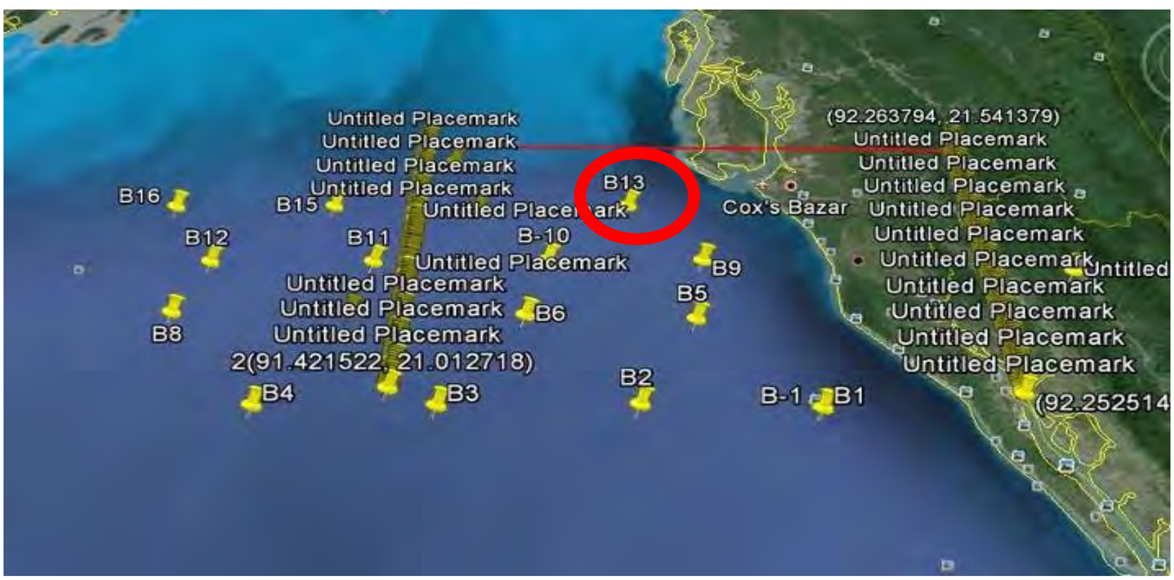


Figure 4.3: Location of B13 (Source: Google Earth)

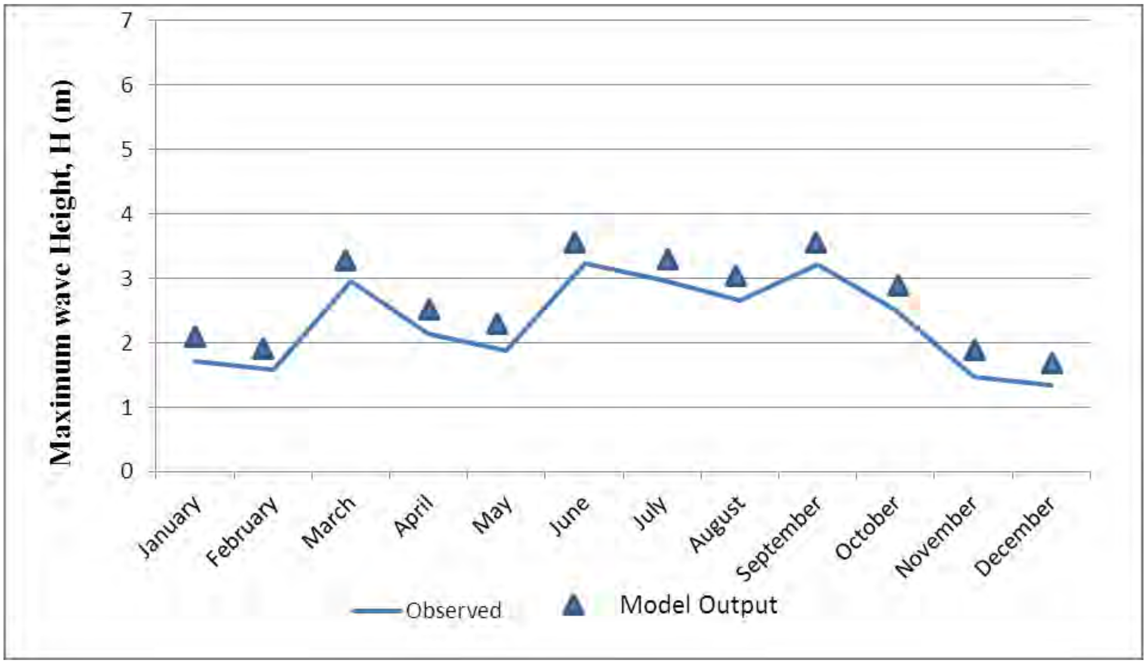


Figure 4.4: Validation of the Model with the Data of Maximum Wave Height.

The small variation between the observed value and the value from model output both in the Figure 4.2 and Figure 4.4 do not have significant percentage of errors and as a whole the result shows good agreement.

4.3 Representation of Model Output for Case 1

Case 1 is the boundary condition generated within the study area for the data of 2004 to 2013 at point B1. An observation was made for suspended sediment and bed load movement pattern by changing wave angle for case 1 and it representing here one by one. At first, the model was run for the wave angle 230^{o}. Gradually it was changed for every 10^{o} and the model output is presented here up to 290^{o}. After 290^{o} the suspended sediment movement and after 270^{o} the bed load movement was found insignificant.

Table 4.1: Summary of Wave Angle, Height and Period for Case 1

Case 1	Point B1						
BTM (X coordinate)	706828.1595						
BTM (Y coordinate)	320910.5413						
Wave Angle (θ °)	230°	240°	250°	260°	270°	280°	290°
Wave Height (m)	2.09	1.19	1.19	1.19	1.28	1.28	1.28
Wave Period (sec)	13.7	14.2	14.2	14.2	13.8	13.8	13.8

4.3.1 Suspended Sediment Movement Pattern for Case 1

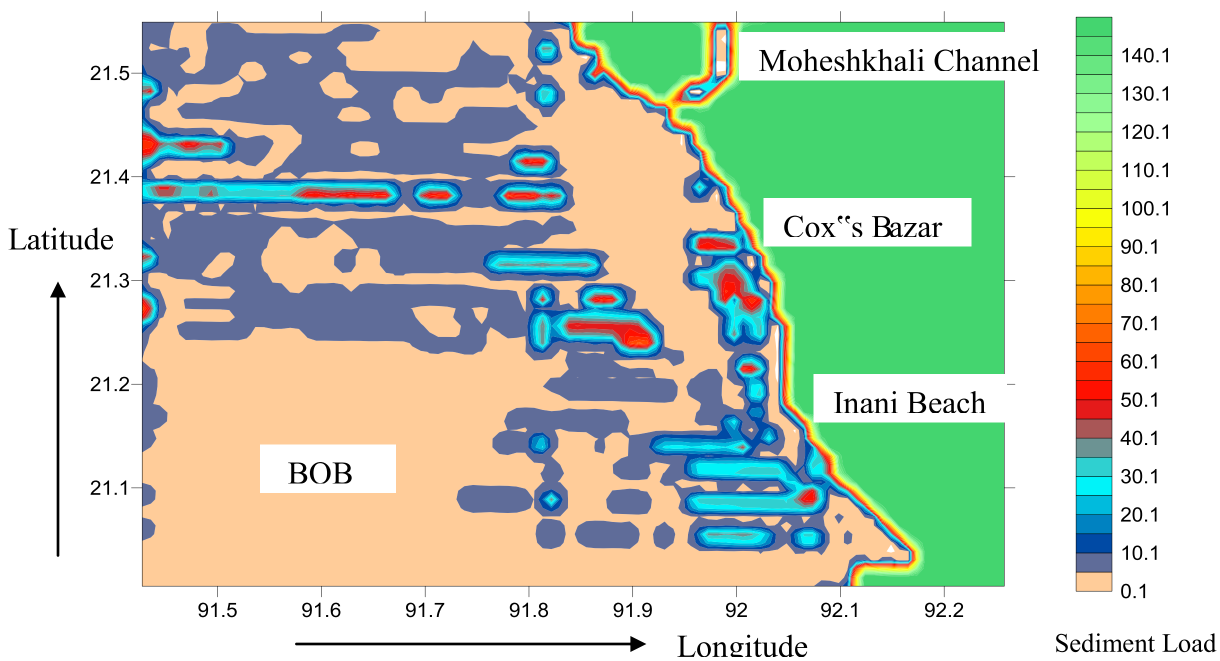


Figure 4.5**:** Suspended sediment load for incoming wave angle 230° for case 1

Figure 4.5 showing, for incoming wave angle 230° a considerable amount of suspended sediment coming from deep sea to the shore. The amount of sediment concentration is much higher along the shore line than the other point of the study area. Here the sediment concentration is lower near the Moheshkhali channel and tends to concentrate away from the channel.

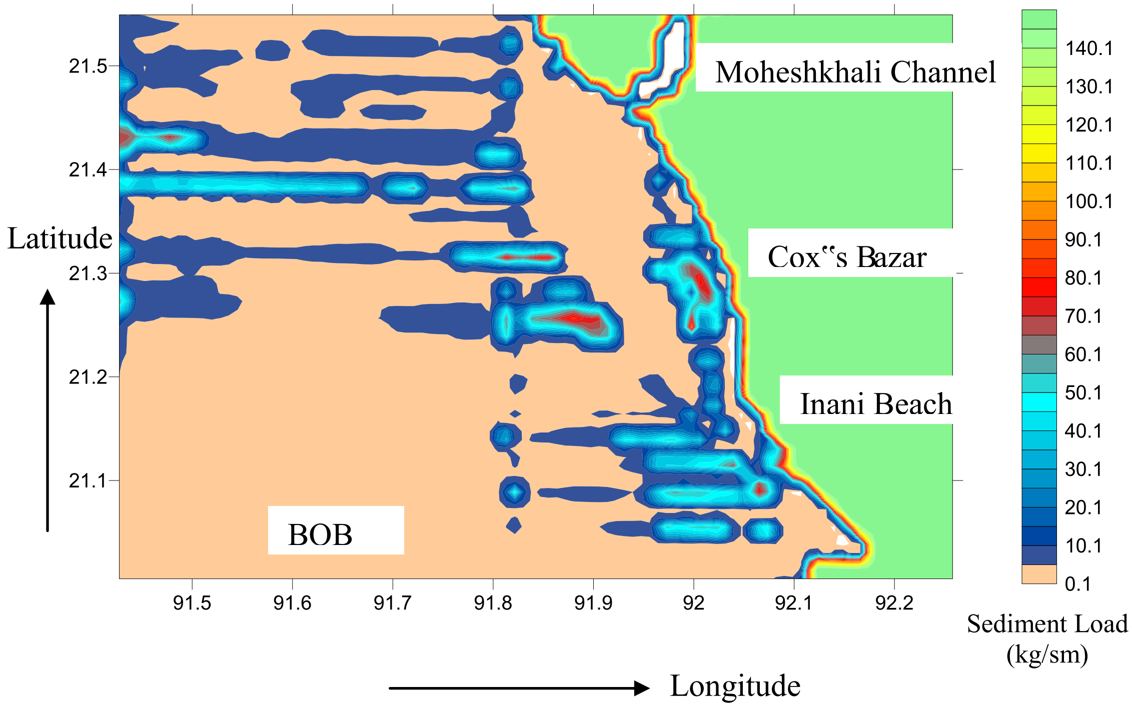


Figure 4.6**:** Suspended sediment load for incoming wave angle 240° for case 1

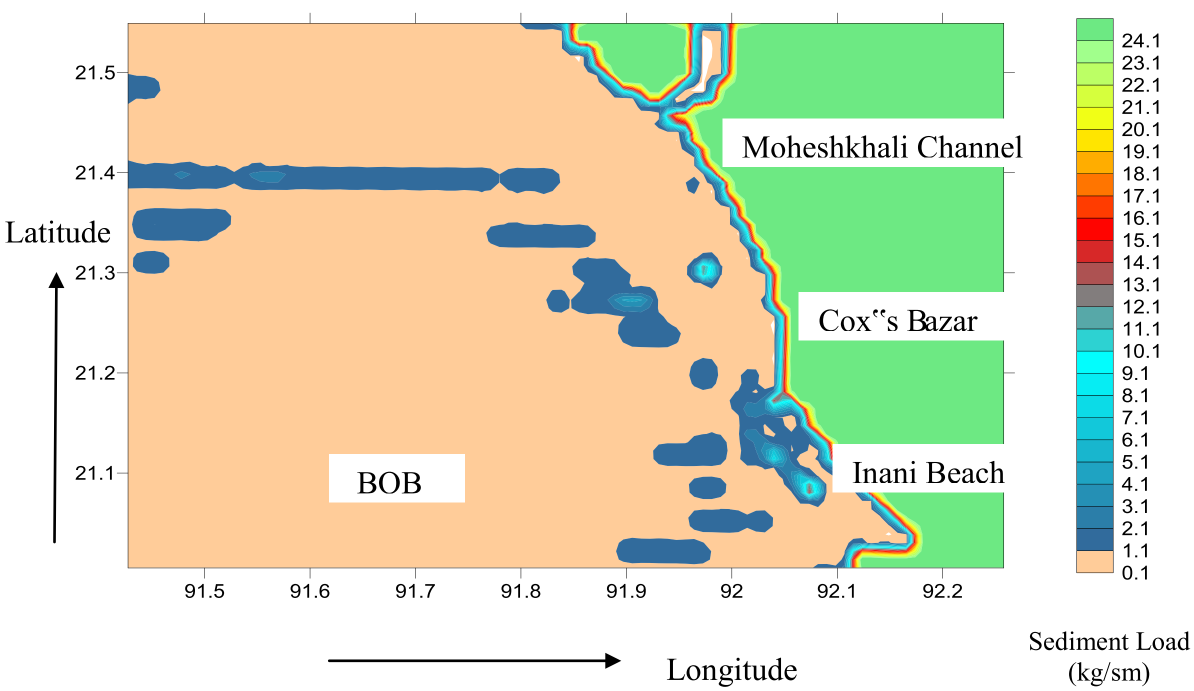


Figure 4.7**:** Suspended sediment load for incoming wave angle 250° for case 1.

From the Figure 4.6 it is clearly found that the suspended sediment load decreased drastically for changing the wave angle from 230^{o} to 240^{o}. Here, the suspended sediment concentrates also along the shore line like the previous one.

Figure 4.7 showing that few sediment volume found along the shore line for incoming wave angle 250^{o} and the volume drastically reduced from the previous one.

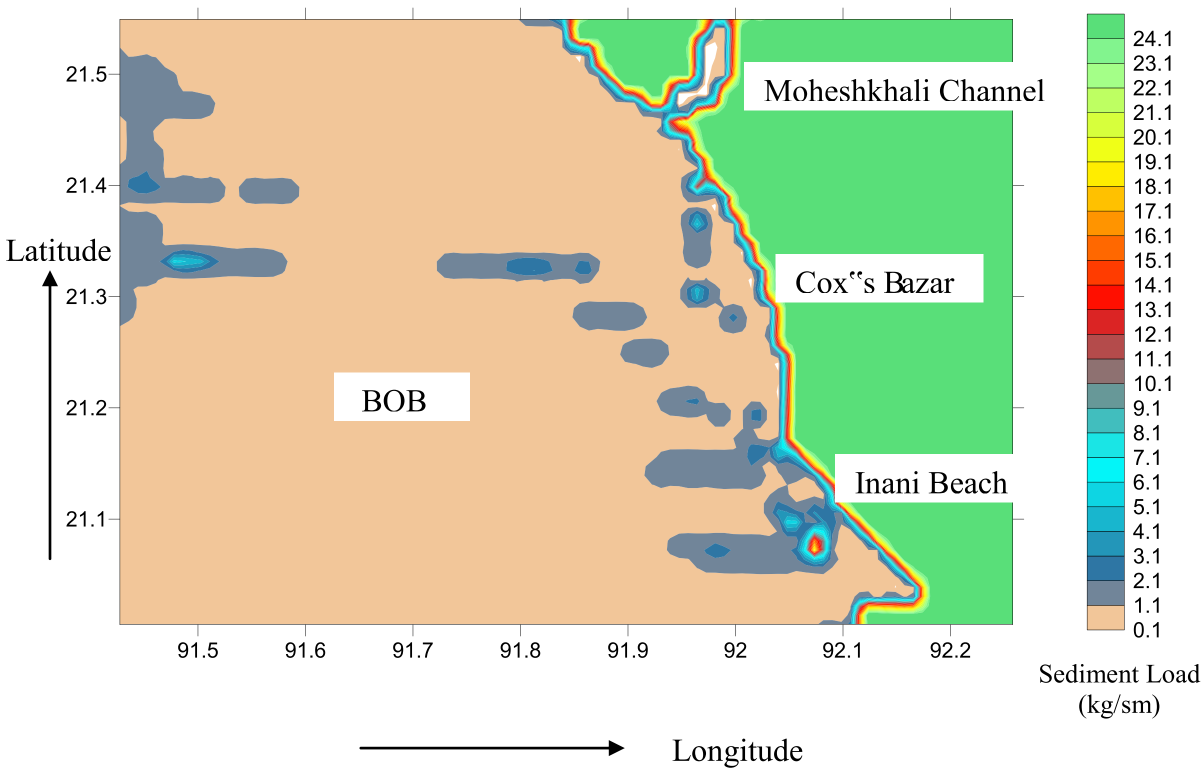


Figure 4.8**:** Suspended sediment load for incoming wave angle 260^{o} for case 1.

For incoming wave angle 260^{o}, amount of suspended sediment coming from the deep sea and it tends to concentrates along the shore line away from the Moheshkhali channel.

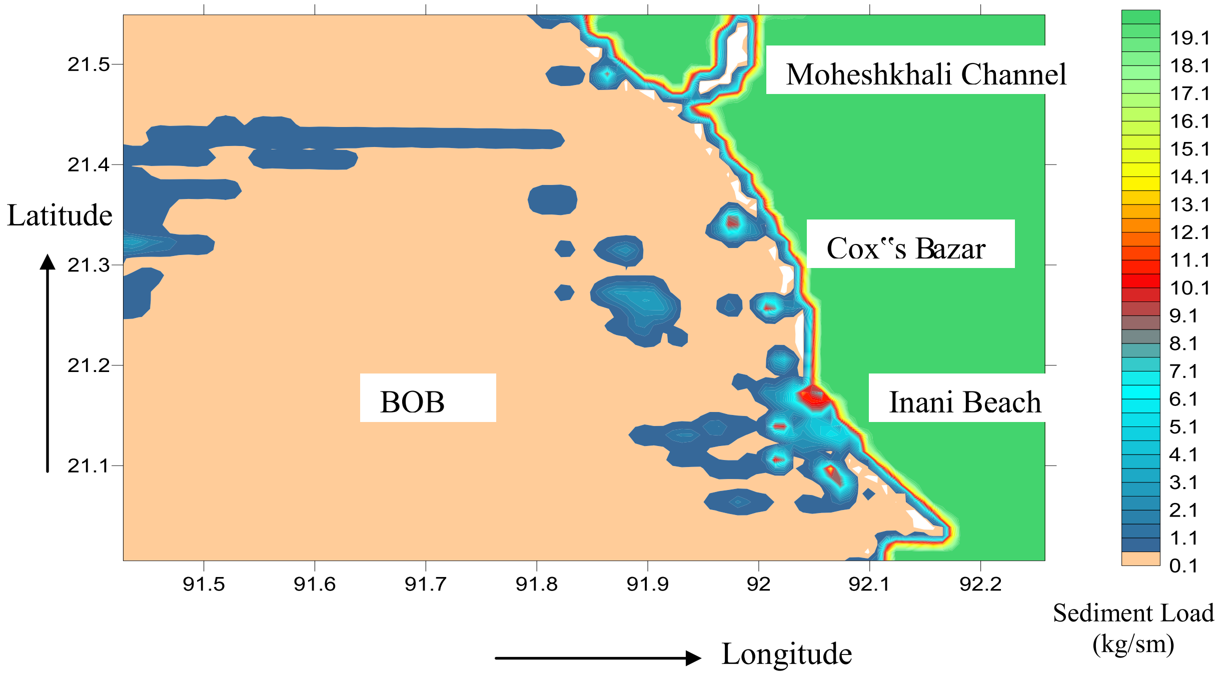


Figure 4.9**:** Suspended sediment load for incoming wave angle 270° for case 1.

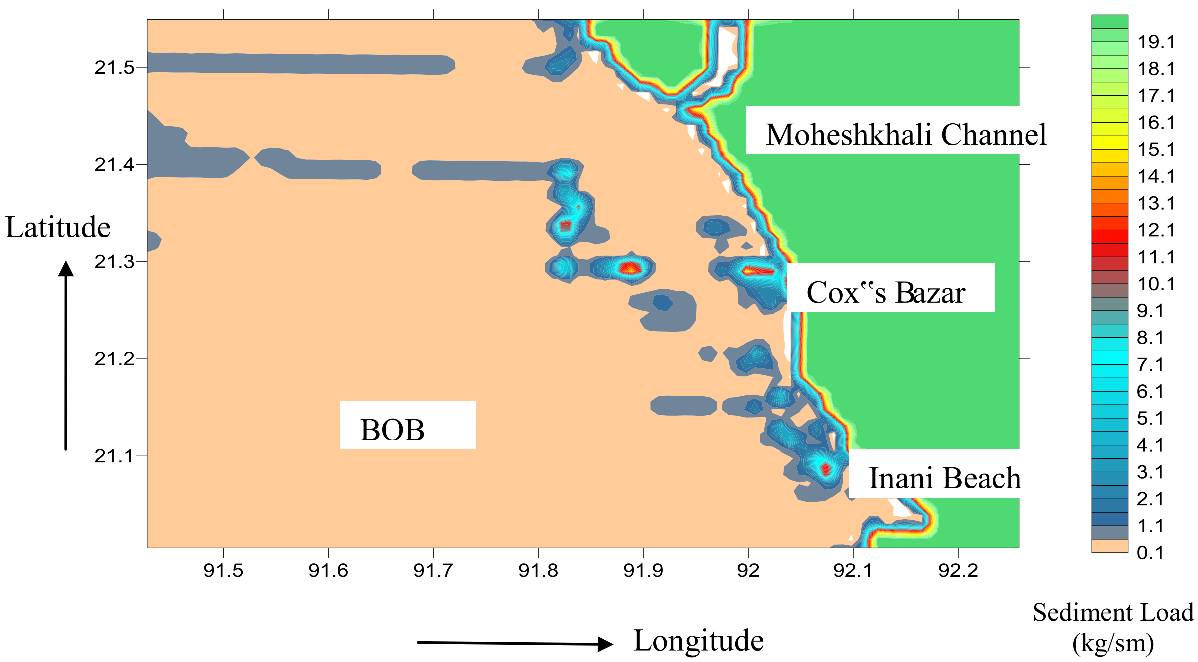


Figure 4.10**:** Suspended sediment load for incoming wave angle 280° for case 1.

Figure 4.9 showing that for incoming wave angle 270^{o}, a negligible amount of suspended sediment concentrates along the shore line.

Figure 4.10 showing that for incoming wave angle 280^{o}, decreasing amount of sediment concentrates along the shore line and the sediment movement pattern is almost same as Figure 4.9.

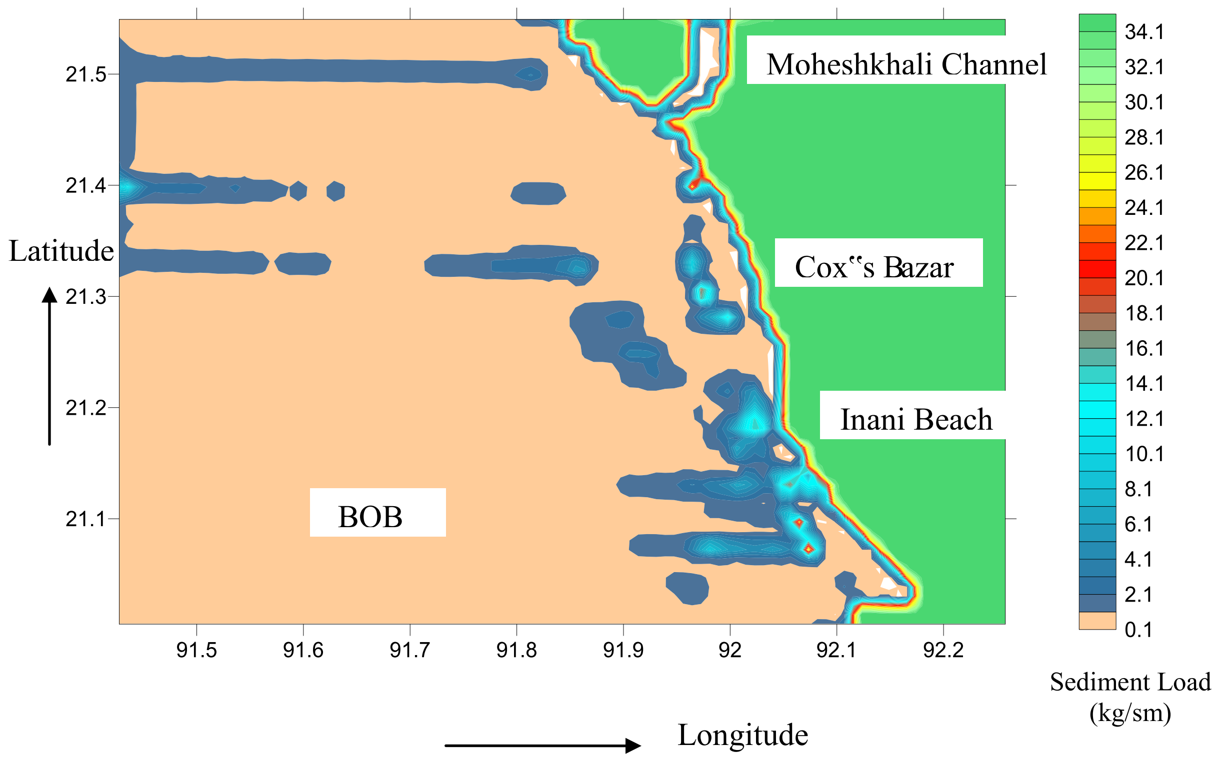


Figure 4.11**:** Suspended sediment load for incoming wave angle 290^{o} for case 1.

The above figure represents that the amount of sediment transportation has increased for the wave angle 290^{o} than the previous cases where the wave angle was 250^{o} and more.

4.3.2 Bed Load Movement Pattern for Case 1

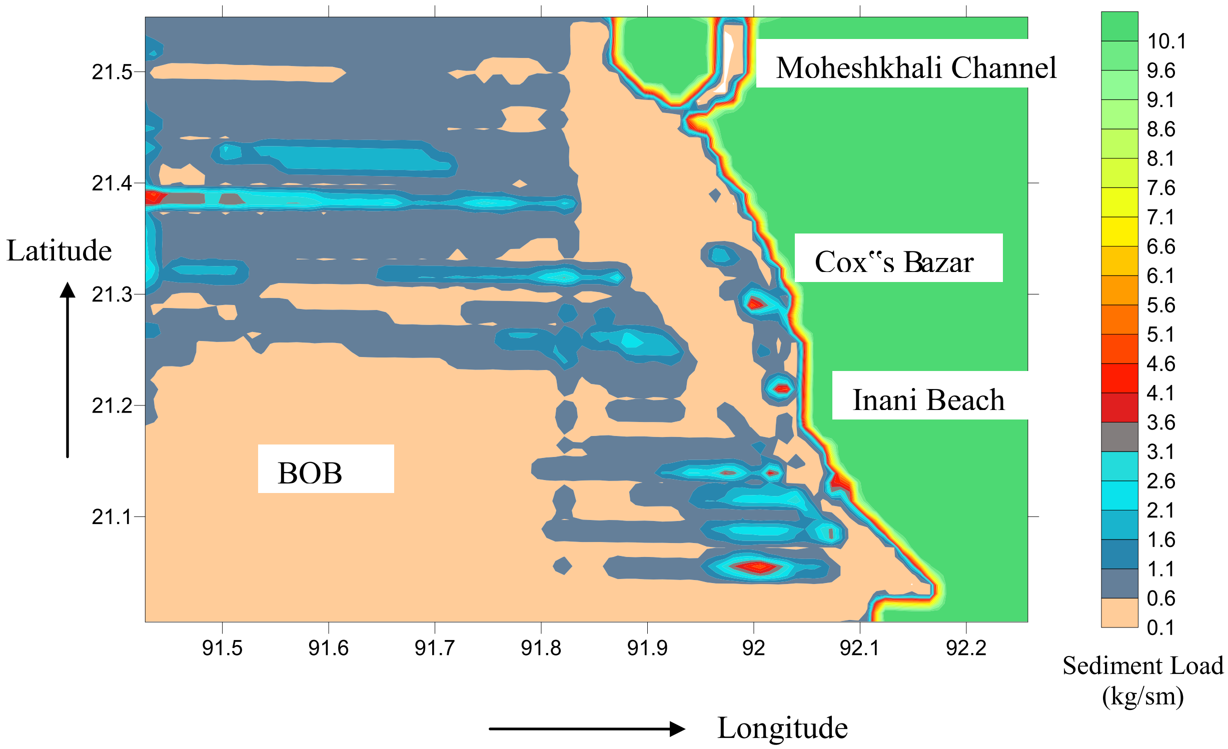


Figure 4.12**:** Bed load for incoming wave angle 230^{o} for case 1.

Figure 4.12 showing that a small amount of bed load is coming to the shore line for incoming wave angle of 230^{o}. Here the sediment concentration is lower near the Moheshkhali channel and tends to concentrate away from the channel. The amount of bed load is negligible compared to the suspended sediment load for incoming wave angle of 230^{o} for case 1.

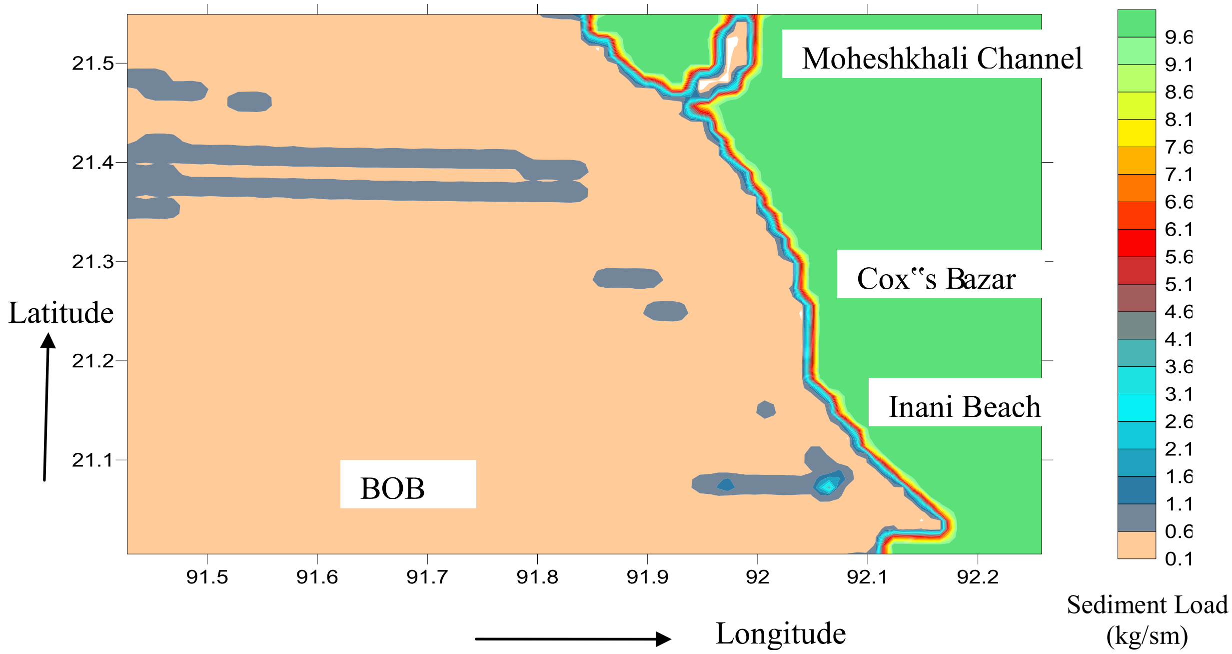


Figure 4.13: Bed load for incoming wave angle 240° for case 1.

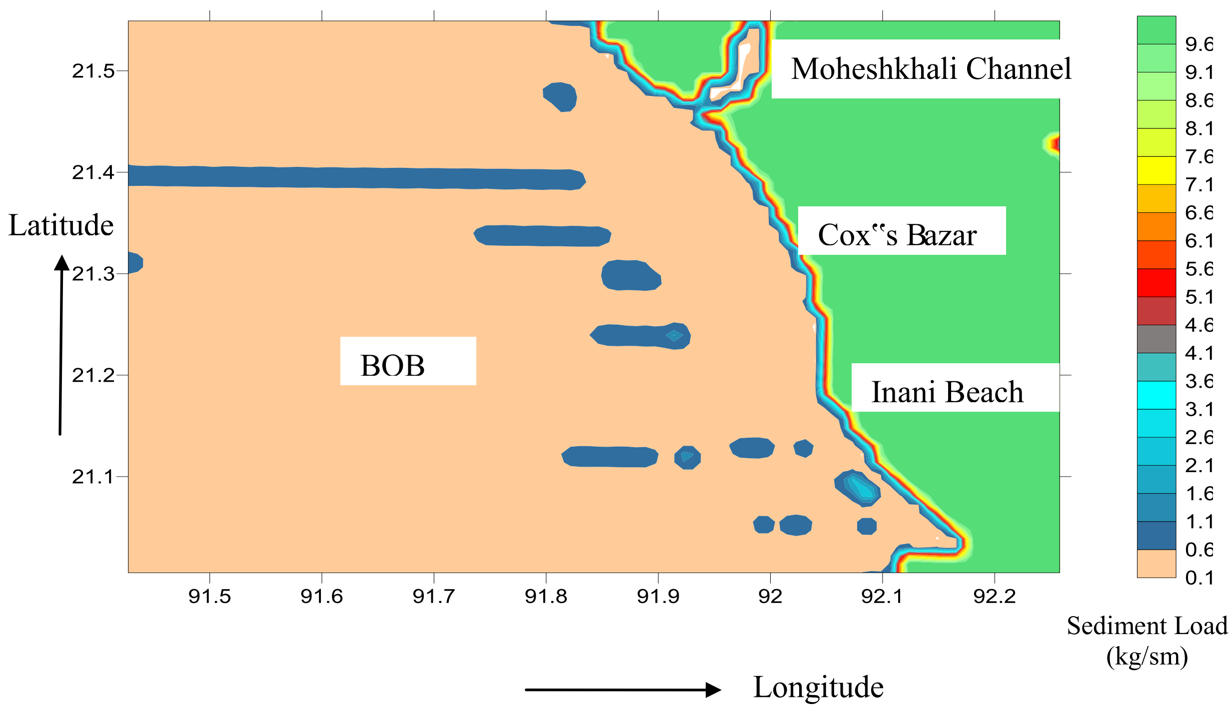


Figure 4.14: Bed load for incoming wave angle 250° for case 1.

In Figure 4.13 a medium amount of bed load is coming from deep sea to the shore line for incoming wave angle of 240° but the amount is much lower than the previous one. The sediment volume reduced drastically.

The amount of incoming bed load is gradually decreasing in Figure 4.14. For wave angle 250 **°**, the sedimentation pattern remaining almost same as like as the wave angle of 240**°.** But the volume of concentration is less than the previous two cases of bed load.

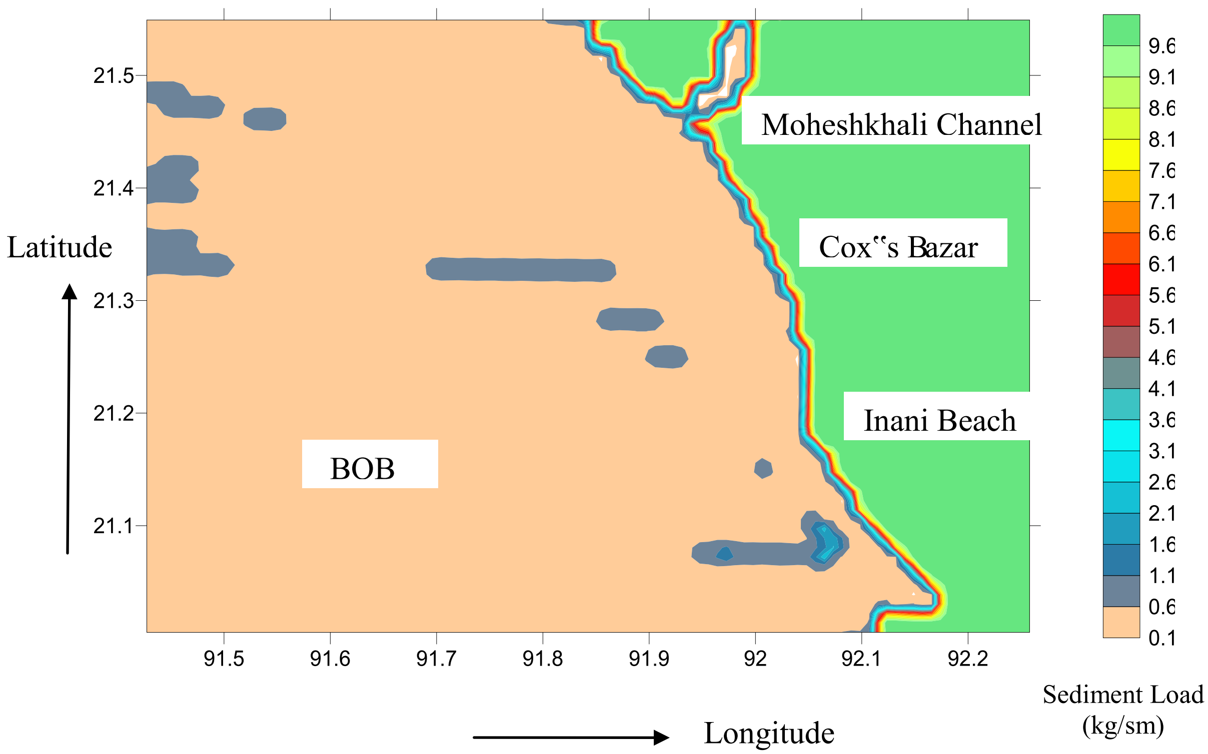


Figure 4.15**:** Bed load for incoming wave angle 260° for case 1.

From the above Figure it is clearly found that the amount of bed load decreased gradually for changing the wave angle from 250° to 260°.

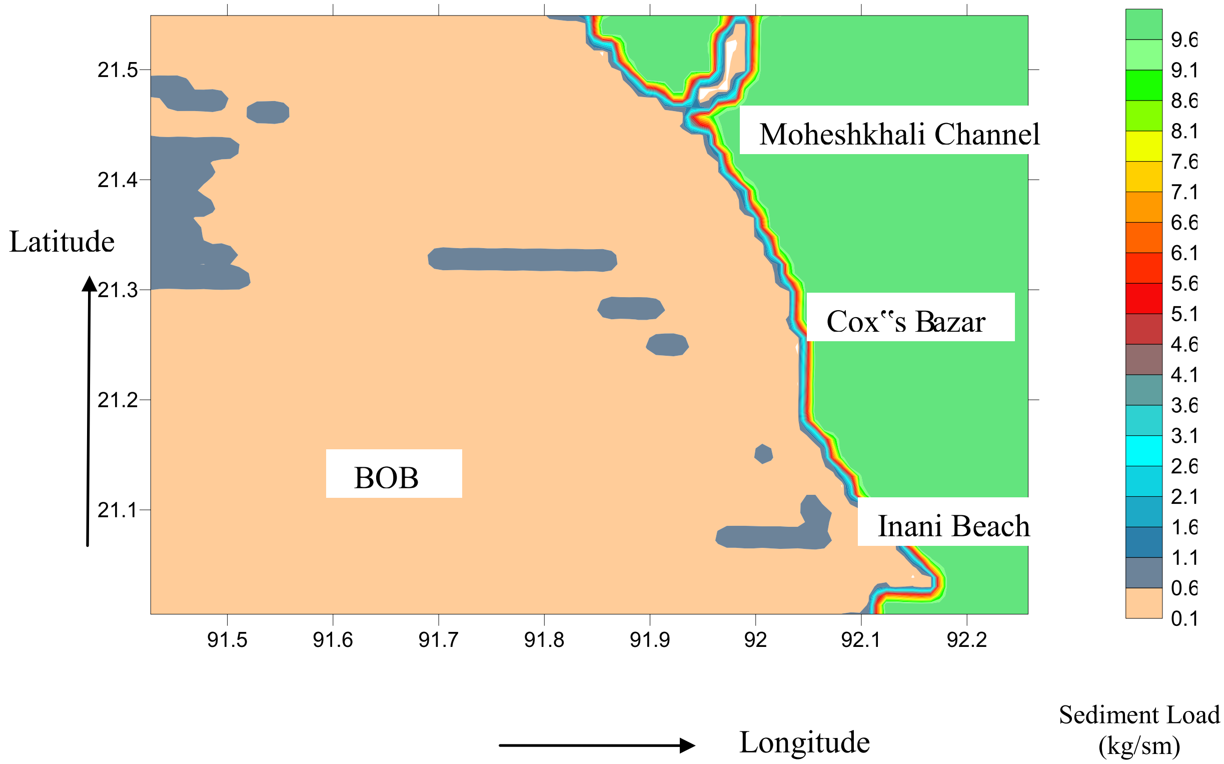


Figure 4.16**:** Bed load for incoming wave angle 270^{o} for case 1.

This Figure represents that the sediment concentration increased for incoming wave angle of 270 $^{\mathbf{o}}$ than the previous one.

4.4 Representation of Model Output for Case 2

Case 2 is the boundary condition generated from the outside of the study area for the data of 2004 to 2013 at point B11. An observation was made for suspended sediment and bed load movement pattern by changing wave angle for case 2. At first, the model was run for the wave angle 230^{o}. Gradually it was changed for every 10^{o} and the model output is presented here up to 290^{o}. After 290^{o} the suspended sediment movement and after 270^{o} the bed load movement was found insignificant.

Table 4.2: Summary of Wave Angle, Height and Period for Case 2

Case 2	Point B11						
BTM (X coordinate)	643074.0882						
BTM (Y coordinate)	350680.0044						
Wave Angle (θ^{o})	230^{o}	240^{o}	250^{o}	260^{o}	270^{o}	280^{o}	290^{o}
Wave Height (m)	1.0	1.59	1.59	1.59	1.13	1.13	1.13
Wave Period (sec)	11.9	11.7	11.7	11.7	14.1	14.1	14.1

4.4.1 Suspended Sediment Movement Pattern for Case 2

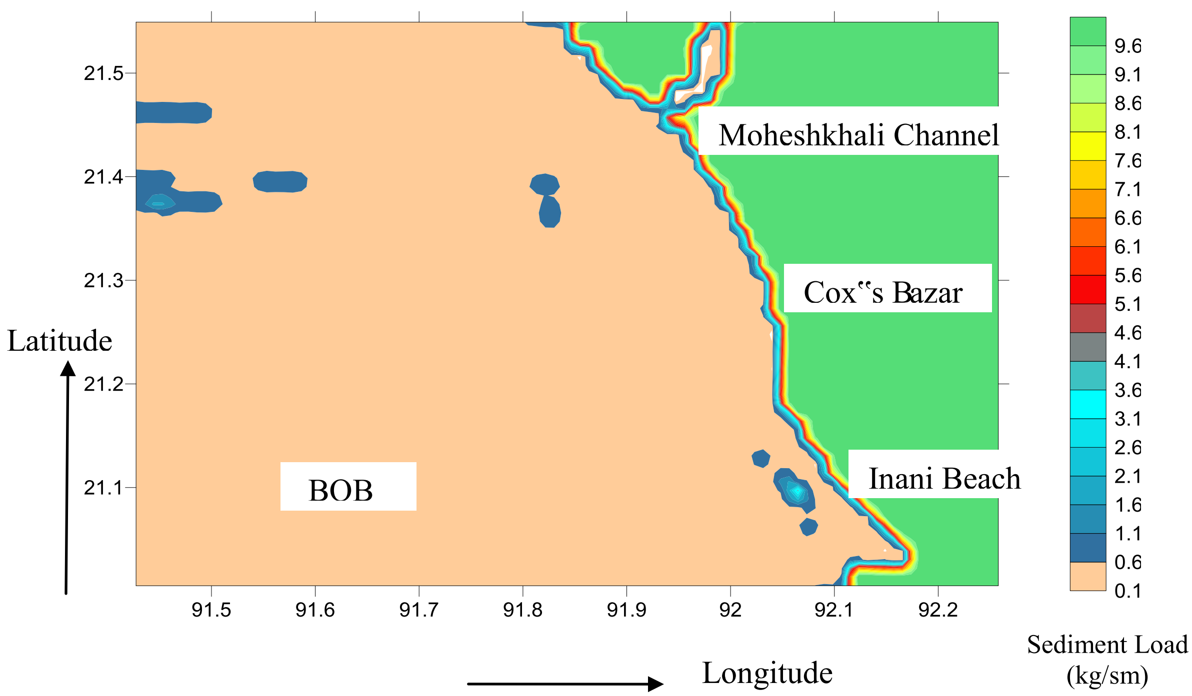


Figure 4.17: Suspended sediment load for incoming wave angle 230^{o} for case 2.

Here the figure showing a small amount of suspended sediment transported from the deep sea to the shore line in case 2. A great variation in amount of sediment concentration is found with case 1.

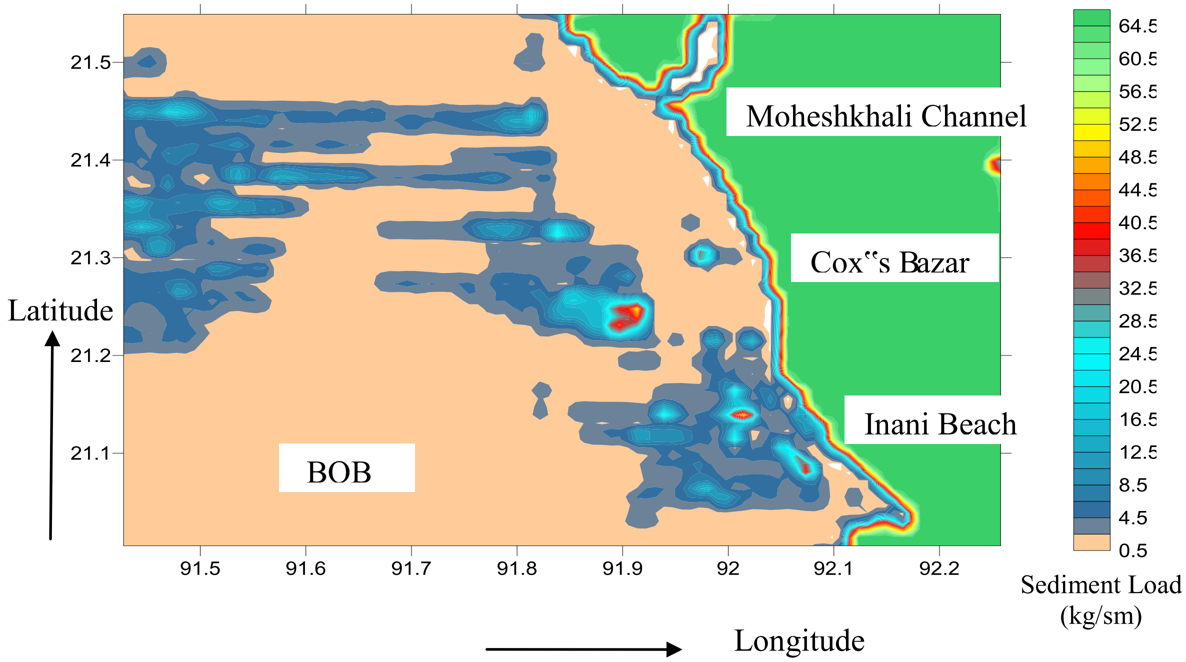


Figure 4.18: Suspended sediment load for incoming wave angle 240° for case 2.

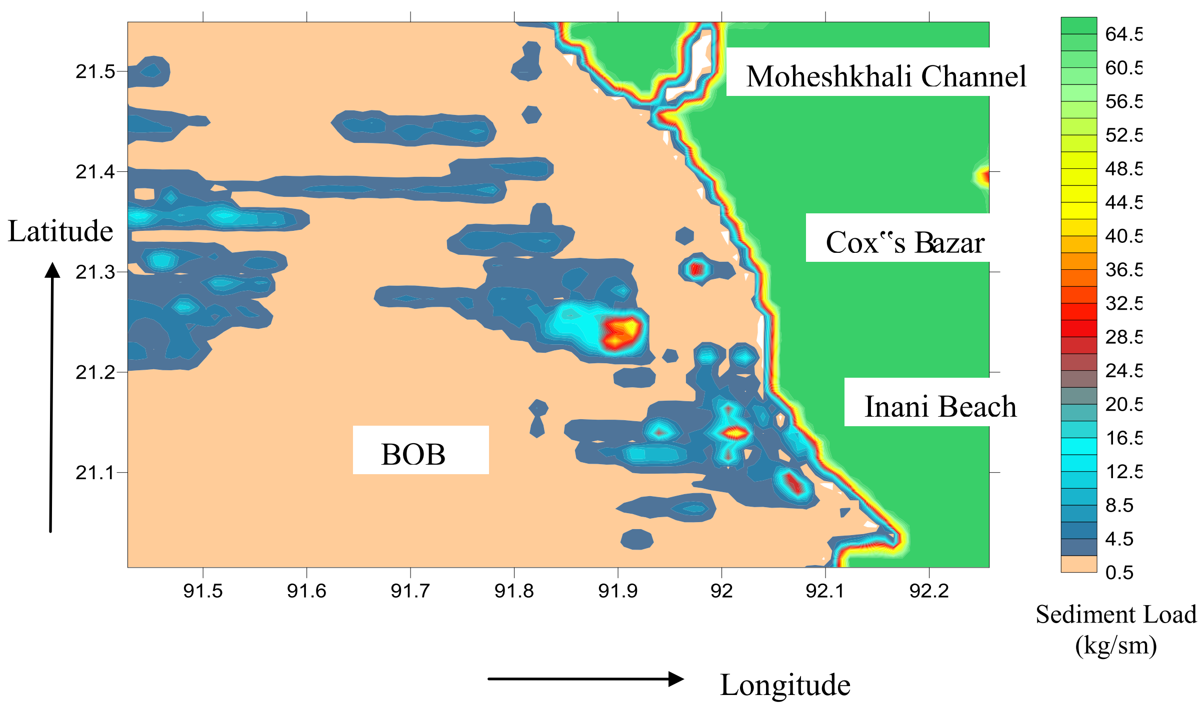


Figure 4.19: Suspended sediment load for incoming wave angle 250° for case 2.

Figure 4.18 sowing that sediment concentration for suspended sediment has increased here for wave angle 240^{o} than the previous one of 230^{o} and it concentrates along the shore line away from the Moheshkhali Channel.

From Figure 4.19 it can be observed that the sedimentation concentration for suspended sediment has decreased here for wave angle 250^{o}

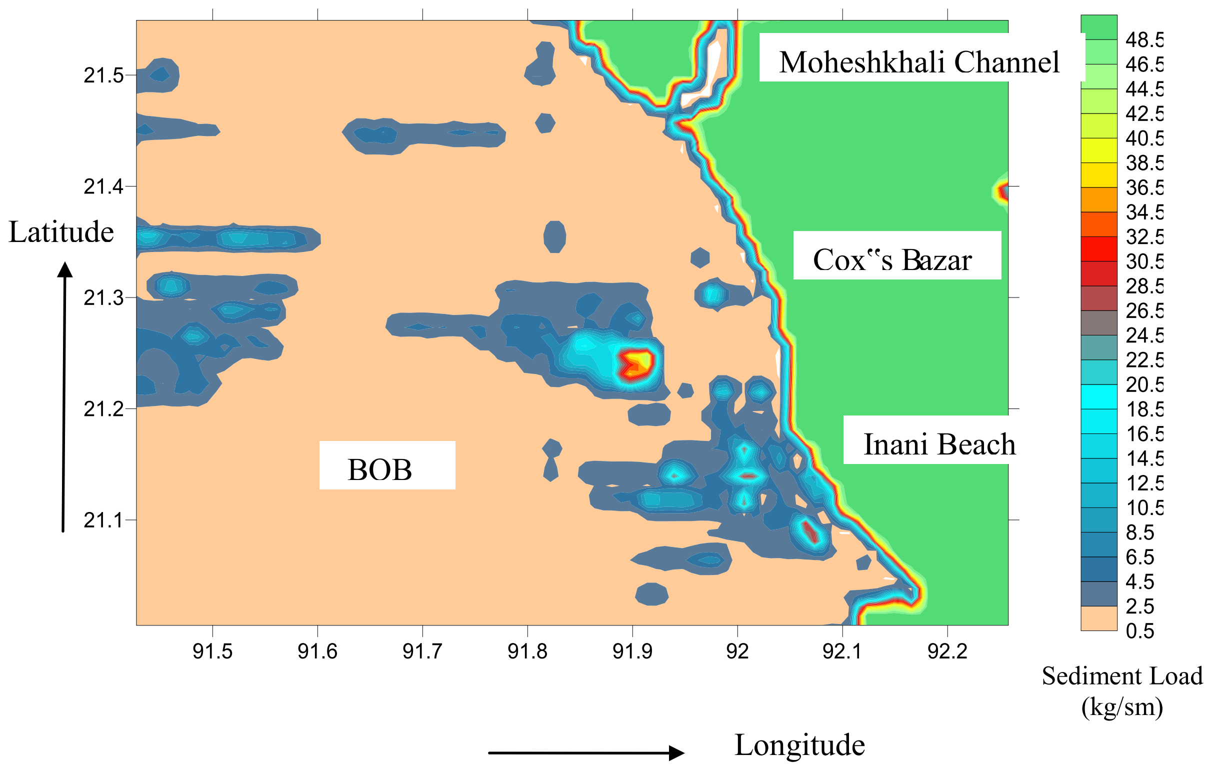


Figure 4.20: Suspended sediment load for incoming wave angle 260^{o} for case 2.

The sedimentation pattern for suspended sediment here is following the pattern of sedimentation for wave angle 240^{o} and 250^{o}. But the concentration at different point along the shore line has increased for the wave angle 260^{o}.

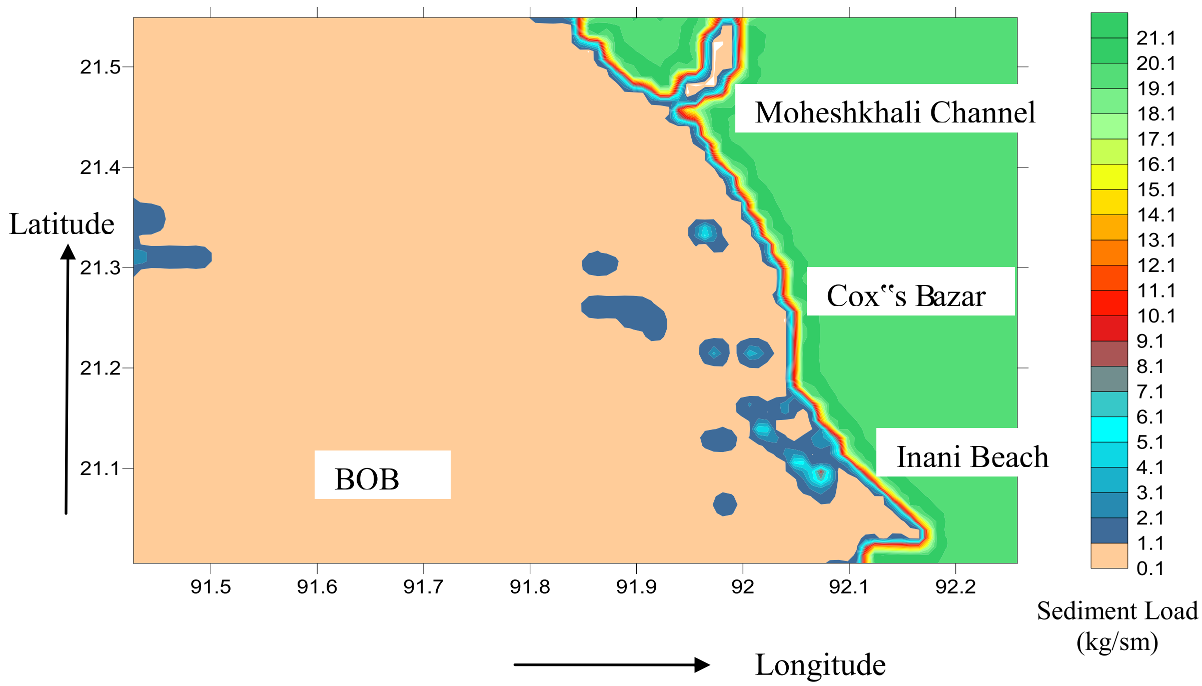


Figure 4.21: Suspended sediment load for incoming wave angle 270° for case 2.

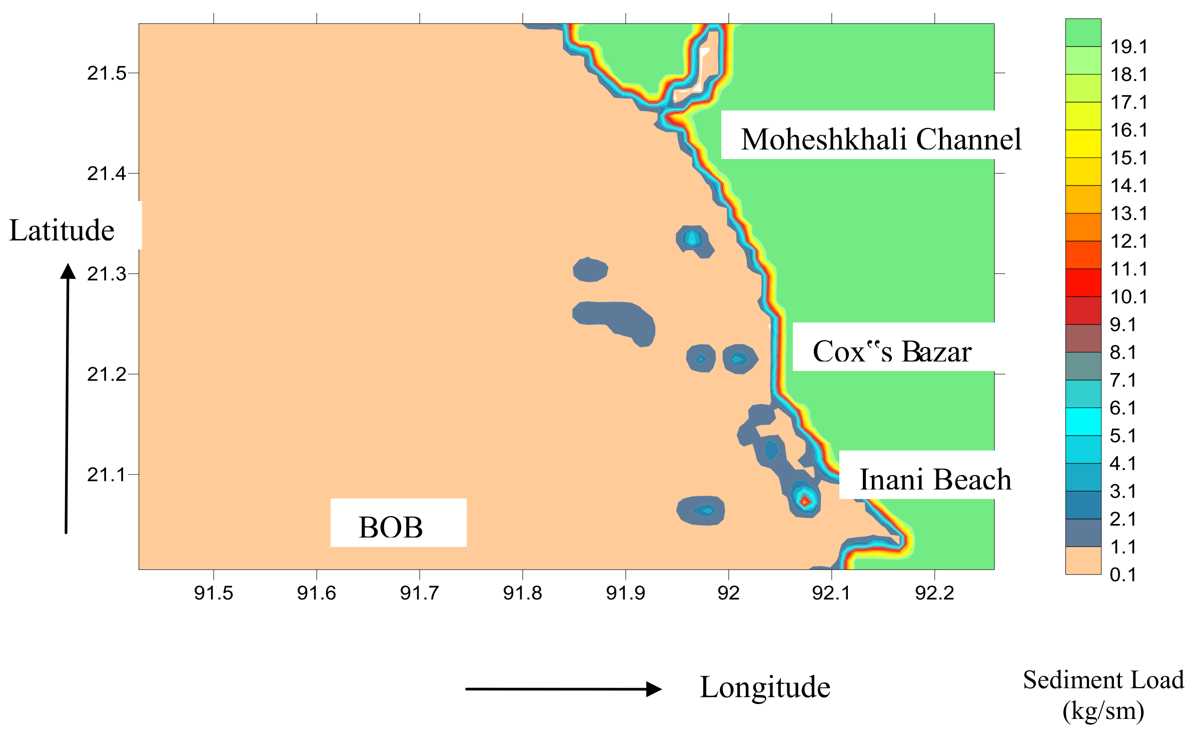


Figure 4.22: Suspended sediment load for incoming wave angle 280° for case 2.

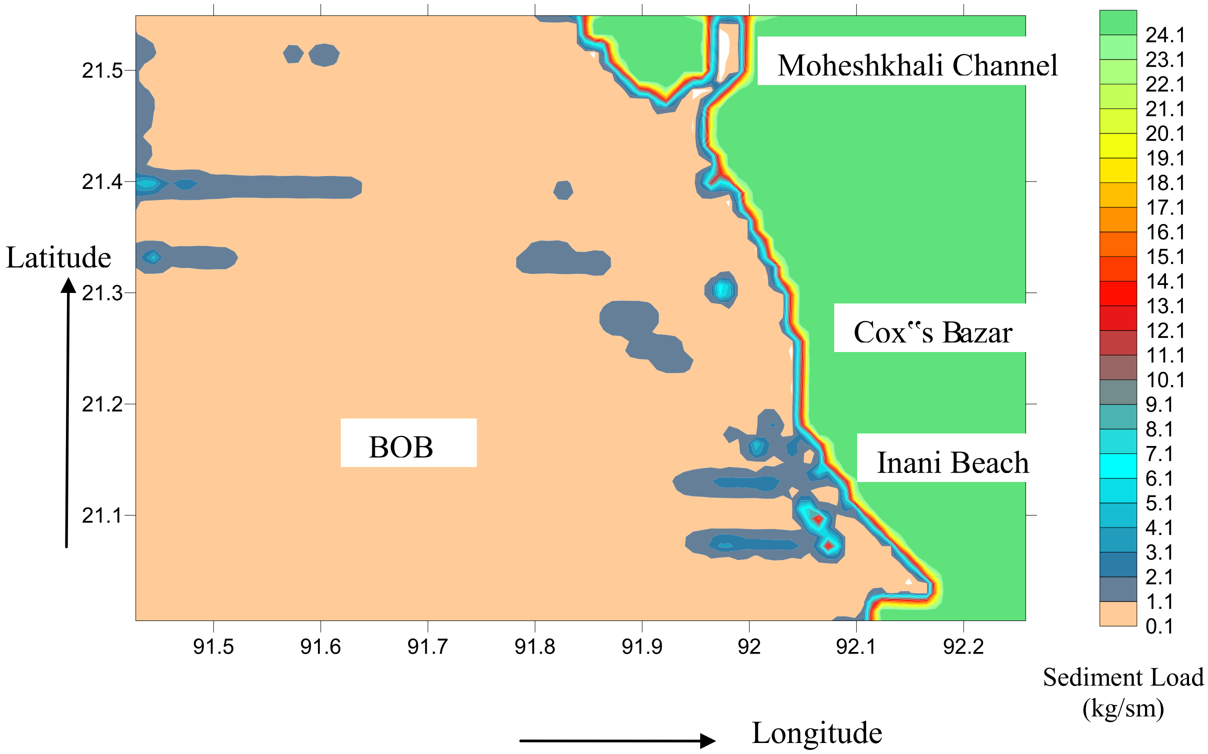


Figure 4.23: Suspended sediment load for incoming wave angle 290^{o} for case 2.

For case 2, sediment transportation rate for suspended sediment is drastically reduced for incoming wave angle of 270^{o}, 280 ^{o} and 290 ^{o}. From Figure 4.21, 4.22 and 4.23 it is found that the amount of suspended sediment concentration is very much negligible as it is found in Figure 4.19 and 4.20.

4.4.2 Bed Load Movement Pattern for Case 2

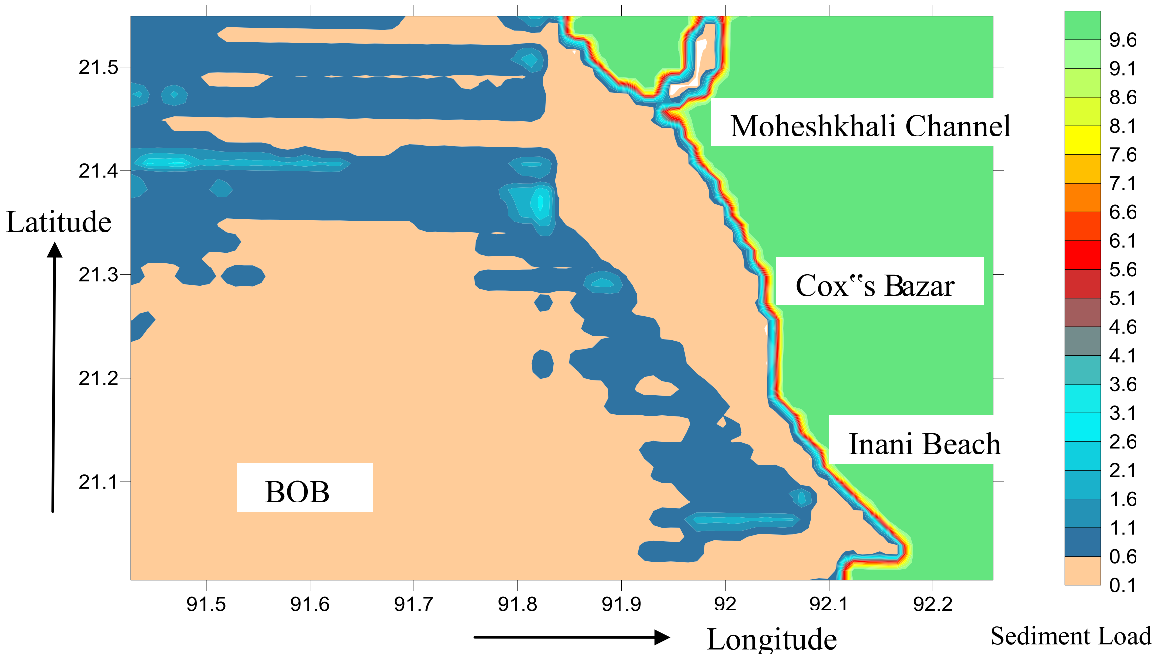


Figure 4.24**:** Bed load for incoming wave angle 230° for case 2.

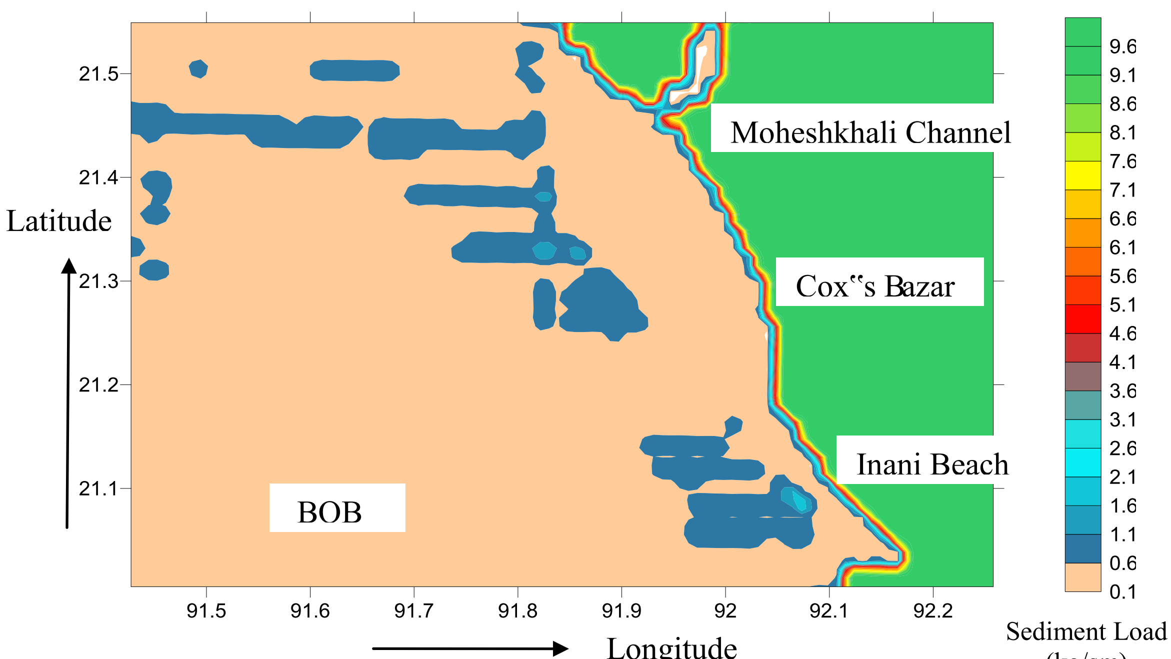


Figure 4.25: Bed load for incoming wave angle 240° for case 2.

In Figure 4.23 small amount of bed load is coming from deep sea to the shore line for incoming wave angle of 230°. Here the sedimentation pattern is almost same as it was in case 1 for 230° wave angle.

In Figure 4.24 the amount of bed load is decreasing than the previous one. But a considerable amount concentrates along the shore line.

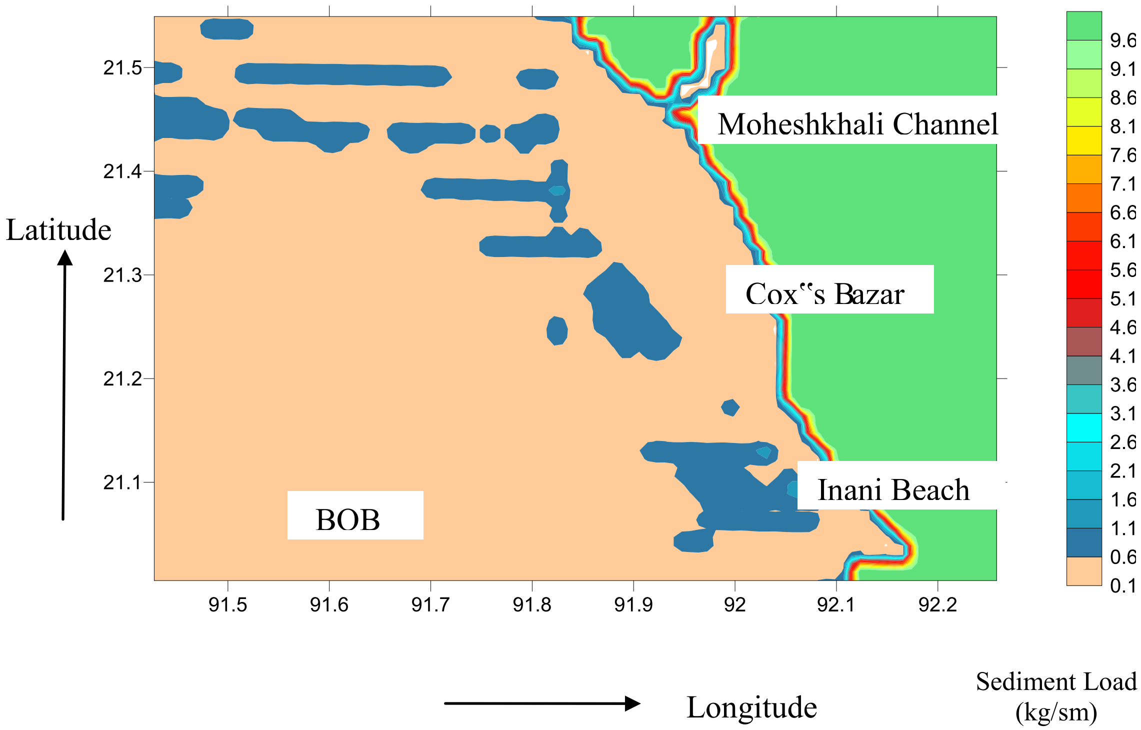


Figure 4.26: Bed load for incoming wave angle 250° for case 2.

The sedimentation pattern for bed load is almost same for the wave angle of 240° and 250°.

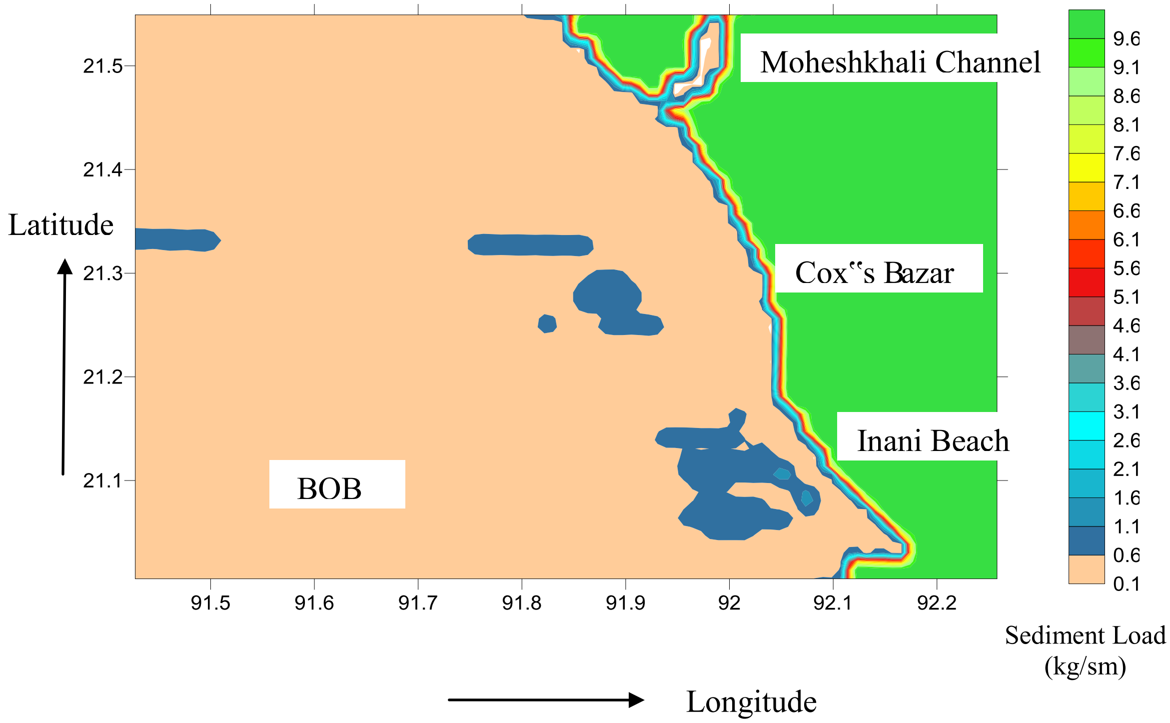


Figure 4.27: Bed load for incoming wave angle 260° for case 2.

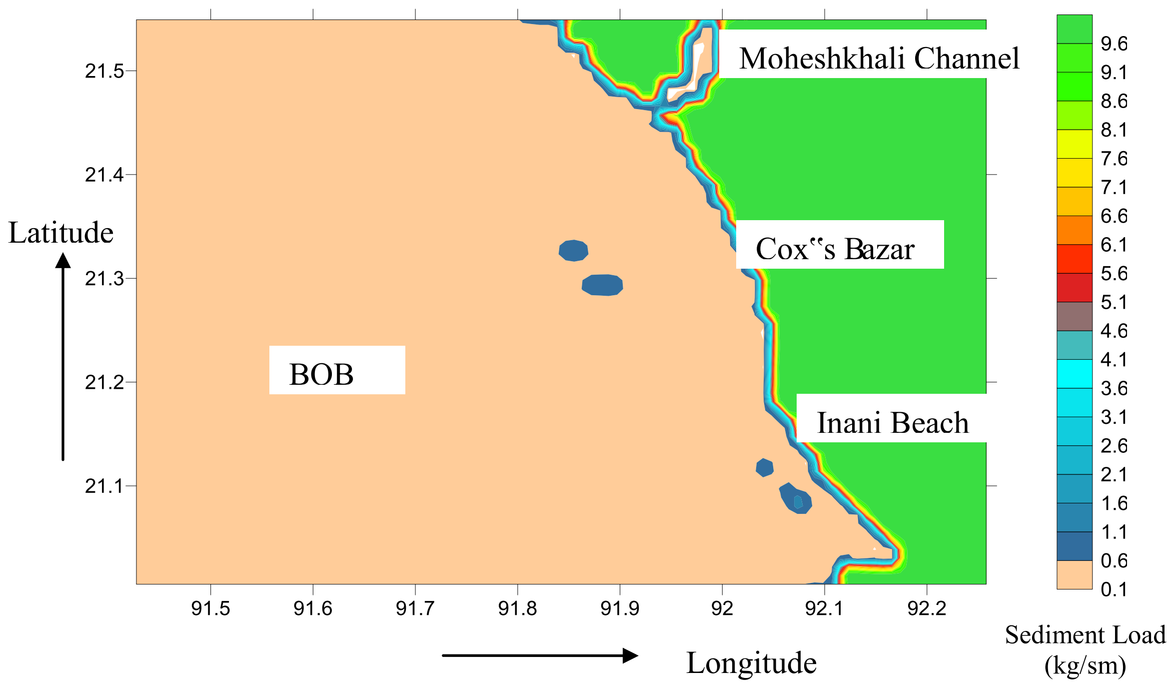


Figure 4.28: Bed load for incoming wave angle 270° for case 2.

In Figure 4.26 sedimentation pattern also following the previous pattern for incoming wave angle of 240^o and 250^o.

In Figure 4.27 the bed load concentration for incoming wave angle of 270^o is almost insignificant.

4.5 Representation of Wave Height Changes for Case 1

The pattern of wave height changes from deep sea to the shore line of the study area for case 1 is represented here. The model output for different wave angle is plotted as a line graph in a excel sheet to observe the wave height changes along the study area for section A-A.

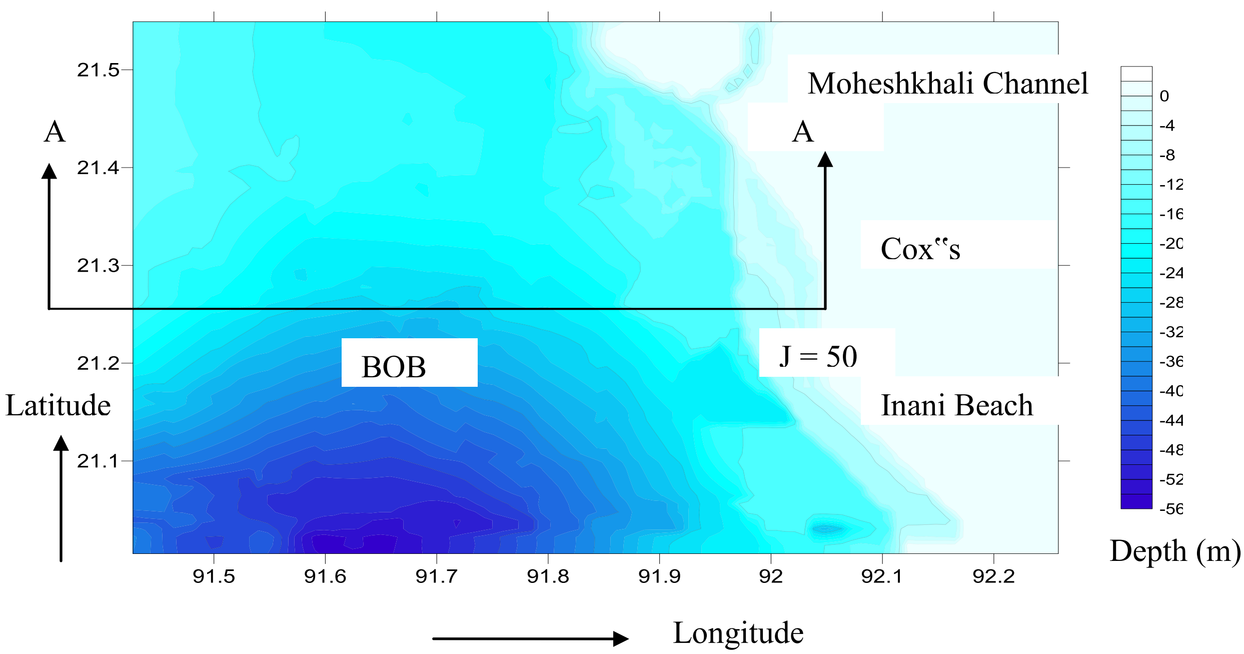


Figure 4.29: Section A-A of the Bathymetry.

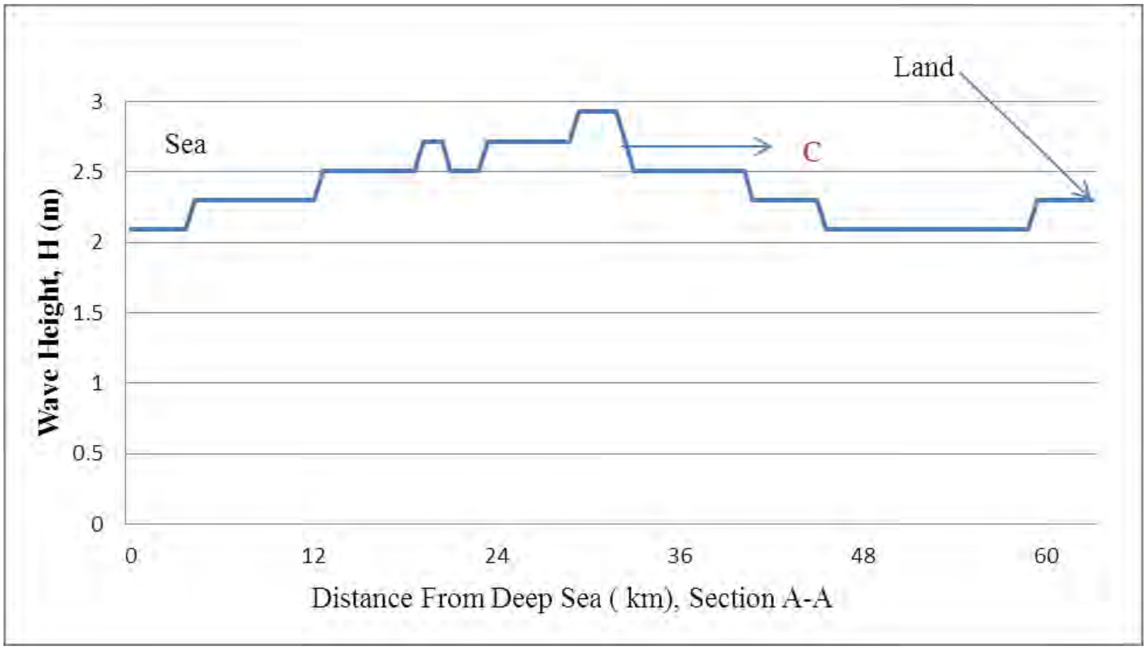


Figure 4.30: Wave Height changes for wave angle 230^{o} for case 1.

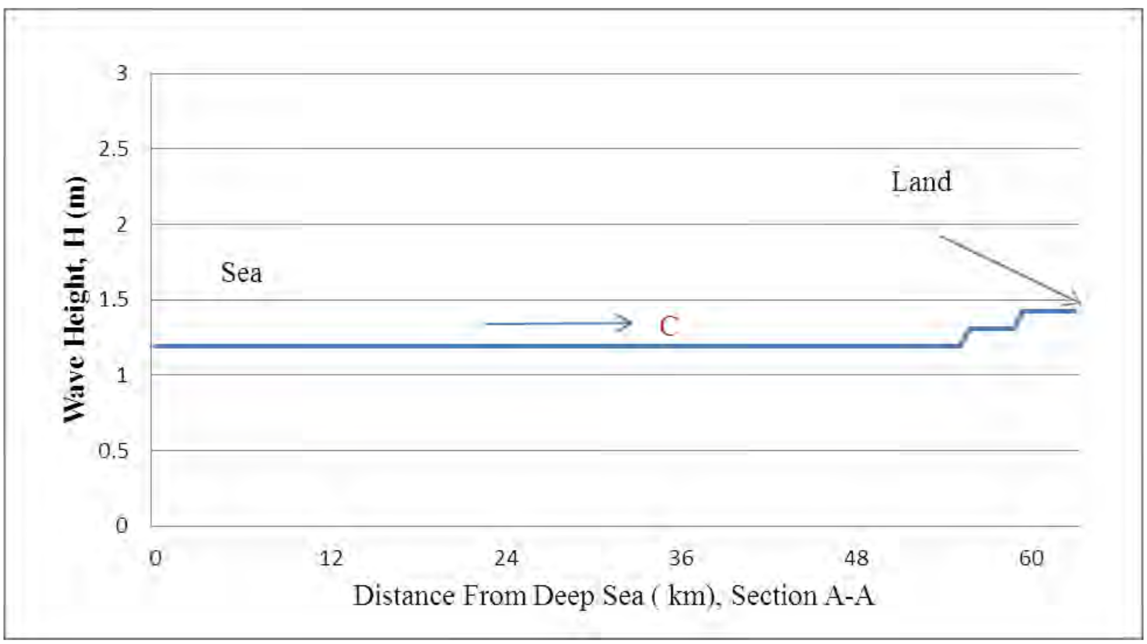


Figure 4.31: Wave Height changes for wave angle 240^{o} for case 1.

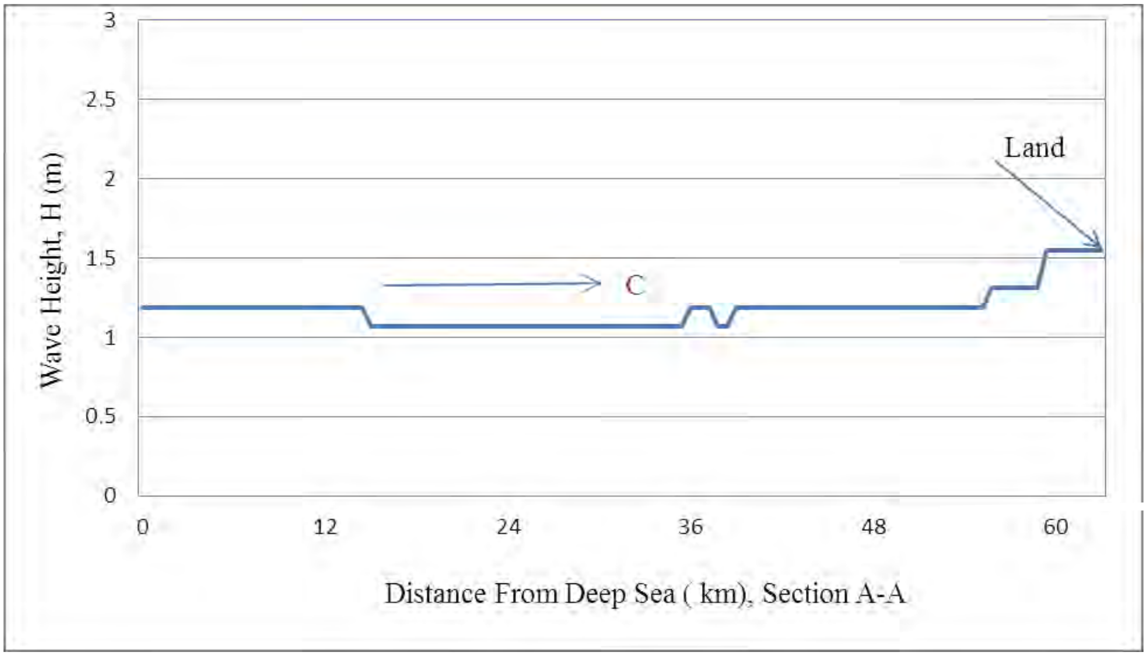


Figure 4.32: Wave Height changes for wave angle 250° for case 1.

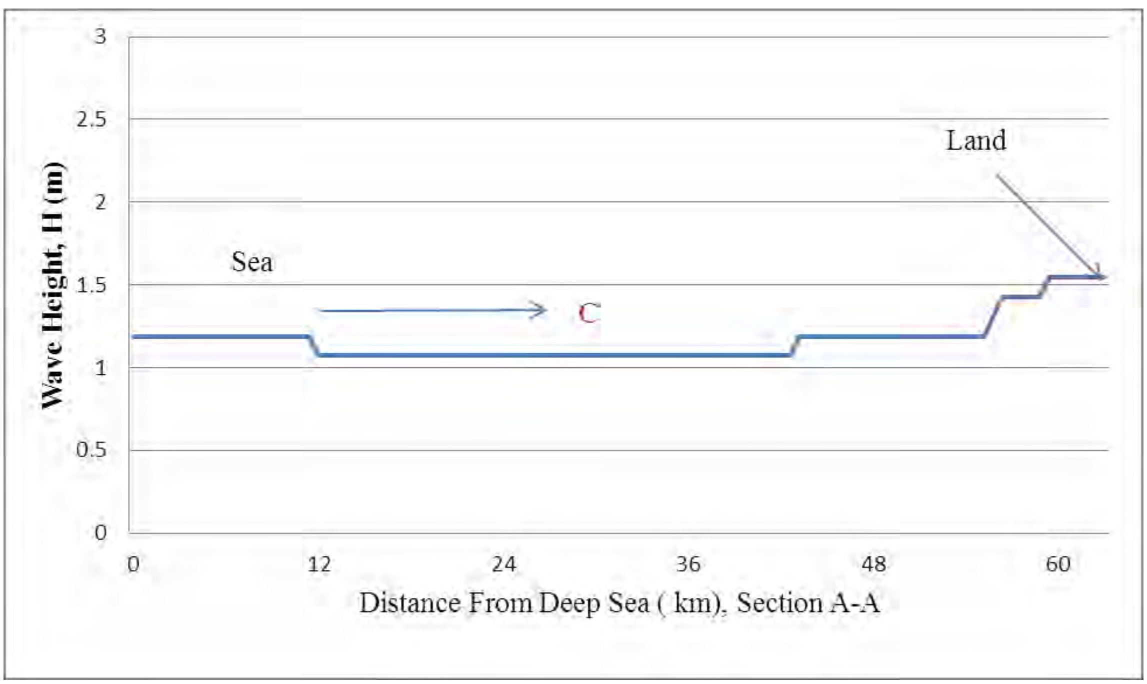


Figure 4.33: Wave Height changes for wave angle 260° for case 1.

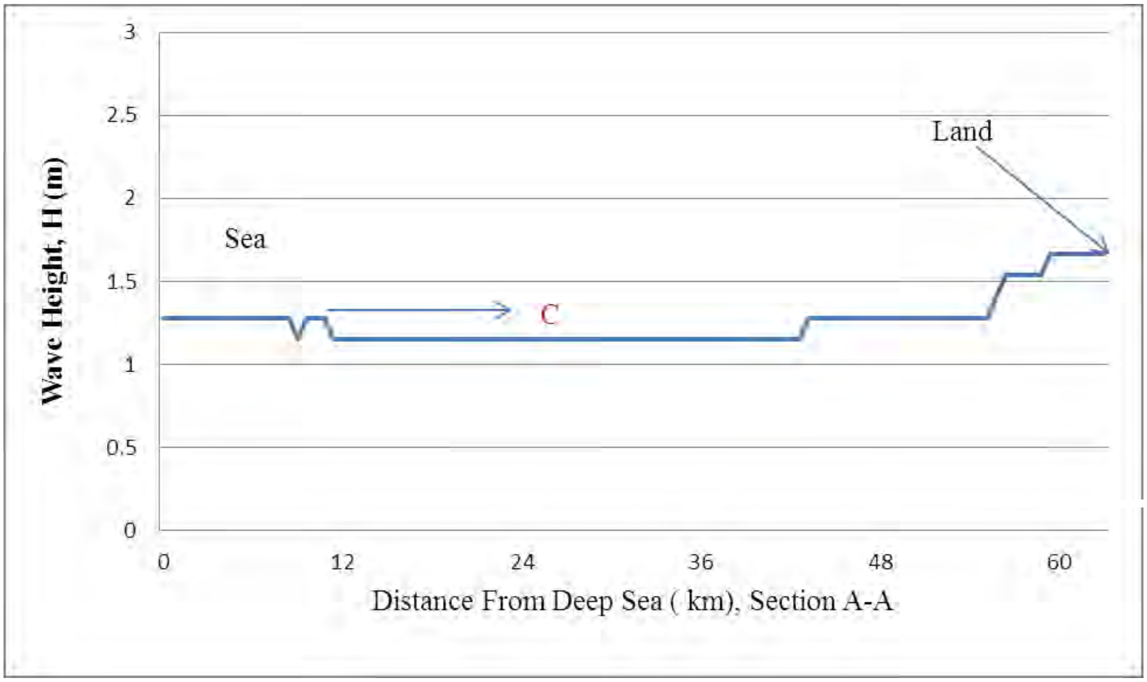


Figure 4.34: Wave Height changes for wave angle 270° for case 1.

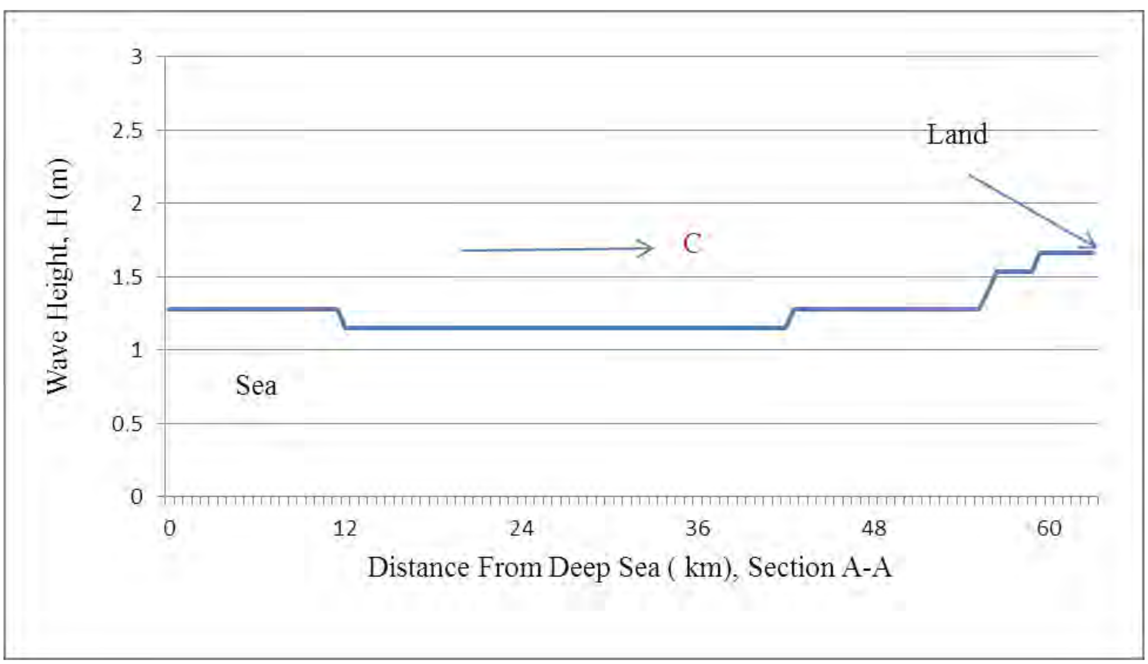


Figure 4.35: Wave Height changes for wave angle 280° for case 1.

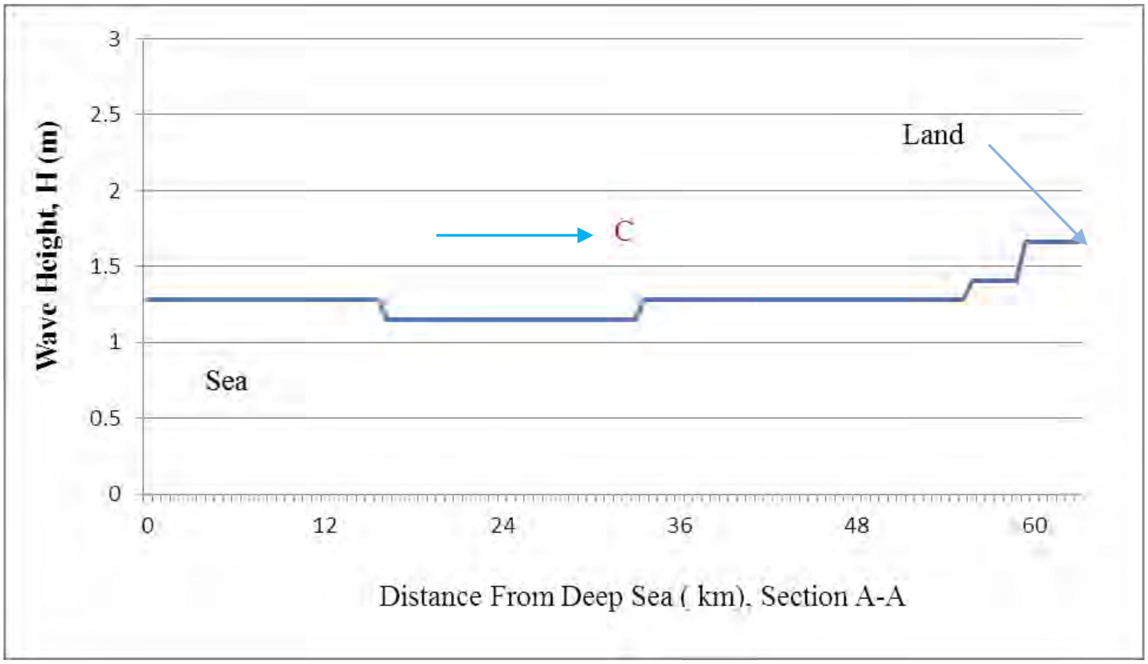


Figure 4.36: Wave Height changes for wave angle 290^{o} for case 1.

For case 1, From Figure 4.28 it is observed that the wave height changes is so abrupt for incoming wave angle 230^{o}. It becomes more flatten for incoming wave angle 240^{o} showing figure 4.29. For incoming wave angle 250^{o} to 290^{o} wave height changes found abruprt only near the shore line.

4.6 Representation of Wave Height Changes for Case 2

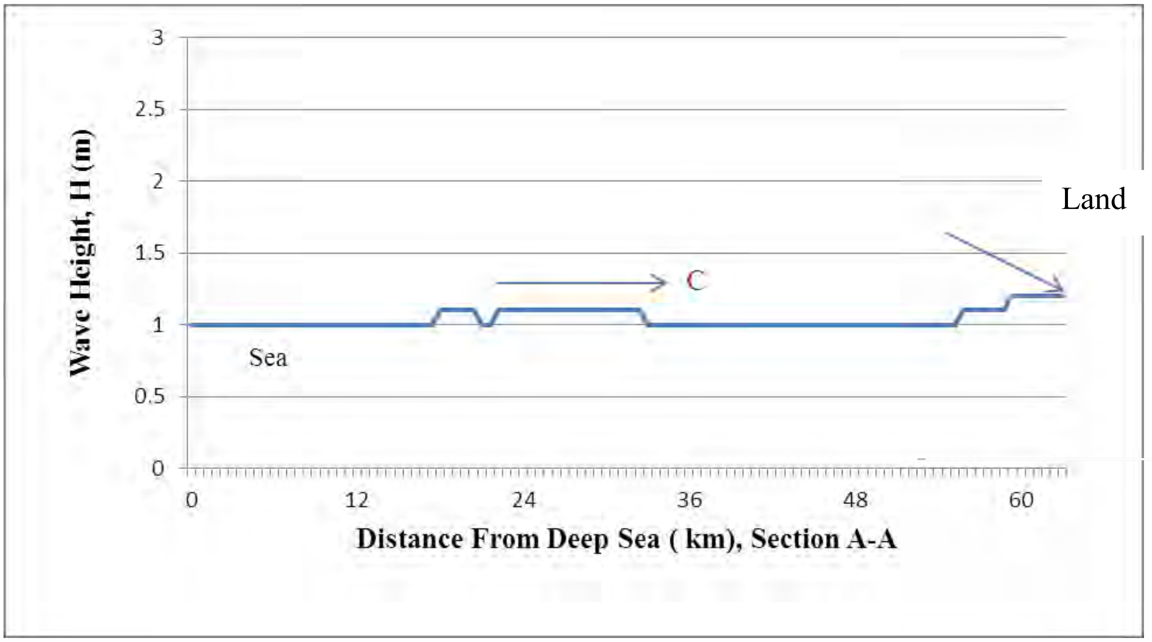


Figure 4.37: Wave Height changes for wave angle 230° for case 2

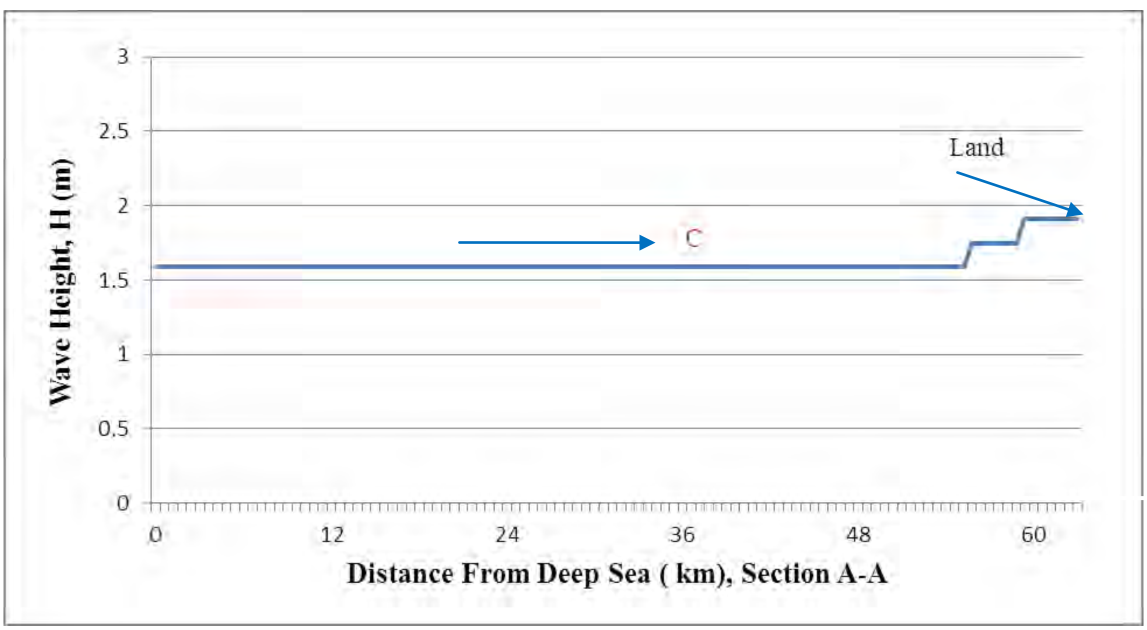


Figure 4.38: Wave Height changes for wave angle 240° for case 2

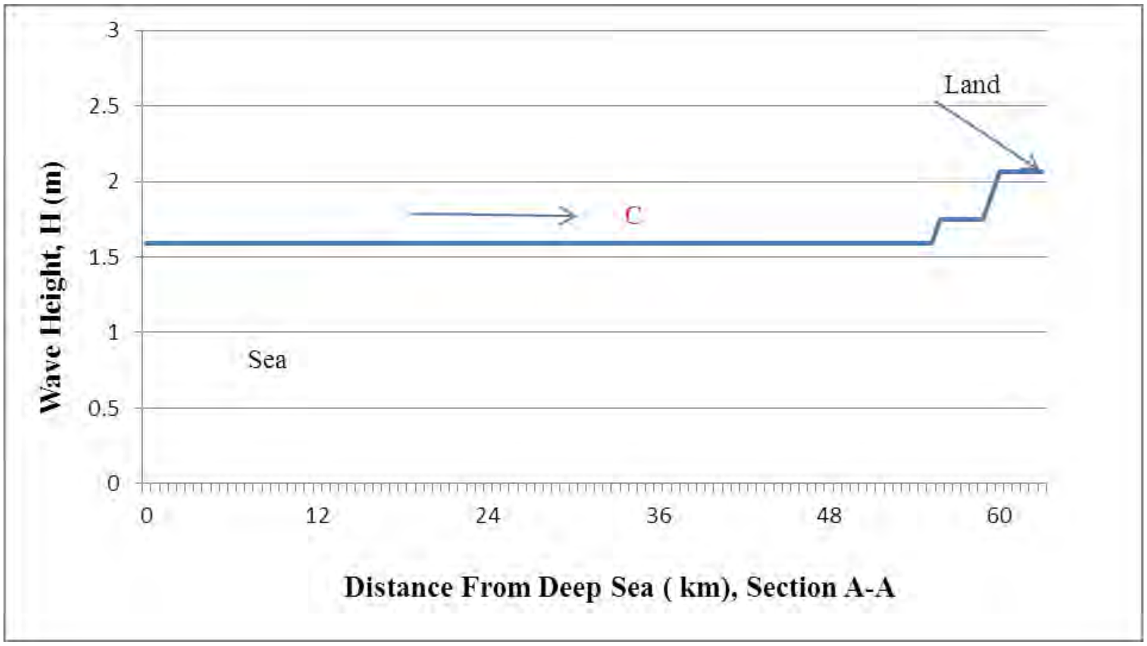


Figure 4.39: Wave Height changes for wave angle 250^o for case 2

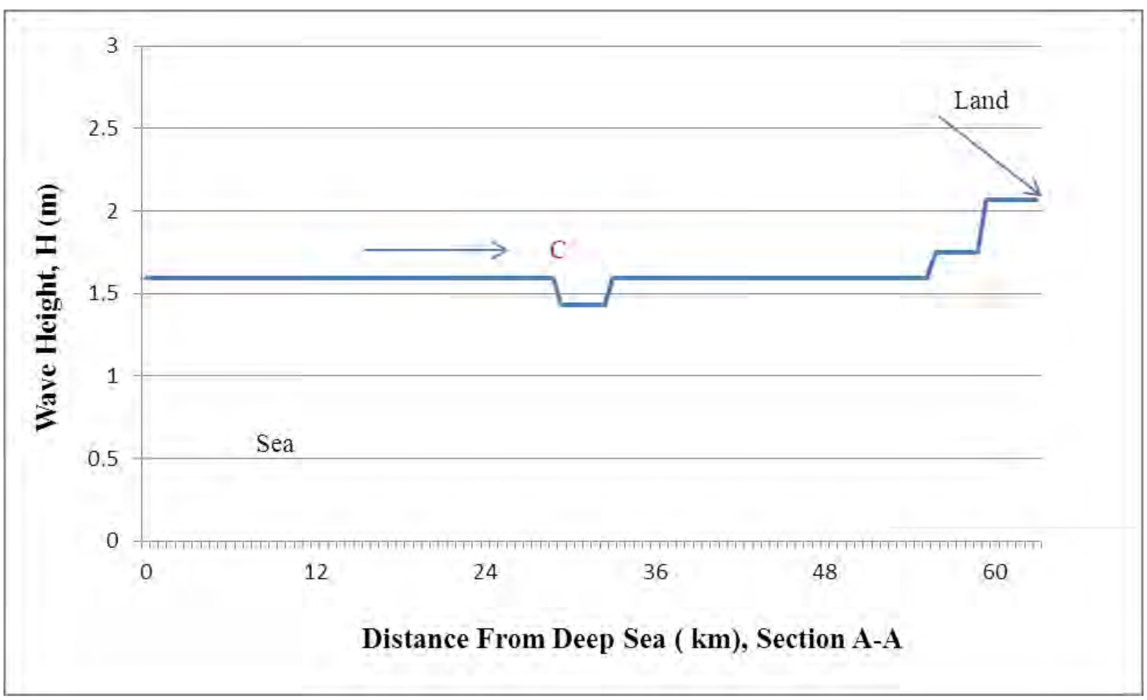


Figure 4.40: Wave Height changes for wave angle 260^o for case 2

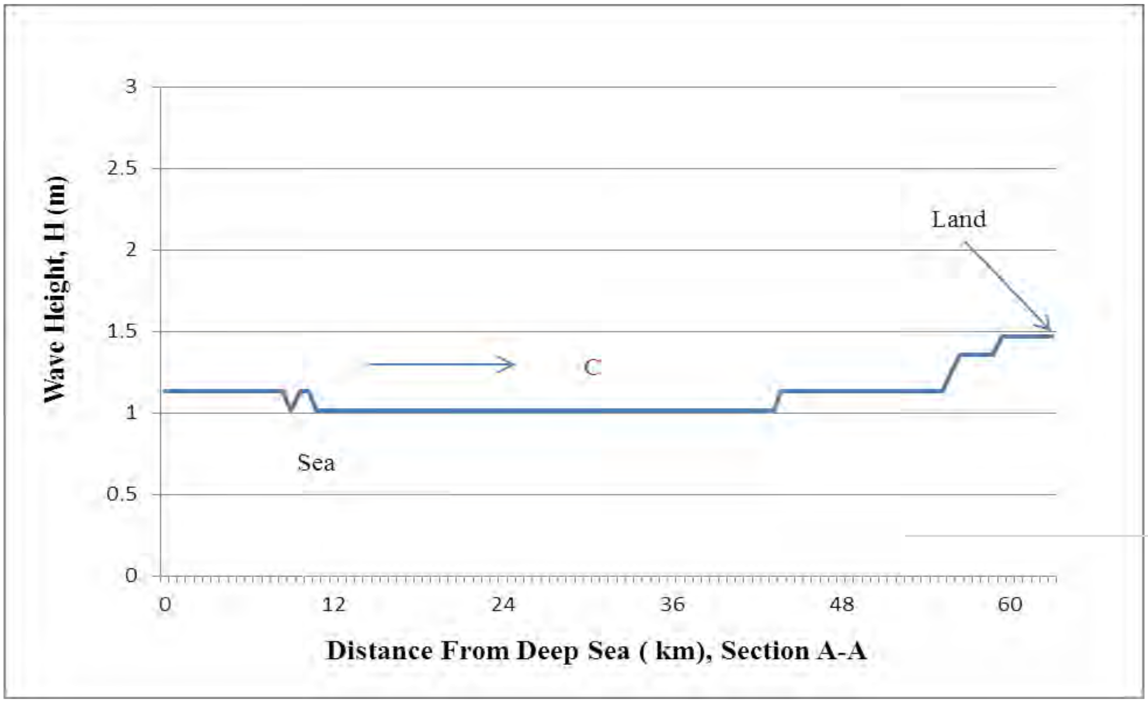


Figure 4.41: Wave Height changes for wave angle 270^{o} for case 2.

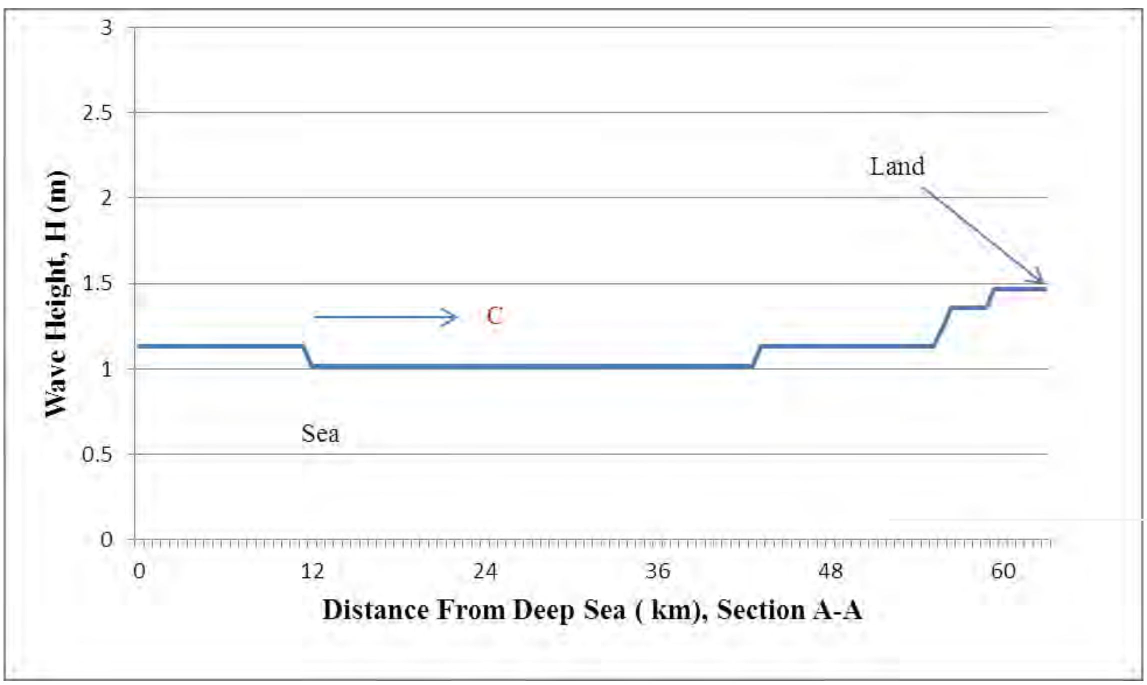


Figure 4.42: Wave Height changes for wave angle 280^{o} for case 2.

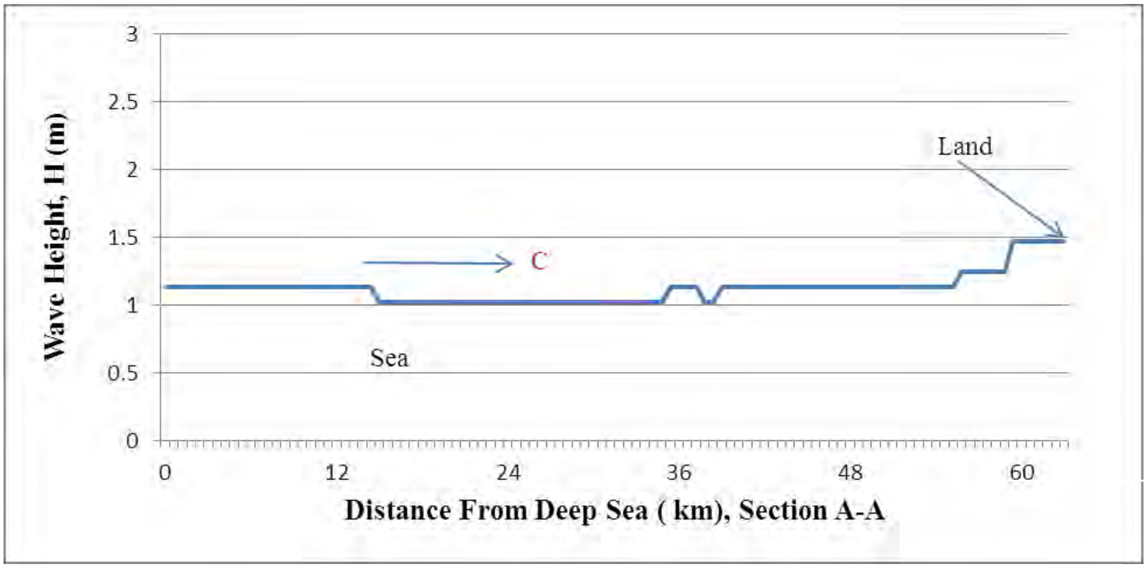


Figure 4.43: Wave Height changes for wave angle 290° for case 2.

For case 2, From Figure 4.35, 436, 4.37 it is observed that there is no abrupt changes in wave height and it is almost flatten. The pattern is almost same for incoming wave angle 230° to 250°. The wave height changes found more abruprt for more increasing wave angle from 260 ° to 290°.

4.7 Representation of Radiation Stress

Radiation stress is the depth-integrated and thereafter phase-averaged excess momentum flux caused by the presence of the surface gravity waves which is exerted on the mean flow. The long shore sediment transport rate is calculated by using one-dimensional momentum equations for both velocity components and the turbulent diffusion equation for sediment concentration. The driving force in the momentum equations is the radiation stress induced by wave breaking.

Here some scenario of radiation stress is represented from the output of the DIVAST model for the wave angle of 230°, 250°, 270° and 290° for case 2 along the section 1-1 and 2-2 of the study area.

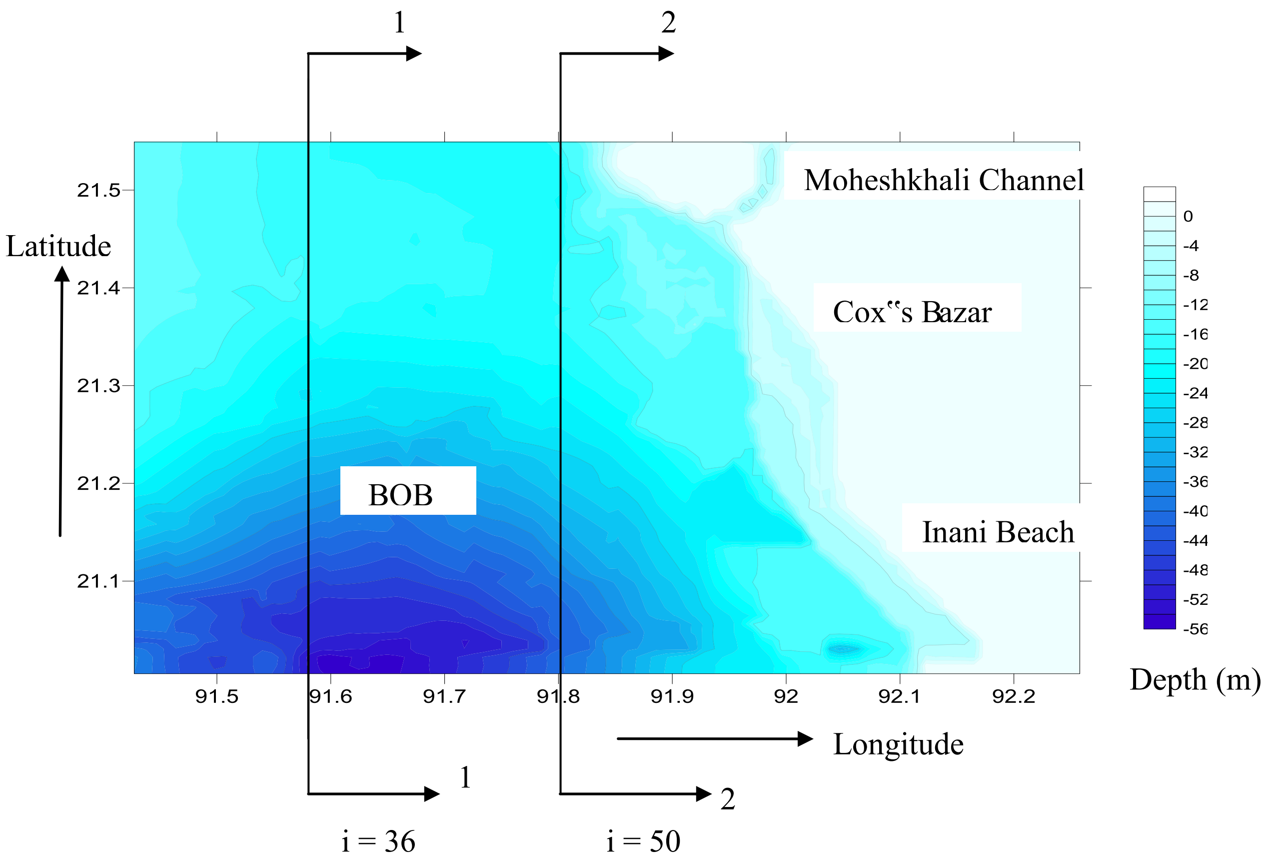


Figure 4.44: Section 1-1 and Section 2-2 0f the Bathymetry

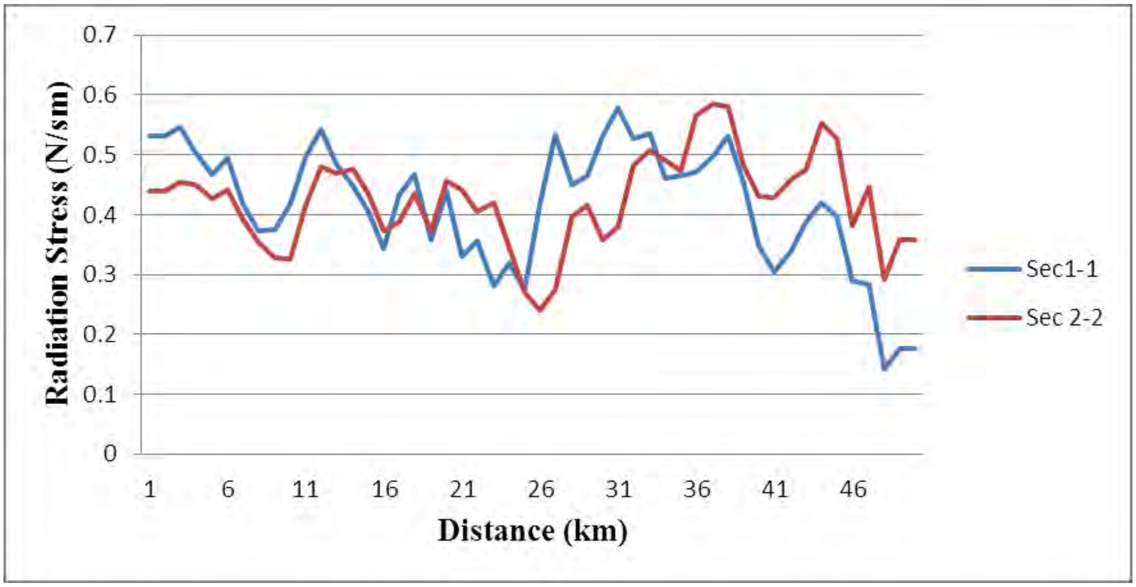


Figure 4.45: Radiation Stress for wave angle 230^o for case 2.

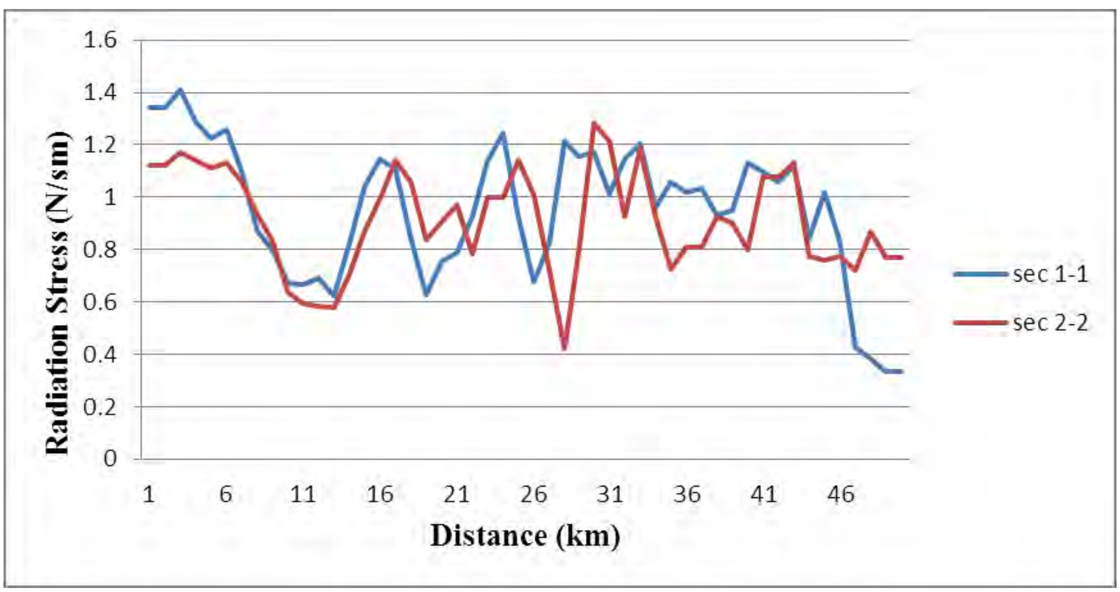


Figure 4.46: Radiation Stress for wave angle 250^o for case 2.

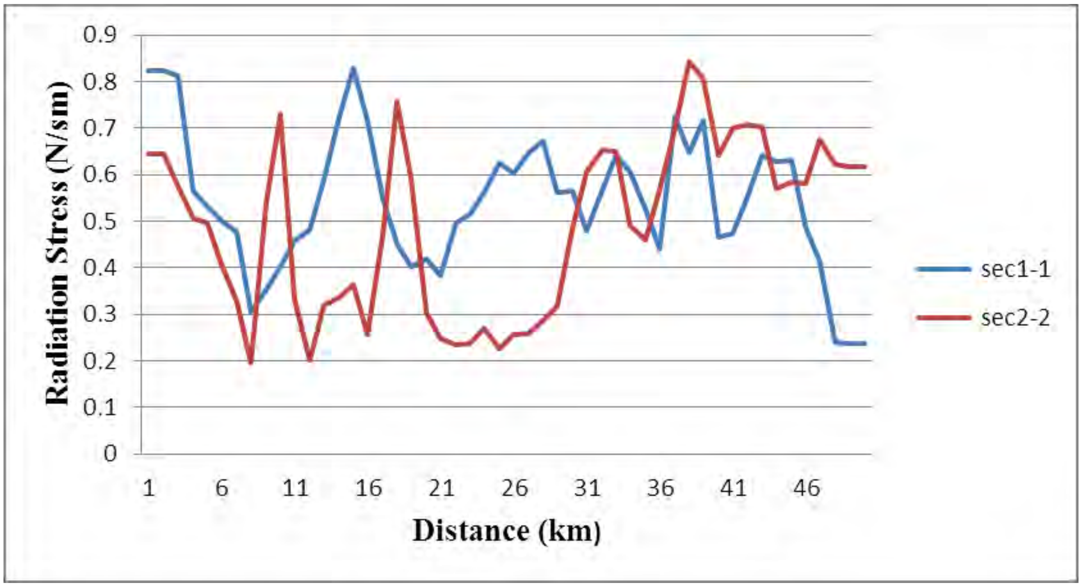


Figure 4.47: Radiation Stress for wave angle 270° for case 2.

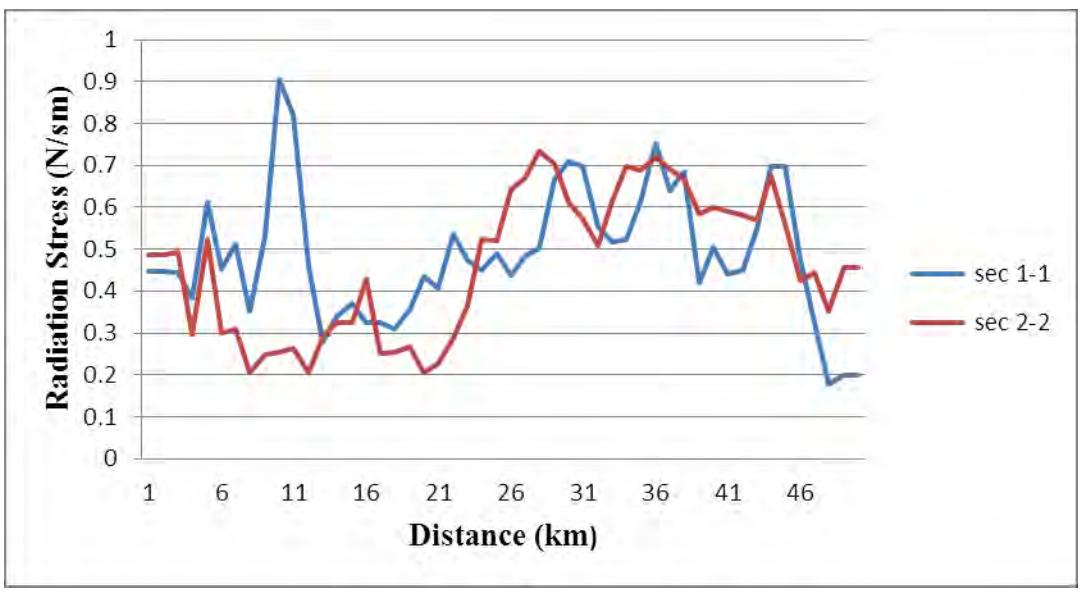


Figure 4.48: Radiation Stress for wave angle 290° for case 2.

From the above figures showing the radiation stresses it can be observed that the radiation stress along section 1-1 is higher at most of the point than the radiation stress along section 2-2. In both setion, section 1-1 and section 2-2 the radiation stress changes abruptly.

4.8 Summary

An analysis is made in this chapter with the output of the model plotted in surfer to assess the sediment movement pattern in nearshore coastal water of Cox‟s Bazar. The wave angle 230^o for case 1 and 240^o for case 2 were found most critical because of a considerable amount of suspended and bed load movements occur with these wave angles. For increasing wave angle both the suspended sediment and bed load movement found decreasing at a greater extent.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 General

Sediment is a socio-economic, environmental and geomorphological resource, as well as a tool of nature. Changes in sediment quantity and quality can have a significant impact on a range of social, economic and environmental systems. The mechanism of sediment transport has been a subject of study for centuries. The coastal sediment transport is one of the important processes that controls the beach morphology, and determines in large part whether shores erode, accrete, or remain stable. Huge amounts of sediment are being used for flood protection, beach nourishment and habitat and wetland protection. No doubt that sediment transport is one of the main tools in coastal zone management and coastal engineering design practice (Kamal et al., 2009).

5.2 Conclusions of the Study

After analyzing from the results of the previous chapter the concluding remarks are found as follows:

1. In case of suspended sediment the highest amount of sedimentation is found for incoming wave angle of 230^o and 240^o for case 1.

2. Generally here it was found that the sedimentation rate decreased gradually for the higher value of wave angle. But exception was found for incoming wave angle 290^o for both in case 1 and case 2.

3. The amount of suspended sediment transportation has found much more higher than the amount of bed load transportation.

4. After 290^{o} the suspended sediment movement and after 270^{o} the bed load movement was found very much negligible.

5. The sediment concentration is higher along the shore line than the other point of the study area.

6. In most of the cases the sediment tends to concentrate away from the area of Moheshkhali channel.

7. For incoming wave angle of 240^{o}, 250 ^{o} and 260 ^{o}, the sediment movement pattern is almost same both for the suspended sediment and the bed load.

8. For case 1 it is observed that the wave height changes is so abrupt for incoming wave angle 230^{o}. It becomes more flatten for incoming wave angle 240^{o}. For incoming wave angle 250^{o} to 290^{o} wave height changes found abruprt only near the shore line.

9. For case 2 it is observed that there is no sudden wave height changes and it is almost flatten. The pattern is almost same for incoming wave angle 230^{o} to 250^{o}. The wave height changes found more abruprt for more increasing wave angle from 260 ^{o} to 290^{o}.

10. The radiation stress along section 1-1 is higher at most of the point than the radiation stress along section 2-2. In both setion, section 1-1 and section 2-2 the radiation stress changes abruptly.

5.3 Recommendations of the Study

Some recommendations is presented here as part of the ongoing research for assessment of sediment movement pattern along nearshore coastal water of cox"s bazar.

1. Similar studies can be carried out with other numerical models to assess the sediment movement pattern along nearshore coastal water of cox‟s bazar and the pattern of sedimentation can be compared with the pattern found in this research work.

2. The data of 2004 to 2013 was collected for this research work. But more recent and up to date data can be used for generating more reliable Boundary conditions.

3. DIVAST model has the only option of selecting one grid size out the whole domain of the model area and it does not support any variation of grid size. So, for further studies the smaller grid size is recommended for more appropriate assessment of sediment transportation.

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