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Tidal River Sediment Management–A Case Study in Southwestern Bangladesh

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***Abstract*—**The problems of severe drainage congestion and water logging in the southwestern Bangladesh have been solved by an innovative concept, Tidal River Management (TRM). TRM involves the uniform raising of the land inside a tidal basin (beel) while simultaneously maintaining the proper drainage capacity in the river. The present practice of TRM is to link the river with the selected beel by constructing a link canal at the entrance of which most of the sedimentation takes place. This localized sedimentation also creates drainage congestion and water logging making it unattractive to landowners who participate in the program. In this paper a functional sediment management plan is presented to get rid of this problem.

***Keywords*—**Beel, embankment, MIKE 21 Flow Model FM, Tidal River Management.

I. Introduction

TECTONICALLY active and geologically youngest drainage basin of the world is the Bengal basin [1] which has been formed by alluvial sediment deposition from the Ganges, Brahmaputra and Meghna river systems [2]. This basin forms the world largest sediment dissemination system [2] and biggest submarine fan [3]. Such repeated sediment deposition raises the land level only close to the river bank keeping the land low in between the two rivers. This low land is called "beel". A Tidal Basin is a depressed low-lying area or beel adjacent to the sediment-laden tidal rivers.

The rivers of the Bhabodah area, which is situated in southwestern Bangladesh, are characterized by active deposition of sediment which significantly reduces their drainage capacity [4]. In addition, the sedimentation problem has been aggravated in this region by the construction of costal polders that de-linked the floodplains from the rivers and diminished upstream flow during the dry season [5]. Consequently, severe drainage congestion and water logging in this area was observed since the early eighties. Khulna-Jessore Drainage Rehabilitation Project (KJDRP) was implemented during 1994-2002 to solve these long-standing problems [6]. However this project failed to solve the drainage problems. Later on, a popular concept based on generations of indigenous water management practice was adopted which is known as Tidal River Management (TRM).

TRM involves natural tide movement in rivers and taking full advantage from it. During flood tide, sediment-borne tidal water is allowed to enter into an embanked low-lying area (tidal basin) where the sedimentation takes place during long storage period and thus acts as a sedimentation trap. During ebb tide, the water flows out of the tidal basin with greatly reduced sediment load and eventually erodes the downstream riverbed and increases the drainage capacity. The natural movement of flood and ebb tide along the tidal basin and downstream river, maintains a proper drainage capacity in that river. Reference [7] recognized the merit associated with the TRM approach. This is in fact a natural water management process with very little human intervention but it needs strong participation and consensus with a great deal of commitment and sacrifice of the stakeholders for a specific period. This period can last from 3 to 5 years or even more depending on the tidal volume and the area of the beel [8].

The TRM is an eco-technological concept and designed to solve the water-logging problem while at the same time improving the environment. By implementing the concept, the natural environment was restored and the ecology of the wetlands was conserved. Sediment management inside beel and maintaining the proper drainage capacity of the river through sequential operation of a potential beel for TRM by involving people's participation for sustainable drainage management are the two main objectives in this area. From field visits and monitoring results it has observed that sedimentation inside the beel was not uniform in Beel Kedaria and East Beel Khuksia (EBK). So, the main objective was not attained by the TRM practice for the lack of technical effectiveness during TRM operation. The present practice is that one or two link canal is constructed which connects the tidal basin with the river. But, in almost all cases most of the sedimentation takes place near the entrance of the link canal. Sediment management has been the most challenging yet important aspects of TRM in the study area [9]. People allow their land to be used for tidal basin operation without any compensation, hoping that the land will rise after three or four years. However, monitoring results and community consultation reveal that almost in all cases sedimentation inside the tidal basin does not occur as expected [10]. This results in people's unwillingness to allow their land for basin operation. Besides, social conflicts among various groups like farmers, fisherman, landowners, etc., and institutional conflicts among government agencies, water management

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association (WMA) and local government institutions (LGIs) have made the TRM practices unsuccessful [11].

In this paper a functional sediment management plan is presented for future TRM practice considering all relevant technical, social and economical aspects. This will also enhance the overall environmental conditions. A short description of the study area is presented in the next section, followed by the methodology of this study. The results and discussions are presented in the section 'Result and Discussion'. The conclusion and recommendations are presented in the last section.

II. Study Area

The study area is located in the southwest region of Bangladesh within the Khulna division and falls under the administrative jurisdiction of Jessore and Khulna. The study area lies in between 22°49′40.3″-23°6′27.1″N and 89°13′32.46″- 89°26′15.43″E. The area is characterized by morphological active tidal rivers and creeks, which provide drainage for a system of embanked hydrological units. Rivers in the study area are only rain-fed. The main river system in the study area is the Mukteshwari-Hari river system which is shown in Fig. 1. There are several channels (natural channel) in this study area which are important for drainage. But most of these are dead because of sedimentation on the bed and the land grabbed by the people which cause the drainage congestion problem worst. The channels which are not dead carry mainly water from rainfall and runoff to the beels and rivers in the wet season. The study area has a huge number of beels (Fig. 1) which are very important for biodiversity, such as freshwater fish and birds. The beel area is about 45% of the total study area [12].

III. Methodology

Two beels were selected for this study. One is East Beel Khuksia (EBK) where TRM has fully operational; and another is Beel Kapalia (BK), where TRM is still being established. The methodologies followed in the study can be divided into four steps; 1) Selection of sediment management options 2) Assessment of technical feasibility of the options 3) Economic analysis of the options and 4) Finalization of option(s).

A. Selection of Sediment Management Option

It is difficult to select the suitable option without involving the stakeholder groups who has a direct role in those particular problems [13]. So, stakeholder participation is very important to solve the complex social and environmental problems like sediment management [14].

Local stakeholder lives in the vicinity of the site and can provide valuable information to identify the most concerning criteria with their local knowledge [15]. In this context, Participatory Rural Appraisal (PRA) tool is widely used all over the world to gather information from the local people [16]. The ideas, views and knowledge of the rural people are being taken into account in decision making processes in the PRA approaches [17]. In this study, PRA tools were used to collect primary data regarding uniform sedimentation inside the tidal basin.

Out of a suite of different PRA tools such as the Semi Structured Interview, Resource Mapping and Focus Group Discussion (FGD) were used to identify the sediment management options.

The general practice of TRM operation was to construct one or two link canal to connect the tidal basin with the river. But in that case most of the sedimentation took place in the vicinity of the link canal [4]. Normally silt does not spread out in the areas far away from the canal. Therefore, to get the uniform sedimentation inside the tidal basin dredging or re-excavation of the canals was viewed essential.

Finally three socially acceptable options for TRM operation were identified for the uniform sediment deposition inside the tidal basin and dredging was considered for all the three options. The three identified options of TRM are described below.

1. Option- 1

In this option, each beel was divided into three compartments by considering an embankment around each compartment (Fig. 2). To allow sedimentation in one compartment at a time, only that compartment was connected with the river by cutting an artificial canal, which is called link canal. In every year each compartment was connected with the river for four months periods alternatively. The compartments were devised based on three criteria: area of the compartment, existence of channel in the compartment, and land topography of the beel.

2. Option- 2

In this option, an embankment was considered along the both banks of the main channel (left channel) in the tidal basin and thereby allowing sedimentation by cutting the embankment part by part gradually from downstream to upstream for both beels as shown in Fig. 3. The total length of the main channel of BK and EBK is 3660m and 5760m respectively. For the first year the embankment was considered for a length of three quarter of the total length of the main channel i.e., 2745m for BK (Fig. 3 A1) and 4320m for EBK (Fig. 3 A2) and sedimentation was allowed for the rest part. For the second year embankment was removed in such a way that half of the main channel was open for water flow and sedimentation (Fig. 3 B). In the third year the embankment was exist for only one quarter of the main channel and the rest three quarter was allowed for sedimentation (Fig. 3 C). Finally in the fourth year, sedimentation was allowed for full channel without any embankment (Fig. 3 D).

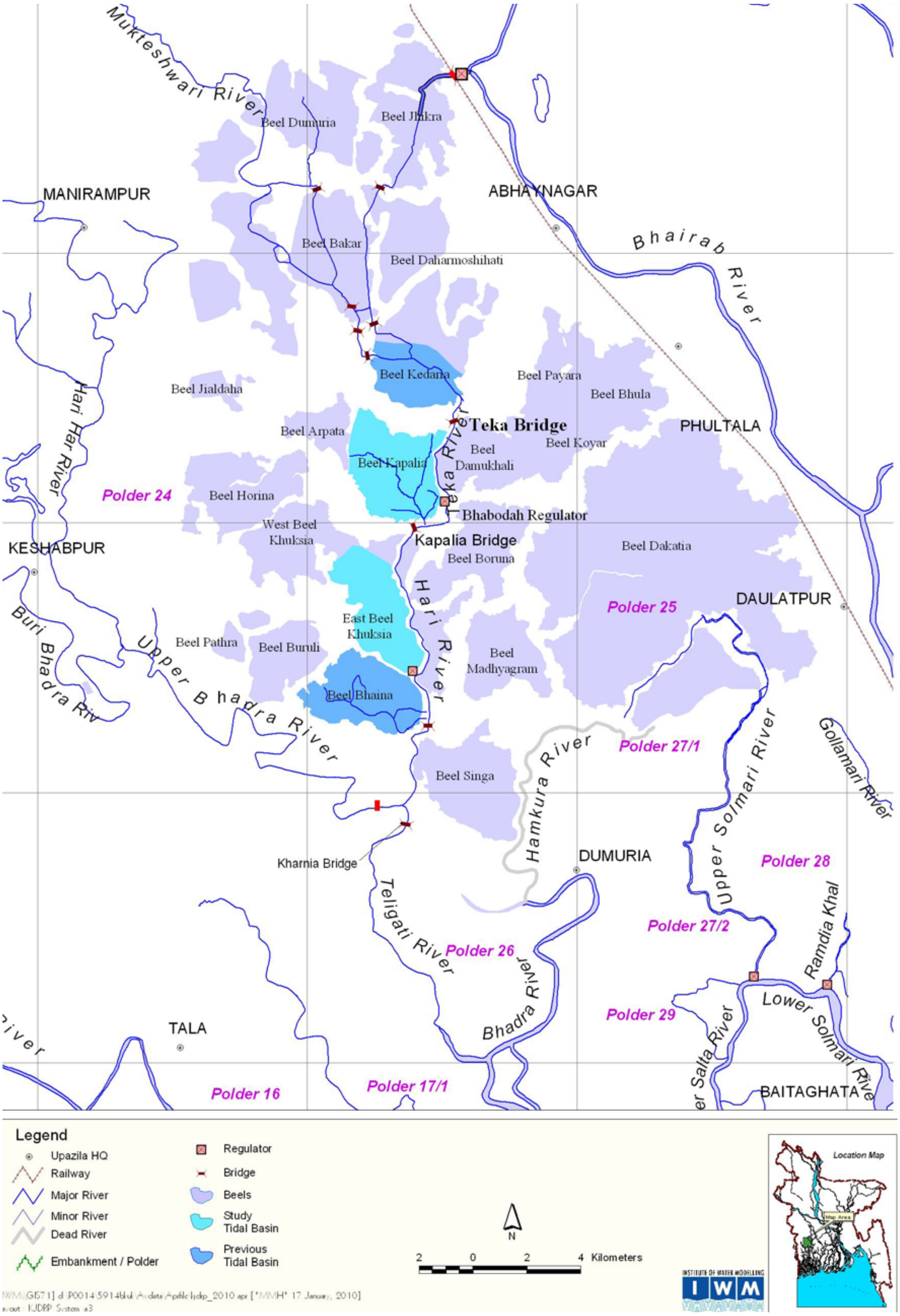

Fig. 1 Existing beels (tidal basins) and River system in the study area

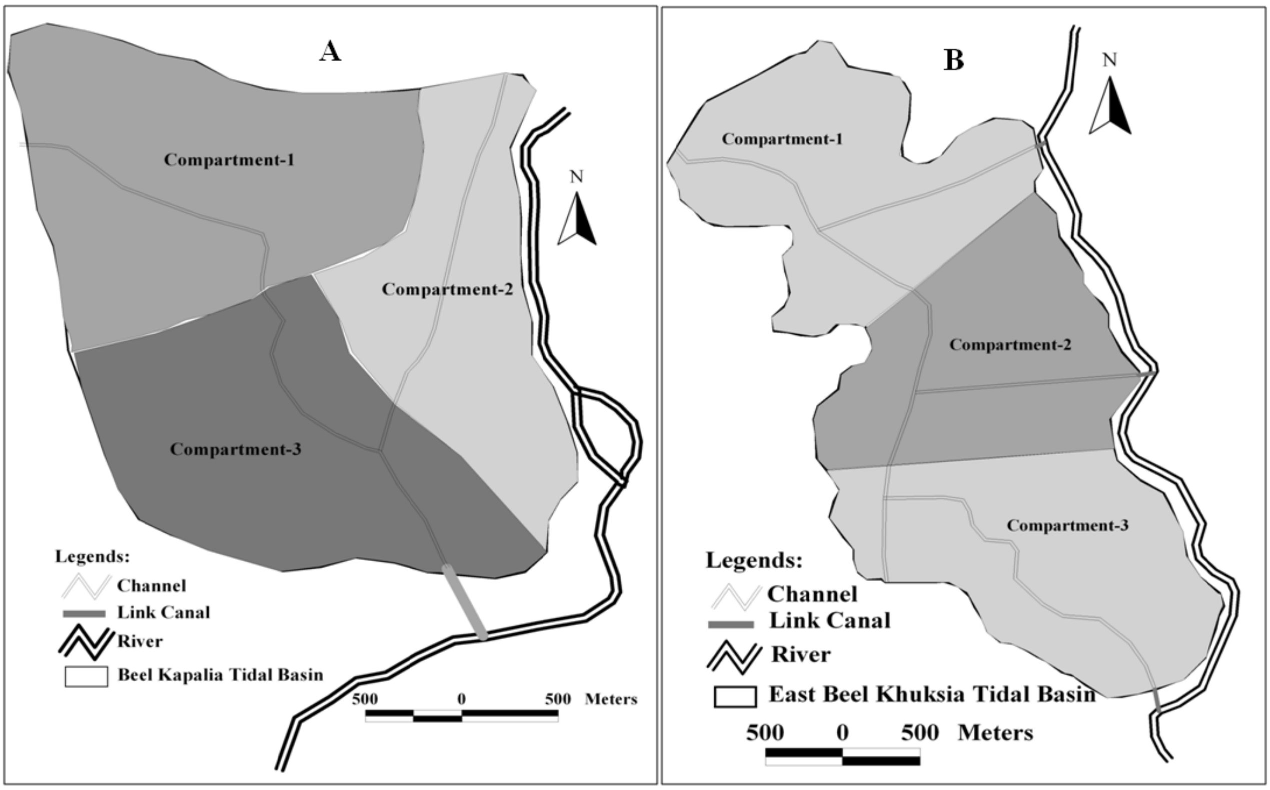

Fig. 2 Schematization of Option-1 for BK (A) and EBK (B)

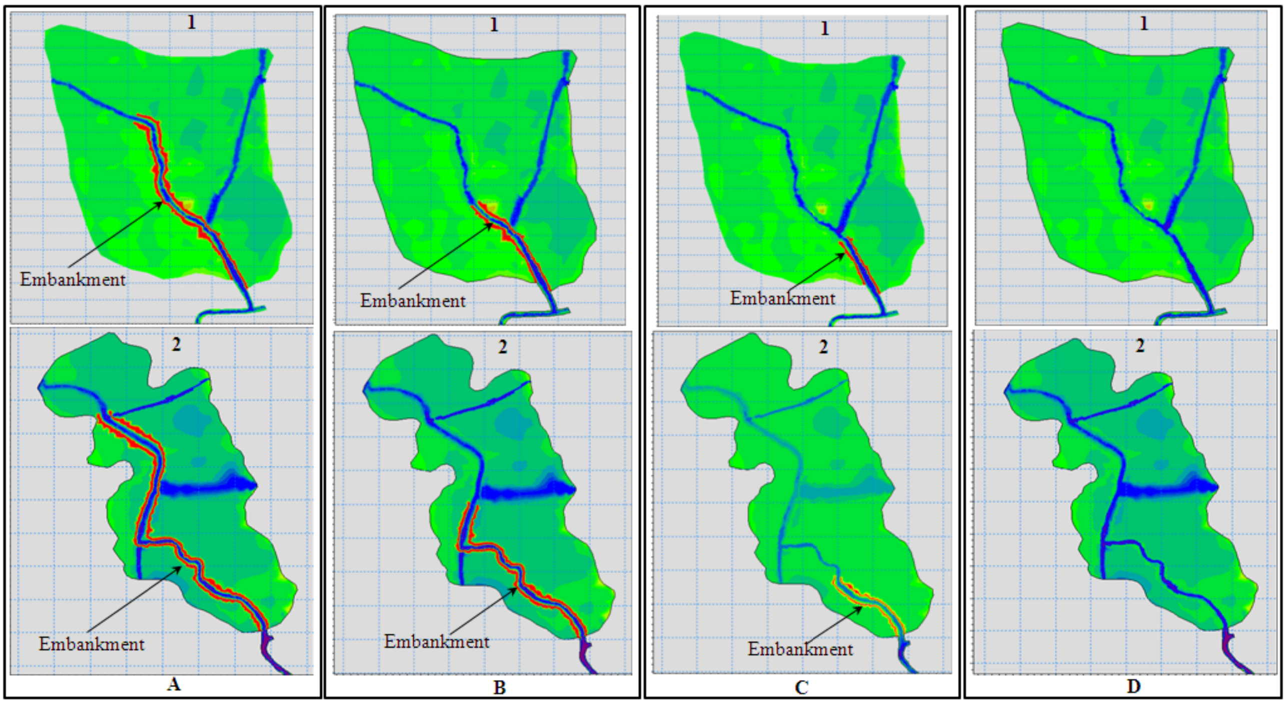

Fig. 3 Schematization of Option-2 for both beels; (A) the length of the embankment was considered three quarter (A), half (B) and one quarter (C) of the main channel; no embankment was considered (D)

3. Option- 3

In this option, all the existing major channels of the beel were connected with the river by link canals, i.e. allowing sedimentation in the whole basin at the same time (Fig. 4). In BK, there are two channels which are nearer to the Hari River and those channels were connected with the river by constructing two link canals (Fig. 4 A). Similarly three channels in EBK were connected with the Hari River with three link canals (Fig. 4 B).

B. Technical Feasibility using the Numerical Modeling

1. Model Selection

Several numerical models (for example MIKE 21, Delft 3D, HEC-RAS) are available to assess the technical feasibility of the above three options by simulating hydraulics and sediment transport [18], [19]. For this study, the numerical software MIKE 21 Flow Model FM [20] has been used because of its advantages and large capacities over other models. MIKE is a professional engineering software package which is capable to simulate the flows of rivers, channels, estuaries and other water bodies [21], [22]. MIKE is a fully dynamic and user-friendly modelling tool for the complete analysis, design, management and operation of simple and complex river systems [20].

The MIKE 21 Flow Model FM uses a depth integrated flexible mesh approach. In this model transport of fine-grained material is averaged over depth and appropriate parameterization of the sedimentary processes is applied. The MIKE 21 Flow Model FM has six modules titled Hydrodynamic (HD), Transport, ECO Lab, Mud Transport, Particle Tracking, and Sand Transport. The HD module is a prerequisite for the other five modules. The resulting flow and distributions of salts, temperature due to variety of forcing and boundary conditions are calculated in HD module [22]. The HD module extracts numerical solutions from the depth-integrated incompressible Reynolds averaged Navier-Stokes equations (two-dimensional shallow water equations) which consists of continuity, momentum, temperature, salinity and density equations.

As the sediment in the study area is cohesive, the Mud Transport module of MIKE 21 Flow Model FM was selected for simulation in this study. Mud is cohesive and fine-grained sediment which has grain-sizes less than 63 microns. The fine-grained sediment normally deposited in the inner sheltered area [23]. Long distance transportation of fine sediment may be happened by the water flow before settling due to the slow settling velocities. These fine-grained sediments permit them to bond together and form larger aggregates which have the higher settling velocities than the single sediment particles [24], [25]. Thus the depositions of larger aggregates take place in the areas where single particles would certainly not settle.

2. Model Setup

Mud transport model setup involves a geometrical description and specification of physical characteristics of the hydrodynamic and sediment transport system of the study area. The major component of the model setup include module selection, domain specification, mesh and bathymetry generation, boundary condition, hydrodynamic and mud transport parameter specification. Most of the components have to specify in the Setup Editor (Fig. 5). There are three separate panes in the setup editor of the MIKE 21 Flow Model FM. Navigation tree, which is situated on the left, shows the structure of the model setup file. The corresponding editor is shown in the central pane of the setup editor when an item in this tree is selected. Validation error is shown in the bottom pane of the setup editor and errors can be minimized dynamically in this pane.

The numerical model was developed integrating the main river system Teka-Hari-Teligati-Gengrail and EBK and BK Tidal Basin. An explicit scheme was used for the time integration. The model domain is subdivided into non-overlapping triangular element or cell (mesh/grid). Generation of suitable cell for the model is important for the reliable result. The total cell number of the model was 13562 and 11122 for BK and EBK respectively. The size of the cell was not uniform in the model. The minimum and maximum area of the cell was 120 m^2 and 20000 m^2. The smaller cell was specified in the river system, channels in the beel and connecting canals. The cell size of the numerical cohesive sediment transport model for both beels is presented in Fig. 6. The bathymetry of the model was generated using the eighty seven measured cross-sections data at different locations of the four rivers (Teka, Hari, Telegati and Gengrail River) and measured topographic data of 50m resolution. Hourly water level data at Kanchannagar site of Gengrail river were used as the downstream boundary of the HD module. In the Mud Transport Module, the downstream model boundary was defined by measured time series suspended sediment concentration and the upstream boundary was defined by constant concentration.

The integrated hydrodynamic and mud transport model was simulated simultaneously. The information of water levels and currents from the hydrodynamic model is used to calculate the sediment transport using a cell-centered finite volume method. The same mesh was used both for hydrodynamic and sediment transport model.

3. Data Collection and Processing

The required data for the hydrodynamic (HD) module of MIKE 21 Flow Model FM are bathymetric data of rivers, topographic data of beels, and time series data of rainfall, evaporation, water level and discharge. The extensive cross-sections and topographic survey data were collected from IWM. The time series data of rainfall and evaporation were collected from Bangladesh Water Development Board (BWDB). Similarly, hourly discharge data for the same period were used as the upstream boundary of the HD model. Moreover, hourly water level and discharge data of Ranai site at Hari river and hourly discharge data of two locations of EBK were used to calibrate the HD model.

Suspended sediment concentration data is required to develop and calibrate the cohesive sediment transport model using the MIKE 21 Flow Model FM modeling system. Hourly suspended sediment samples were collected from IWM for one tidal cycle (13 hours) at two locations in rivers and two locations in beel.

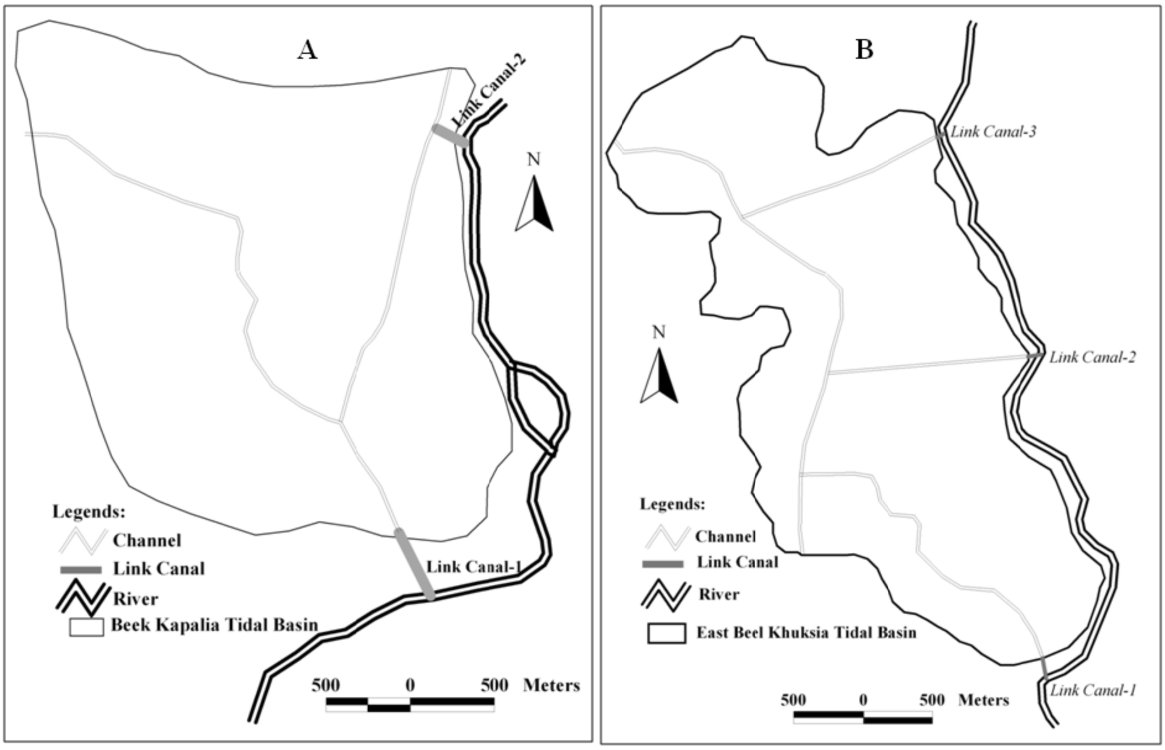

Fig. 4 Schematization of Option-3 for BK (A) and EBK (B)

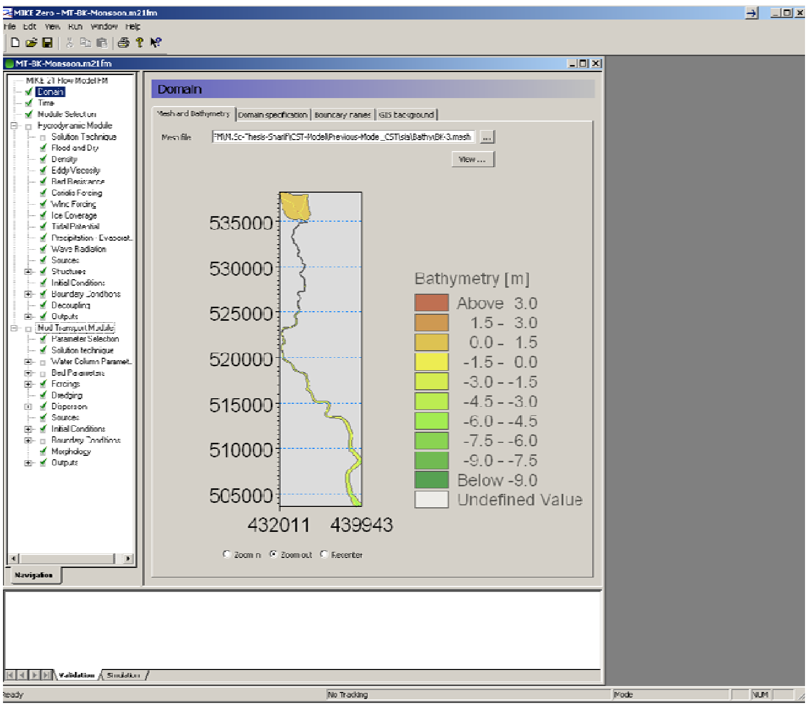

Fig. 5 Setup Editor of MIKE 21 Flow Model FM

4. Model Calibration and Verification

This stage allowed fine tuning of the numerical model by comparing simulation run result with measured values. The goal was to obtain minimum differences between model output and field data. The model was calibrated against water level and discharge in the hydrodynamic model. In the mud transport module, model was calibrated against suspended sediment concentrations using settling velocity, bed roughness height, critical bed shear stresses, dispersion coefficient and concentration at the open boundaries.

A comparison of measured and simulated discharge and sediment concentration data are shown in Figs. 7 and 8, respectively, indicating that a reasonable fairly good calibration was achieved.

To check whether the calibrated model is an adequate representation of the physical system, simulated land elevation were verified with the measured data. The measured land surface was generated from land elevation measurements by topographic survey inside the tidal basin. Good agreement was achieved between the measured and simulated data within different ranges of elevation inside the basin (Fig. 9).

5. Option Simulation

Options identified from the field were analyzed for their technical feasibility using a cohesive sediment transport model developed by the Danish Hydraulic Institute (DHI) Water and Environment. To set the options in the model, the size of the grid was taken very fine. For all the options, total bed thickness change and net deposition in the beels were calculated.

The cohesive sediment transport model was simulated for four years for all of the three options. Continuous four year model simulation of tidal river is quite complex and time consuming. Initially, simulation was first done in the dry period. Then the monsoon flow was simulated with the updated bed level. In this way, prediction for a year was obtained for all options. Then, the model was simulated for different time periods, one to four years, with dredging of canals. Changes of net deposition inside the tidal basin were computed for the next three years after considering the changes that occurred in the previous year.

C. Economic Analysis

To find out the total cost of the options for the EBK and BK, the Economic analysis considered indicative costs of all the works and activities essential for TRM operation.

D. Option Finalization

To find out the acceptable option(s) for sediment management option inside the tidal basin, technical feasibility study and economic analysis were carried out as well as Stakeholder consultation was done.

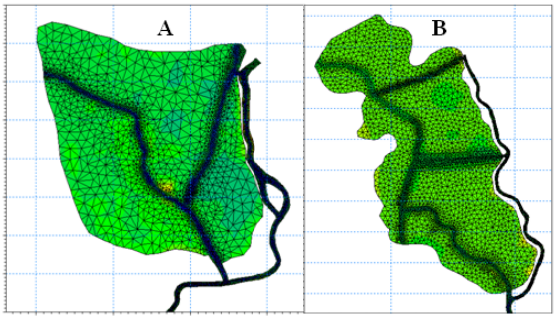

Fig. 6 Cell size of the cohesive sediment transport model for BK (A) and EBK (B)

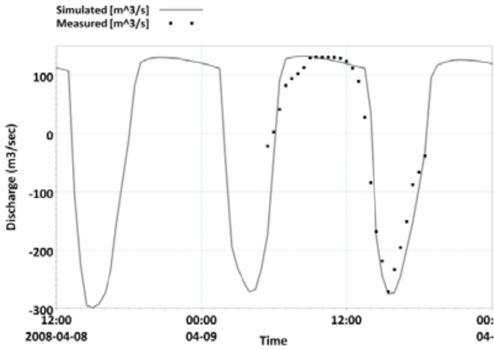

Fig. 7 Comparison of measured and simulated discharge in the Hari River near Dierkatakhali link canal of EBK

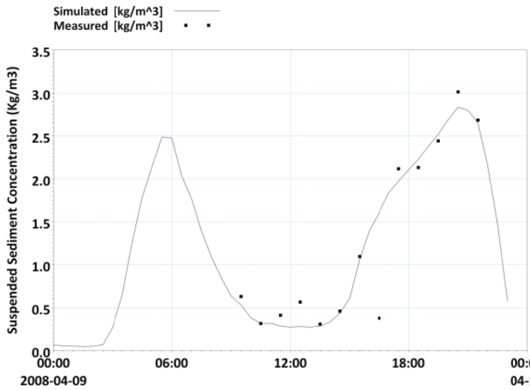

Fig. 8 Comparison of measured and simulated suspended sediment concentration in the Hari River near Dierkatakhali link canal of EBK

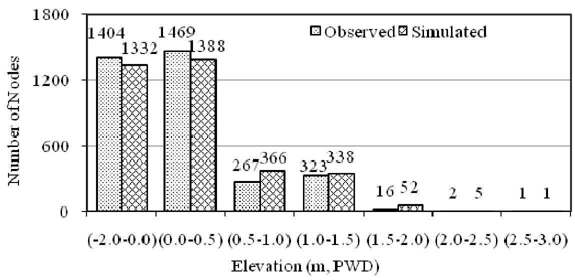

Fig. 9 Graphical comparison of measured and simulated land elevation (m, PWD) within different ranges of elevations

IV. Result and Discussion

A. Analysis of Options Results

The simulated net deposition pattern inside the tidal basin by the operation of TRM in different periods with dredging of channels for all the three options are shown in Figs. 10-12. In Fig. 10, the results (predicted net deposition pattern inside the tidal basin) from Option-1 for one year, three years and four years operation on BK (Figs. 10 A-C) and EBK (Figs. 10 D-F) are presented respectively. The figures show that for both the beels the sedimentation are increasing and distributes from canal to far away year by year. Figs. 10 A and D show that in one year the net sediment deposition around three entry points is high which is around 1m. In rest part of the area the net sediment deposition mostly within 0.1m to 0.2m. After three years that sediment deposition starts to spread all over the tidal basin (Figs. 10 B and E). Finally within a four year period the sedimentation spreads over the whole area and it ranges from 0.3m to 1.0m (Figs. 10 C and F).

In Fig. 11, the predicted net deposition pattern inside the tidal basin from Option-2 for six months, one year, two years, three years, and four years operation on BK (Figs. 11 A-E) and EBK (Figs. 11 F-J) are presented respectively. The impact of embankment on both sides of major canal is clearly viewed in Fig. 11. The figure shows that sedimentation is progressing year by year with the removal of the embankment. At the end of the fourth year the sedimentation spread over the total area. Though the net sediment deposition is high (above 1m) around the main canal and at the remotest point from the main channel the net sediment deposition is 0.4m to 0.5m which is shown in Fig. 11 E. Similar result was found for Beel Khukshia in Fig. 11 J but here the net sediment deposition is from 0.3m to above 1m. Therefore Figs. 11 A to J show that for both the beels the sedimentation are increasing year by year and propagates along the main canal throughout the area within a four year period. Though the sedimentation is not fully uniform but that is in an acceptable limit.

In Fig. 12, the predicted net deposition pattern inside the tidal basin from Option-2 for six months, one year, two years, three years, and four years operation on BK (Figs. 12 A to E) and EBK (Figs. 11 F to J) are respectively. Fig. 12 shows that the response of sedimentation in Option-3 is comparatively slower than Option-1 and Option-2. Though at the end of the fourth year reasonable sedimentation is found in the both tidal basins, however the sedimentation in the EBK is higher than the BK (Figs. 12 E and J).

B. Comparison of Options Results

A comparison of net deposition volume in EBK and BK for the three options is given in Fig. 13. The net deposition volume after 4 years under Option-1, Option-2 and Option-3 are 3.58 million m^3, 4.51 million m^3 and 2.61 million m^3 respectively in EBK and 3.40 million m^3, 3.43 million m^3 and 2.45 million m^3 respectively in BK. Thus the net deposition volume maximum is in Option-2 for both beels. As seen from the figure, maximum net deposition occurred for Option-2 and minimum net deposition occurred for Option-3 in both beels. Net deposition volume is higher in EBK than BK because EBK is located at the downstream of the Hari River. This means that the beels located in the downstream of the river where tidal influence is stronger, are more suitable for TRM operation.

C. Cost of Different Options

The total estimated cost of the three options for the two Beels are presented in Fig. 14. The cost was based on current schedule rates of the Bangladesh Water Development Board. The total estimated cost for the three options are Tk.28,58,48,912; Tk.21,34,55,375 and Tk.35,58,37,393 respectively in EBK and Tk.20,79,89,120; Tk.16,16,72,991 and Tk.25,21,70,405 respectively in BK. Thus Option-2 is the cheapest option for both beels.

D. Stakeholder Consultation for Option Selection

Stakeholder consultation was carried out to finalize the acceptable option(s) for sediment management inside the tidal basin. Discussions of technical feasibility and economic analysis were held with different groups including farmers, fishermen, day laborers and traders. After detailed consideration of the different aspects of sediment management including the estimated cost of options, most stakeholders agreed that Option-2 is the most preferred options.

V. Conclusion and Recommendation

The two main objectives of TRM are uniform rising of land inside a beel and maintaining of proper drainage capacity of river. But due to the lack of technical and social limitations in TRM operation, sedimentation inside the beel was found to be non-uniform. Therefore in this study three socially acceptable sediment management options for the two tidal basins were identified through discussions and consultations with the focus group of the local stakeholders. And the technical feasibility of these options was assessed by a cohesive sediment transport model using MIKE 21 Flow Model FM modeling system. Besides, economic analysis had also been carried out to select the most suitable option. Comparing all the options through technical, social and economic aspects, finally opting-2 is clearly found to be the preferred option for the TRM application. In this option, embankments were considered along both banks of the main channels through the beel and thereby allow sedimentation by gradually cutting the embankment part by part from upstream to downstream.

The models were simulated for a period of four years in this study. However further simulation for a longer period may be carried out to determine the actual required life time of a tidal basin. In addition, water level, discharge and sediment data at several locations can be collected to get better performance of the numerical model for future studies. Furthermore sedimentation volume can be calculated from direct field measurements and can be compared with the simulated result which will also help to clarify the sediment distribution over the entire basin area.

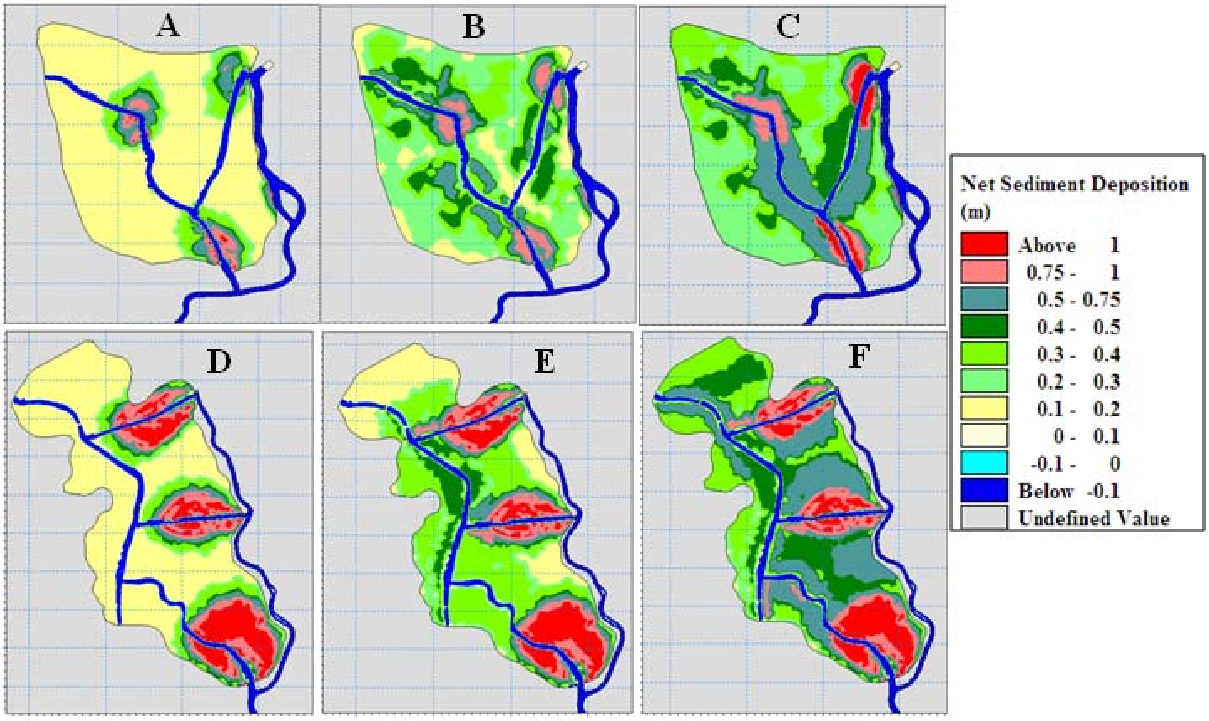

Fig. 10 Predicted net deposition pattern inside the tidal basin for Option-1 after the operation of TRM in different periods with dredging of channels; 1 year operation for BK (A), 3 year operation for BK (B), 4 year operation for BK (C), 1 year operation for EBK (D), 3 year operation for EBK (E), 4 year operation for EBK (F)

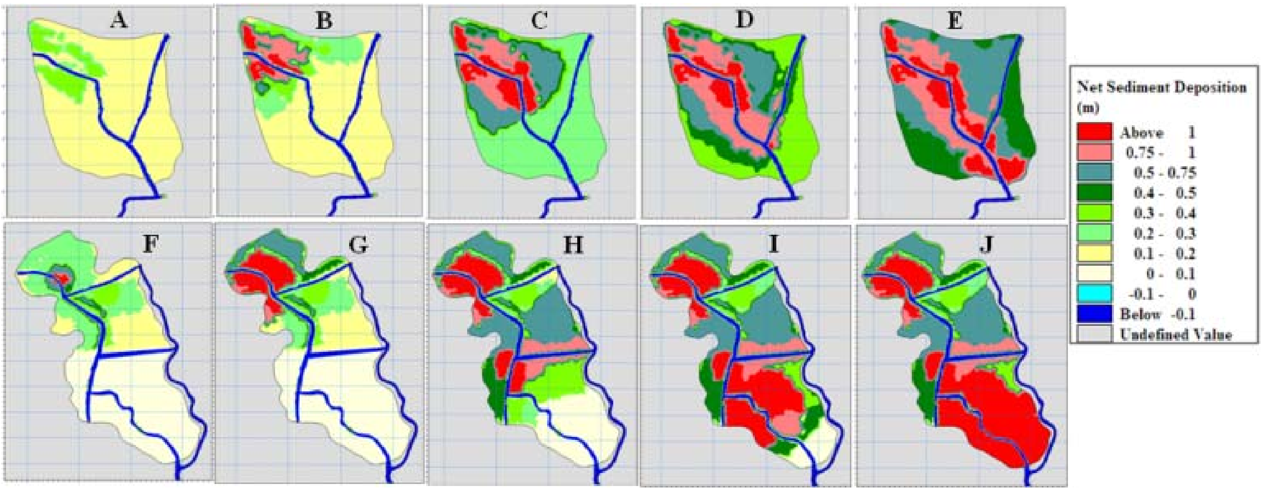

Fig. 11 Predicted net deposition pattern inside the tidal basin for Option-2 after the operation of TRM in different periods with dredging of channels; 6 months operation for BK (A), 1 year operation for BK (B), 2 years operation for BK (C), 3 year operation for BK (D), 4 years operation for BK (E), 6 months operation for EBK (F), 1 year operation for EBK (G), 2 years operation for EBK (H), 3 year operation for EBK (I), 4 years operation for East BK (J)

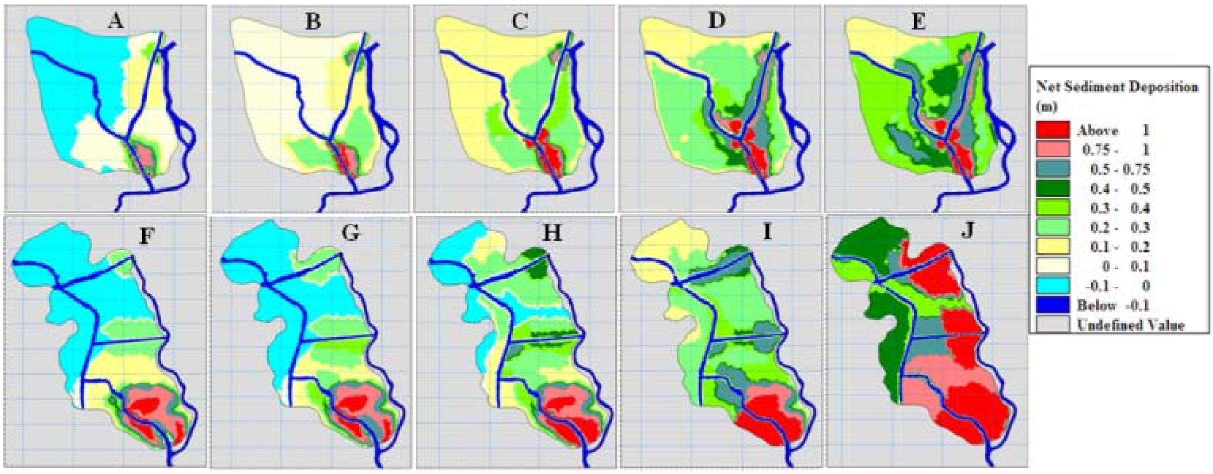

Fig. 12 Predicted net deposition pattern inside the tidal basin for Option-3 after the operation of TRM in different periods with dredging of channels; 6 months operation for BK (A), 1 year operation for BK (B), 2 years operation for BK (C), 3 year operation for BK (D), 4 years operation for BK (E), 6 months operation for EBK (F), 1 year operation for EBK (G), 2 years operation for EBK (H), 3 year operation for EBK (I), 4 years operation for East BK (J)

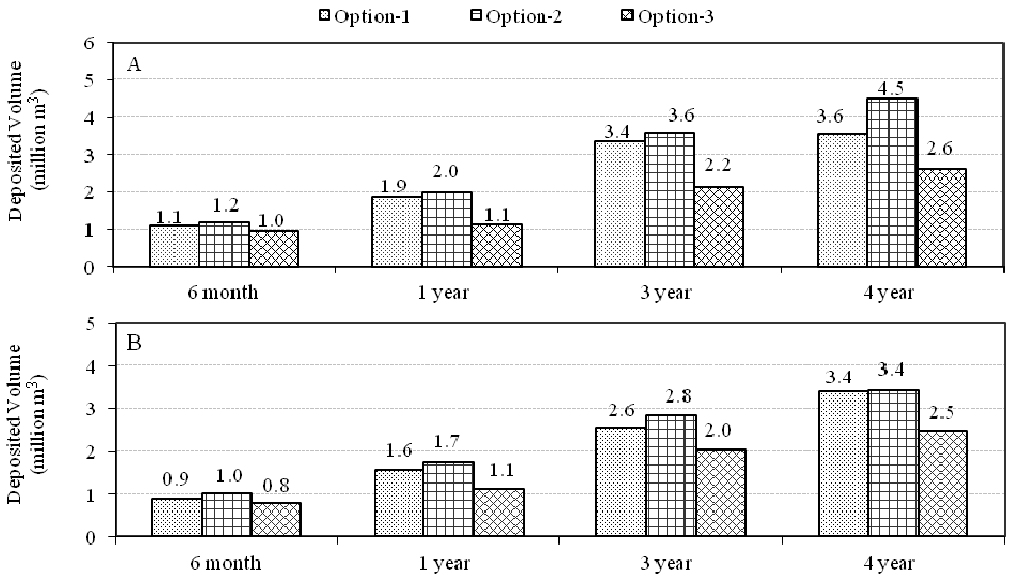

Fig. 13 Net deposition volume plot at different options and time period for EBK (A) and BK (B)

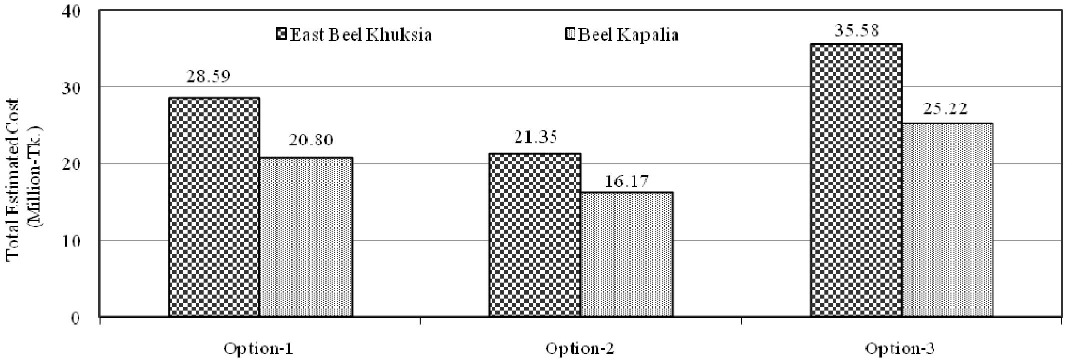

Fig. 14 Total estimated cost for the three options in the two beels

APPENDIX

Abbreviations

BK Beel Kapalia
EBK East Beel Khuksia
TRM Tidal River Management

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