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Prediction equation to estimate the impact below Feni closure

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Abstract

Below a water control structure when flow is obstructed in a tidal channel for a long time, heavy siltation results if the tidal water contains sediment load. A prediction formula for deposition of sediment below a closure dam has been developed by simplifying the two-dimensional vertical convection-diffusion equation of suspended sediment in a fluid. The variables of the prediction equation that influences the siltation are studied and analysed with respect to Feni estuary below the closure in the determination of predicted accretion height. Utilizing the field data of the bathymetric area below the closure, regression analysis has also been done to correlate the rate of accretion with the depth and distance of the channel from the closure dam and the correlation coefficient is found satisfactory. The analysis shows that immediately after the construction of Feni closure dam of Muhuri Irrigation Project (MIP) a rapid siltation have occurred and the level of the area rises about 4m in the first year and 0.6m in the second year. The ratio of the measured accretion to the predicted accretion is termed by an adjustment factor. This factor indicates the impact of dam construction on siltation or in other words effective percentage of inundation time for siltation.

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Keywords: Accretion height, effective percentage of inundation time, turbulence, means high water level, regression analysis.

1. Introduction

Every year the Ganges, Brahmaputra and the Meghna rivers pour about 1000 billion m^3 water into the sea (SSSU-07, 2002). This huge amount of water transports hundreds of million tons sediment every year to the estuary. One third of this sediment that is carried by these rivers is trapped in the sub-aqueous delta and is used in vertical accretion and lateral progression of the sub-aqueous delta (Goodbred and Khuel, 1999).

After implementation of Muhuri Irrigation Project (MIP) in the year 1977-78 to 1985-86 (BWDB,1986) by the BWDB, about 3000ha of new land has been accreted from the sea down to the closure of the MIP. Muhuri Irrigation Project actually is a reservoir project created by the three flushy rivers (1) Feni river (2) Muhuri river and (3) Kalidas-Pahalia river. The creation of this artificial reservoir body, linked with a network of 245 irrigation canals along with 3.411 km closure dam and 40 vent (each vent is 3.65mx3.65m) regulator stops the intrusion of sea water into the MIP area and in consequence land is accreted from sea downstream to the closure due to siltation. The downstream area of Feni closure is greatly influenced by the tidal flow. The tides moving up to the Feni closure twice a day, carry huge quantity of sediment from the sea and play an important role in to and fro transport of sediment in the area.

For the development of water resources in the country closure, dams and regulators will have to be constructed across tidal channels. Similar phenomenon of siltation in a tidal estuary due to stoppage of tidal motion is observed in front of the closures, dams and sluices constructed in the coastal areas to prevent saline water inundation. In the coastal areas, under BWDB, there are thousands of sluices and regulators, which are closed after the monsoon period and are operated on the onset of next monsoon period. Thus virtually, the tidal channel remains closed for several months resulting into heavy siltation in front of the gates, which in turn make the sluices inoperable. Every year to make the sluices operative, silts have to be removed manually. Often excessive siltation renders the sluices totally inoperative. So it is important to understand the process and rate of siltation as well as the extent of siltation in a year at the drainage channel of regulator for proper planning of operation of these structures. Such an understanding would also assist in undertaking proper measures to solve these recurring phenomena after installing a regulating sluice at the mouth of an estuarine river. The area below the Feni closure lies in the Feni estuary. The main objective of this paper is to develop a prediction equation for accretion close to the dam and estimate of the impact of dam.

2. Literature

A crucial element in the development of long-term plans for human interference in estuarine or coastal waters is the prediction of the impact on the bathymetry and coastlines. As the process shaping the estuary are of very complex nature and their long term effects are still not very well understood, a process based prediction is not yet possible. Statistical and empirical techniques applied to field data are useful to extrapolate existing trends. But these predictions can hardly be used as sole predictor if these trends are changing (e.g. due to human interference, catastrophic events, sea level rise). Another very useful technique known as phenomenological approach (it uses statistical/empirical techniques and physical interpretation to identify trends and empirical input/output relations) often used in the predictions of morphological development. Study of siltation process below Muhuri closure was carried out by Shahabuddin (1988). Sediment particles settle under the influences of

2. Formulation of prediction equation below a closure dam

The two-dimensional vertical convection-diffusion equation of suspended sediment in a fluid is:

$$\partial C/\partial t + u_{1*}\partial C/\partial x - \partial/\partial z[\omega_s C + \in_3 {*}\partial C/\partial z] = 0$$

where, C stands for time averaged volume or mass concentration of sediment at time t with fall velocity ω_s at height z from the bed, $\in_3$ is the corresponding turbulent diffusity of the sediment particles and u_1 is the time averaged flow velocity in the longitudinal direction.

For a steady uniform flow situation, the above equation can be simplified as follows (Raudkivi,1990)

$$\omega_s C + \in_3 * dC/dz = 0 \qquad (1)$$

As ω_s is the settling velocity, hence the term ωsC is the average rate of settling due to fall velocity and the term $\in_3$ dC/dz is the upward sediment flow due to turbulence.
According to E. Allersma (1982) once the sediment particles are entrained into the flow, they move under the influences of gravity and turbulence. Gravity causing a sedimentation velocity (ω) and turbulent diffusion (D) causing a gradient type of transport, leading to a resultant vertical flux. In terms of a diffusion equation, this resultant flux of sediment below a closure dam can be expressed (Allersma ,1982) as:

$$T_v = \rho . \omega . C - \rho . D. dC/dy \qquad (2)$$

Here, T_v is the vertical sediment transport, mass per unit area per unit time; C is the sediment concentration by weight; ρ is the density of the water; *dC/dy* is the vertical gradient of sediment concentration. Negative sign indicates sediment flow in the direction of decreasing concentration.

Now due to construction of closure dam across the channel, there will be a reduction of flow velocity. Thus at the downstream of closure, a slack water condition will be created and gradually the flow velocity will reduce to almost zero. So, when the flow velocity is reduced to zero, the turbulent diffusion i.e. D tends to be zero. Then the equation (2) becomes:

$$T_{v/} \rho = \omega . C$$

and per year deposition, S can be derived as,

$$S = k. C_m. \omega.\rho.t /(\rho_s-\rho) \qquad (3)$$

All the variables in equation (3) can be determined from measurements, k is a constant. In practice, all the inundation time throughout the year will not be effective for settling of sediment due to presence of small amount of turbulence near the sea side of a closure. Only a certain percentage of inundation time will be effective for settling sediment. If this percentage is designated by φ, then φ has to be determined by comparing theoretical deposition rate with the deposition rate obtained from direct field measurement. Then,

$$S = \varphi. k. Cm. \omega.\rho .t /(\rho s-\rho)$$

From field measurement we can calculate the annual deposition rate, S.

Thus, $S = \beta. t$

where, $\beta = \varphi. k. C_m. \omega.\rho /(\rho_s-\rho)$

(4)

From this relation, φ will be determined and this equation (4) will be used for analysis the impact of dam on the siltation.

3. Data collection and analysis

Tidal movement: The sea surface rises and falls regularly twice a day along the coast of Bangladesh. So tide in the estuary below the Feni closure is semi-diurnal, which means it has a time period of about 12 hours 25 minutes.

Sediment data: The major source of sediment in the Feni estuary is silt carried by the seawater (Eysink,1983). It is found that the concentration towards the regulator site below the Feni closure is gradually reduced and average sediment concentration during high water flow condition is about 400 mg/l. At the outfall of the estuary, higher value of sediment concentration is observed.

Grain size distribution of suspended and bed material: The analysis of the grain size distribution of sediment in the Feni estuary indicates that the mean grain size of suspended and bed sediment of Feni river varies from 0.012mm to 0.05mm and from 0.03mm to 0.14mm respectively (LRP TR-7,1982).

Bathymetry: The LRP of BWDB have completed the topographic and bathymetric survey work of the area downstream of Feni closure dam. The survey of the area was undertaken by LRP for the years 1982, 1986 and 1987 (the dam was completed on 28th February of 1985). They had prepared two contour maps based on the survey. It should be mentioned here that the level of the area was observed more or less at the same height for the years 1982 to 1985 (before construction of closure). So, the survey data of 1982 hereafter referred as 1985. For the analysis of these maps, about 9 (nine) km^2 survey area are considered. The area is divided into 9 (nine) cross-sectional grids. Each grid is about 2 km long and 170 m wide. These cross-sections give a good coverage of the downstream area close to the Feni closure (Figure 1). The distances of the cross-sections from the Feni closure are 375m, 545m, 720m, 880m, 1040m, 1210m, 1380m, 1540m and 1700m respectively.

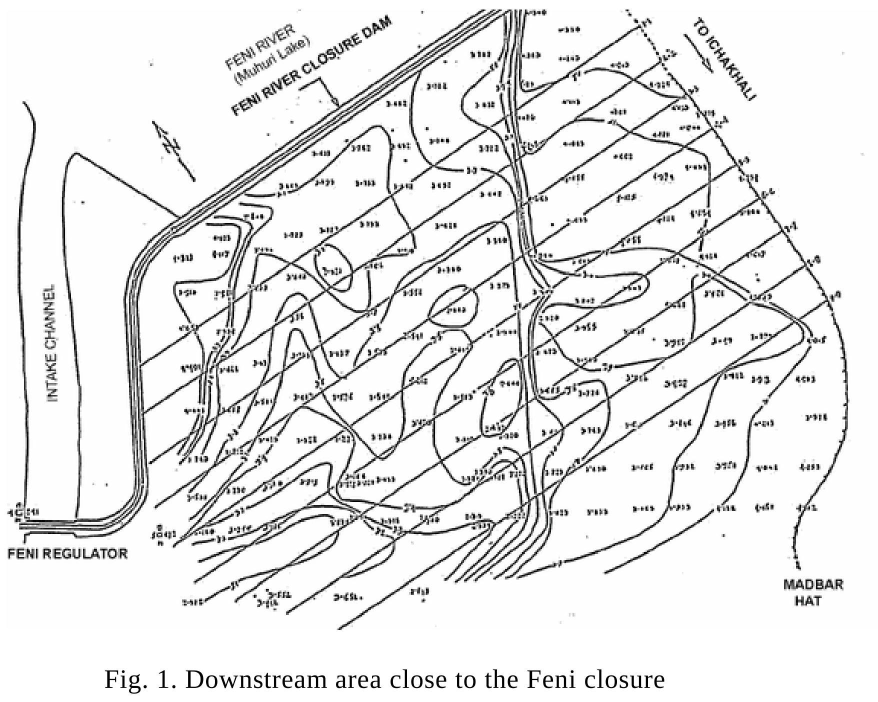

Fig. 1. Downstream area close to the Feni closure

Water Level: During monsoon for the period 2000-2004, the mean and maximum ranges of tide in the Feni estuary have been found as 3.50m and 5.50m respectively. The tides have also been studied on the basis of annual maximum High Water Level data collected over the periods 1985 to 2004 at the gauge downstream of Feni regulator in the Feni river. The maximum high water level and mean of annual maximum high water level of Feni river near Feni regulator is about 6.0m and 5.276m (SOB) respectively over the 20 years period. The seasonal mean high water level of Feni river near Feni regulator for the period 2000-2004 are also shown in Table 1. From this table it has been found that the average of mean high water level during pre-monsoon, monsoon, post-monsoon and dry period are 3.47m, 4.14m, 3.61m and 2.69m (PWD) respectively. Analysis of daily mean high water level of Feni river downstream to the Feni regulator from 2000-2004 shows that the monsoon high water level exceeds 4.50m (PWD) elevation few times a year (PWD= SOB + 0.46).

Table 1
Mean High Water Level of Feni river d/s of Feni regulator for the period 2000-2004

YEAR	MEAN WATER LEVEL IN METER (PWD)			
	Pre-Monsoon (Mar-May)	Monsoon (Jun-Sep)	Post-Monsoon (Oct-Nov)	Dry Period (Dec-Feb)
2000	3.46	4.30	3.62	2.79
2001	3.36	4.05	3.49	2.67
2002	3.38	4.04	3.55	2.56
2003	3.42	4.11	3.76	2.73
2004	3.73	4.23	-	-
Mean	3.47	4.14	3.61	2.69

4. Results and discussions

4.1 Accretion height computation through utilizing the field data by regression analysis

To find out the accretion height, use is made of the data obtained from the contour maps of the bathymetric area. The levels of each cross-section are used to compare the situation between 1985 to 1986 and 1986 to 1987. Here it is assumed that the information and data for 1985 represents situation before closing of the channel and that of 1986 and 1987 represents situation after the closing of the channel. The comparison is made by using the following form of regression equations correlating accretion with previous year's channel bed level using the data of different years for each of the nine cross- sections, that can be expressed as:

$$\Delta h = a \pm bh$$

where, Δh is the accretion height in a year after the construction of closure, a and b are the intercept value and regression coefficient respectively and h is the previous year channel bed level.

From this comparison, it is evident that more or less all the 9 (nine) equations show a definite trend and there exists a good correlation among them. Average coefficients of correlation for the sections considered are found 0.976 and 0.634 in the years 1986 and

1987 respectively. Based on which a general equation for the particular year has been developed (Equations 5 and 6). The value ***a*** and ***b*** of this equation are obtained respectively by correlating the intercept values and regression coefficients of the developed sectional equations with the distance of cross-sections from the closure. Thus the accretion heights have been estimated with respect to the distance of cross-sections from the closure and depth of the channel as shown in Tables 2 and 3.

The analysis of field data for the year 1986 (one year after the construction of the closure dam) gives the following equation to calculate the accretion height during this period.

$$\Delta h_1 = a_1 - b_1 h \quad (5)$$

where, $a_1 = -7.2899 \times 10^{-4} d + 3.98435673$ which is obtained from intercept values versus distance relationship (Fig. 2), $b_1 = +2.545 \times 10^{-5} d + 0.85825081$ which is obtained from coefficient of regression versus distance relationship (Fig. 3), d is the distance from the closure dam in meter, h is the initial bed level of the channel before closure and Δh_1 is the accretion height one year after the construction of closure dam.

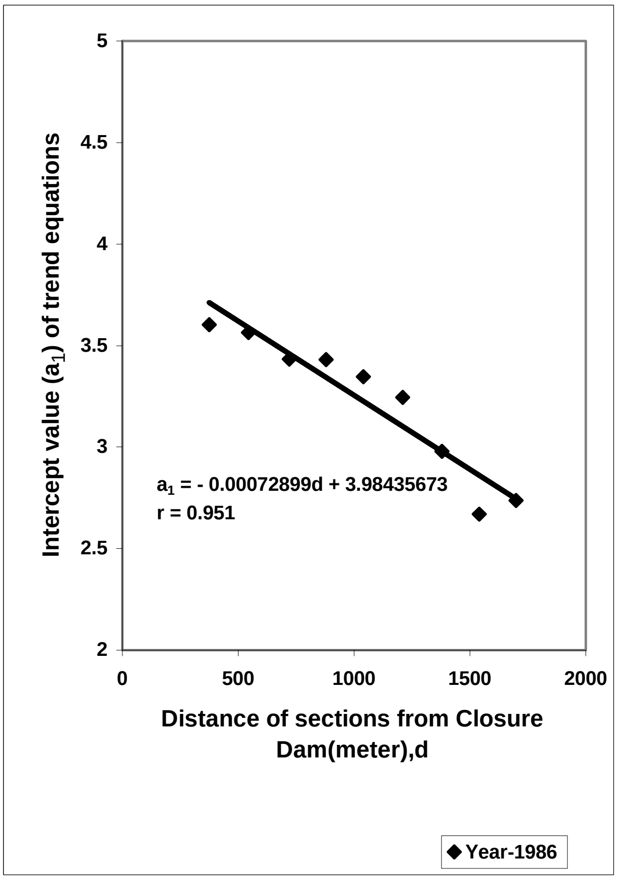

Fig. 2. Relation between intercept values of accretion height equations and the closure distance

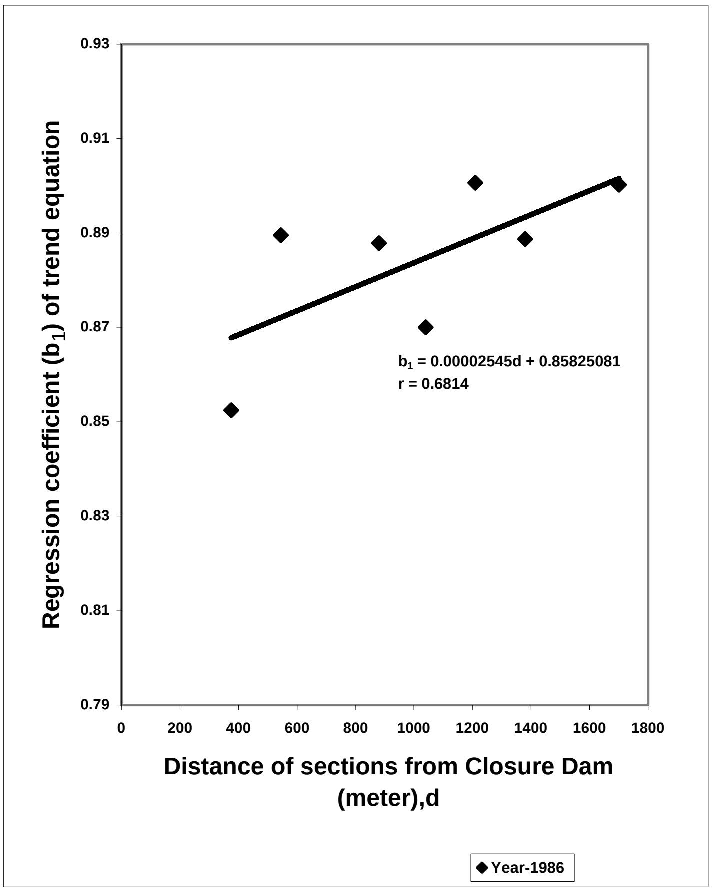

Fig. 3. Relation between regression coefficients of accretion height equations and the closure distance

Similarly from the analysis of field data the following equation is obtained to calculate the accretion height for the year 1987 (over the year 1986).

$$\Delta h_2 \quad = \quad a_2 + b_2 h_1 \tag{6}$$

where, a_2 = + 8.6 x 10^{-4} d + 1.31069 which is obtained from intercept values versus distance relationship,

b_2 =- 1.872 x 10^{-4} d - 0.3551846 which is obtained from coefficient of regression versus distance relationship, d is the distance from the closure dam in meter, h_1 is the bed level of the channel in 1986 (one year after the construction of closure dam) and Δh_2 is the accretion height in the year 1987.

The calculated values of accretion height for the different cross-sections for the year 1986 and 1987 using Equations (5) and (6) are shown in Table 2 and 3 respectively.

Table 2
Computed accretion rate from field data in the year 1986 (one year after construction of closure)

Cross-section	Value of a_1 and b_1 respectively	Average river bed level (m,PWD)	Avg. accretion height (Eq. 5) (meter)
1-1	3.711, 0.868	0.342	3.414
2-2	3.587, 0.872	-0.66	4.163
3-3	3.459, 0.877	-0.0751	3.525
4-4	3.343, 0.881	-0.0753	3.409
5-5	3.226, 0.885	0.5758	2.716
6-6	3.102, 0.889	0.9504	2.257
7-7	2.978, 0.893	1.6758	1.482
8-8	2.862, 0.897	1.825	1.225
9-9	2.745, 0.902	1.75	1.167

Table 3
Computed accretion rate from field data in the year 1987 over the silted up channel of 1986

Cross-section	Value of a_1 and b_1 respectively	Average river bed level (m,PWD)	Avg. accretion height (Eq. 6) (meter)
1-1	1.958, -0.425	3.725	0.375
2-2	2.094, -0.457	3.7	0.403
3-3	2.234, -0.49	3.425	0.556
4-4	2.362, -0.52	3.4	0.594
5-5	2.490, -0.55	3.325	0.661
6-6	2.626, -0.582	3.175	0.778
7-7	2.762, -0.614	3.325	0.720
8-8	2.890, -0.643	3.025	0.945
9-9	3.018, -0.673	3.0	0.999

4.2 Estimation of the impact of dam

A prediction equation for obtaining rate of accretion down to a closure dam has already been obtained and described in equ. (3). The variables of the prediction equation in the Feni estuary close to the dam are found as:

C_m = mean sediment concentration at the bathymetric survey area of Feni estuary, 400 ppm
ω = fall velocity of sediment for average D_{50} = 25 μm in Feni estuary, 6.8x 10^{-4} m/sec

ρ = density of water, 1000 kg/m^3
ρ_s = density of sediment, 2650 kg/m^3

Duration of inundation, t is calculated by considering mean tide curve of Feni estuary. From this curve the duration of inundation time for each section of the bathymetric survey area are calculated for different years. The results are summarized in Tables 4 and 5.

Thus all the variables of the prediction equation are obtained from field measurements. The computed values of accretion height for the years 1986 and 1987 are then calculated by using equation (3) and presented in column (5) of Tables 6 and 7 respectively.

Based on the bathymetric survey as discussed, calculated accretion heights in Tables 2 and 3 have also been presented in column (3) of Tables 6 and 7. Then the impact of dam on siltation through the reduction of turbulence i.e., effective percentage of duration of inundation time for siltation (which is a function of depth of channel and distance from the closure dam) have been calculated by using equation (4). Thus adopting these sequences of action, the impact of dam have been estimated and presented in column (8) of Tables 6 and 7. From this result it is seen that the effective percentage of inundation time for deposition of sediment decreases from 93.94% to 45.02% and increases from 44.85% to 67.12% as the distance of the section increases from dam in the years 1986 and 1987 respectively. It means that in the Feni river mouth completely reverse phenomenon is observed in the following two years immediately after the completion of the closure dam, which is interpreted in the following article. Study carried out by Shahabuddin (1988), found that the impact of dam decreases from 66.2% to 33.7% in the year 1986 and increases from 13.2% to 30.9% in 1987 as the distance of the section increases from the dam. Reasons of these changes are mainly due to refinement of sediment deposition rate by incorporating the submerged sediment density with the vertical sediment transport in

Table 4
Cross- section wise per tide inundation period for the year 1982-85

Cross-Section	Average bed level in the year 1985 (meter)	Duration of inundation time/tide (in hour)
1-1	0.342	9
2-2	-0.66	10.6
3-3	-0.0757	9.5
4-4	-0.0753	9.6
5-5	0.5758	8.3
6-6	0.9504	7.5
7-7	1.6758	6.3
8-8	1.825	6.0
9-9	1.75	6.2

Table 5
Cross- section wise per tide inundation period for the year 1986

Cross-Section	Average bed level in the year 1986 (meter)	Duration of inundation time/tide (in hour)
1-1	3.725	2.0
2-2	3.70	2.2
3-3	3.425	2.7
4-4	3.40	2.8
5-5	3.325	3.0
6-6	3.175	3.1
7-7	3.325	3.0
8-8	3.025	3.5
9-9	3.00	3.56

Table 6

Effective percentage of inundation time for sediment deposition in 1986, φ
(oneyear after the construction of closure)

Cross-section	Distance from dam (meter)	Deposition h (meter) from field measurement	Duration of Inundation sec/tide	Deposition s (meter) by Eq. 3	Coeff. β (m/sec)	Discrepancy ratio φ by Eq. 4
1-1	375	3.414	32400	3.763	0.0001054	0.9074
2-2	545	4.163	38160	4.431	0.0001091	0.9394
3-3	720	3.525	34200	3.972	0.0001031	0.8876
4-4	880	3.409	34560	4.013	9.864E-05	0.8494
5-5	1040	2.716	29880	3.47	9.09E-05	0.7827
6-6	1210	2.257	27000	3.135	8.359E-05	0.7198
7-7	1380	1.482	22680	2.634	6.534E-05	0.5627
8-8	1540	1.225	21600	2.508	5.671E-05	0.4884
9-9	1700	1.167	22320	2.592	5.228E-05	0.4502

Table 7
Effective percentage of inundation time for sediment deposition in 1987, φ

Cross-section	Distance from dam (meter)	Deposition h (meter) from field measurement	Duration of Inundation sec/tide	Deposition s (meter) by Eq. 3	Coeff. β (m/sec)	Discrepancy ratio φ by Eq. 4
1-1	375	0.375	7200	0.836	5.208E-05	0.4485
2-2	545	0.403	7920	0.92	5.088E-05	0.4382
3-3	720	0.556	9720	1.129	5.72E-05	0.4926
4-4	880	0.594	10080	1.171	5.893E-05	0.5074
5-5	1040	0.661	10800	1.254	6.12E-05	0.527
6-6	1210	0.778	11160	1.296	6.971E-05	0.6003
7-7	1380	0.72	10800	1.254	6.667E-05	0.5741
8-8	1540	0.945	12600	1.463	0.000075	0.6458
9-9	1700	0.999	12816	1.488	7.795E-05	0.6712

the derivation of prediction equation and use of sediment concentration value at the bathymetric survey area near the Feni closure in the calculation of predicted accretion height. The impact of dam in terms of effective percentage of inundation time for siltation of sediment with respect to distance has been presented in Fig. 4. A comparison of computed accretion and predicted accretion with distance from dam have also been presented in Fig. 5 and Fig. 6. In absence of the more data of the cross-sectional grids for different years immediately after the construction of Feni closure dam, the subsequent impact with distance could not be assessed. But from the results (Tables 2 and 3) and subsequent years land elevation measurement data shows that the impact of dam becomes insignificant over time.

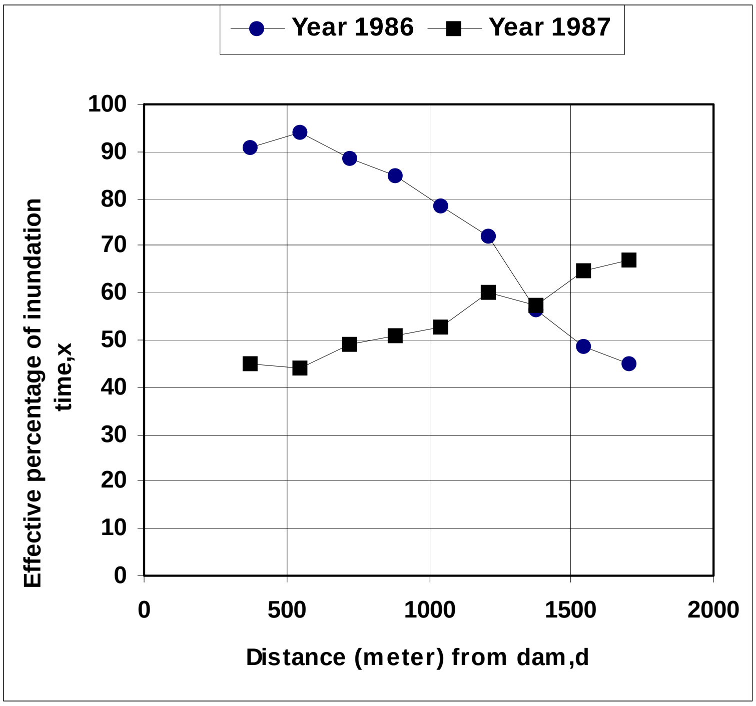

Fig. 4. Impact of dam (in terms of effective percentage of inundation time for deposition of sediment) with respect to its distance

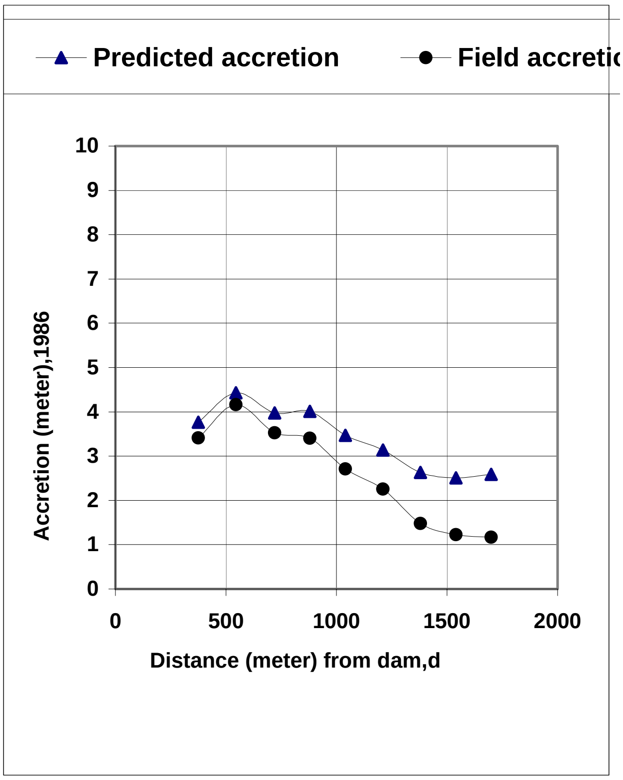

Fig. 5. Predicted and field accretion with respect to distance, 1986

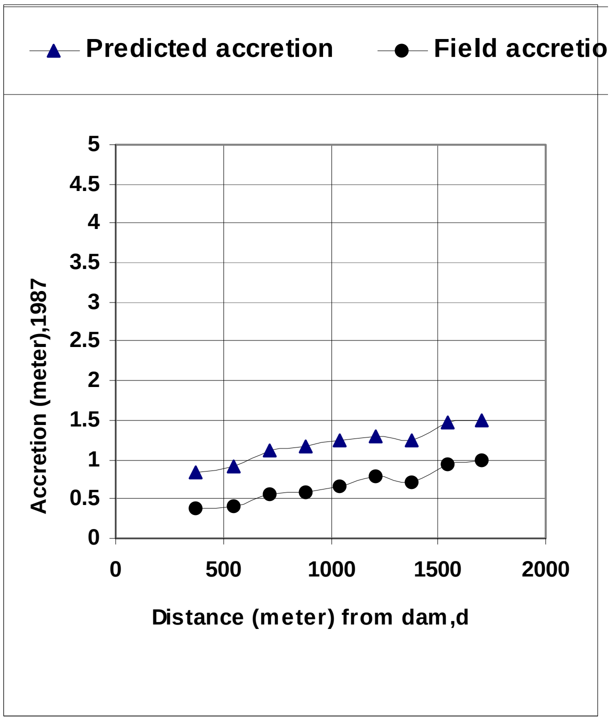

Fig. 6. Predicted and field accretion with to respect to distance, 1987

4.3 Impact of dam: an interpretation of the water column and turbulence of water

It is found that the accretion height presented in Tables 6 and 7 is higher than that obtained directly from field measurements (Fig. 5 and Fig. 6). The reason is that, the situation of completely slack water condition below the closure dam is considered during the analysis of the Equation (3). But this ideal condition rarely exists below a closure. It means, all the inundation time throughout the year are not to be effective for settling of sediment due to presence of small amount of turbulence near the sea side of the closure dam or D*dC/dy of the Eq. (2) is not exactly zero. Therefore, only a certain percentage of inundation time is effective for settlement of sediment. The calculation for the year 1986 and 1987 shows that (Tables 6 and 7) the effective percentage of inundation time or the impact of closure for deposition of sediment decreases from 93.94% to 45.02% and increases from 44.85% to 67.12% respectively as the distance of the section increases from the dam (Fig. 4).

In the year 1986, since the depth of the water column decreases as the distance of the section from the closure increases, therefore the only variable that influences the deposition of sediment during this period is the turbulence effect of water. In the channel nearer to the closure dam, reduction of turbulence is greater than those in the far channel. That is why the effective percentage of inundation time decreases with the increase of distance of the channel from the closure dam. But in the case of 1987, the trend is completely different (the effective percentage of inundation time increases with the distance). During this period, as the distance from the closure dam increases, the depth of the water column also increases. So, though the effect of turbulence increases with the increase of the distance of the channel from the closure, yet the effect in the particular section is less than that of the previous shallower section nearer to the closure.

Therefore in the year 1987, the impact of Feni closure in terms of effective percentage of inundation time for deposition of sediment increases with the distance of the section from the dam. It is found from the subsequent years land elevation measurement data that the impact of the closure ultimately reduced to zero as the silted up area increases about near to the mean high water level.

5. Conclusions

The prediction formula for deposition of sediment below a closure dam has been developed by simplifying the two-dimensional vertical convection-diffusion equation of suspended sediment in a fluid. Acceptability of this prediction formula has been judged by comparing the computed accretion height obtained through utilizing the field data by regression analysis. Results of the comparisons show the reasonable agreement. The analysis shows that in the following two years immediately after the construction of Feni closure, the impact of dam on siltation through the reduction of turbulence or the effective percentage of inundation time for deposition of sediment decreases from 93.94% to 45.02% and increases from 44.85% to 67.12% respectively as the distance of the section increases from the dam. The subsequent years land elevation measurement data reveals that with respect to monsoon mean high water level, this accretion process progresses laterally and vertically until the impact of the closure is reduced to zero or the silted up area becomes matured.

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Abbreviations

BWDB Bangladesh Water Development Board.
LRP Land Reclamation Project.
MIP Muhuri Irrigation Project.
PWD Public Works Department.
SOB Survey of Bangladesh.
SSSU Survey and Study Support Unit.