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CAUSES AND IMPACTS OF FLOOD-2000 IN THE BORDER DISTRICTS OF THE SOUTHWEST REGION OF BANGLADESH AND POSSIBLE MITIGATION MEASURES: A CASE STUDY

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Abstract

The occurrence of flood is nothing new in context of Bangladesh. But the late monsoon flood of 2000 in the border districts of Southwest Region (SWR) drew special attention of all not only for its severity but also for its being very abnormal and unusual in nature. There was no example of occurrence of such a flood in the living memory of the people of that region. The sudden onrush of floodwater from across the border left no time for the people to take any defense measure for the protection of their lives and properties. All standing crops had been damaged and most of the homesteads had been damaged fully or partially. What was more alarming, the flood gave serious jolt to the prevailing socio-economic relations to the detriment of the landless people and small and marginal farmers. River Research Institute (RRI) took up a study program to find out causes and impacts of the flood and to suggest some possible mitigation measures. Accordingly a five-member study team with a co-ordinator was formed to carry out a case study. The study team collected and analyzed the available information within limited time period and reported their findings with some recommendations. The findings of this study will provide comprehensive information on the various facets of flood disaster in the study area.

Introduction

Bangladesh has been facing recurrent pattern of floods during monsoon and scarcity of water during dry season since time immemorial. The people of Bangladesh have learnt to make necessary adjustments to minimize the effects of floods on their lives and the ecology. But there are years when floods exceed the normal limits thereby upsetting the balance between man and nature. The situation becomes worse if the flood is of very unusual in nature. Such was the very abnormal late monsoon flood that had been experienced by the people of the South West Region (SWR) of Bangladesh in the year 2000. The area is generally considered as a flood-free region because it did not face a flood of such a magnitude in the last 55 years or so. In the absence of advance information everyone was taken by surprise during the onslaught of such abnormal flood. The flood was caused by sudden onrush of water from West Bengal in India and people had little time to evacuate with their valuables. The severity of the flood took a heavy toll in human and animal lives damaging homesteads, crops and other properties on an extensive scale. The unprecedentedly long duration of the flood had added to the sufferings of the people. A vast area of Meherpur, Chuadanga, Jessore and Satkhira districts were gone under water. Near about 2.5 million people were affected.A five-member RRI team conducted a study on the causes and impacts of the flood to suggest some possible mitigation measures for likely future flood. The findings of the study are based on available information. The sources of information are field visit, questionnaire survey, discussions with the concerned officials in the flood-affected region and hydrological and morphological data of some rivers of the region. The random sampling technique was followed in the questionnaire survey. The questionnaire was prepared to assess the household socio-economic characteristics of the flood affected region, socio-economic impacts of the flood and awareness, preparedness and response of the flood affected people to cope with

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the disaster caused by the recent and likely future floods. The study team also made attempt to understand the social problems and conflicts that had arisen out of the flood.It is revealed from the study that the long duration of flood resulted from the lack of adequate drainage facilities. The polder areas of Satkhira district are subjected to water logging during heavy rainfall and it was seen that water remained stagnant in those areas when flood water was drained off from most of the affected region. In addition to the unplanned constructions of roads, bridges and culverts many other obstacles to the draining away of the floodwater were reported by the local people and concerned officials. Removal of some of such obstacles may result in social conflicts. In some localities people managed to protect their lives and properties or to reduce the extent of damage through united endeavor by obstructing the entrance of flood water or by releasing water through cutting existing roads or embankments. In some cases such actions were proved to be detrimental to the neighboring localities. It is revealed from the study that most of the affected people are poor and most of the damaged homesteads are made of raw materials. Therefore, rehabilitation of the flood stricken population was of utmost importance. The lessons from this flood need to be assimilated and reviewed in order to shape policies to find a long-term solution to similar floods apprehended in the future.

Area, Location and physiographic condition of the flood affected region

The flood-affected region includes parts of Meherpur, Chuadenga, Kushtia, Jhenaidah, Jessore and Satkhira districts bordering with West Bengal in India. It is located between 22 ^{0}27' and 23 ^{0}40' north latitude and between 88 ^{0}25' and 89 ^{0}20' east longitudes. The region represents the typical physiographic characteristics of moribund Gangetic delta. The average annual rainfall is about 170 cm. The area is generally low-lying with gentle slopes with few elevations exceeding 10 m above sea level. While the northern part is characterized by a rolling topography which drops at a slope of 1:7500 to about 6 m above sea level along a line through Jessore and Faridpur, the topography south of this line becomes much flatter and the number of beels and depressions increases. The tidal limit is approximately co-incident with the 6 m contour. The average inundation depths range from 0 to 90 cm. The inundation in the region generally results from the local heavy rainfall and over bank spill of the rivers. However, some areas south of Satkhira town suffer from tidal flooding. The rivers flowing through this region are either dead or dying.

Flood in 2000

In the South West region of Bangladesh more than 450 mm rainfall occurred on September 18 –24, 2000 (BWDB report on flood). The average rainfall in the region for the month of September is 250 mm (BWDB report on flood). In fact heavy rainfall started to occur throughout the country on September 16. As a result almost all low-lying lands went under water. The flood spill came from the overflowing Kodla and Ichamati rivers and entered Kobadak and Betna rivers in Meherpur, Mahespur and Sarsa areas. The district of Satkhira witnessed the onslaught of flood first on September 27 when floodwater entered Chandanpur of Kalaroa Upazila bordering with India. The floodwater engulfed the whole of Kalaroa Upazila within October 2. The flood infiltration then occurred when floodwater of the Border River Sonai forced a breach in the embankment of Polder-1 at Khaitala 2 km north of Baikari border. Another source of spill was at Keragachi just north of Polder-1. The flood-affected areas of Greater Kushtia, Jessor and Satkhira have been shown in Figure-1, Figure-2 and Figure-2a respectively.During the flood almost all except the brick-built houses damaged fully or partially. Floodwater submerged thousands of acres of agricultural fields causing severe damage to the Aman rice and Rabi crops. The stagnation of floodwater for longer time made the situation worse. Many of the flood-affected families lost all or some of their livestock. Many of them had little or no time to move to safer places with their livestock. For the same reason they also had to lose all of their portable belongings. Floodwater also caused damage to the trees, vegetable gardens, and loss of fishes from the ponds. During the occurrence of flood innumerable infrastructures namely schools, colleges, government and private establishments, roads, bridges and culverts had gone fully or partially under water. In many areas of the flood affected region drinking water crisis resulted from the damage of tubewells. A serious disruption in the communication network caused due to the damage of hundreds of Km of both unmetalled and macadamized roads in many areas. Many bridges, culverts and water development infrastructures namely regulators, ring dikes etc, also damaged fully or partially. In many areas people cut roads, closures and ring dikes to facilitate quick drainage of floodwater.

Causes of the flood and delayed drainage

Based on the available information the causes of the recent flood and also the reasons for delayed drainage were found to be

- Excessive rainfall
- Onrush of water from West Bengal
- Flood spill from the Ganges
- Breach at the ring dike
- Reduction in the transport capacity of the rivers and canals:
- Unplanned floodplain development
- Poor drainage facilities
- Construction of shrimp enclosures
- High tide level

A profile of the case study area

In order to address the socio-economic characteristics of the flood affected region and to assess the socio-economic impacts of the flood six Upazilas of different flood affected districts were selected for questionnaire survey. These Upazilas are Kalaroa, Debhata, Satkhira Sadar, Jibannagar and Mujibnagar. Random sampling technique was followed in the questionnaire survey. A number of 300 people were interviewed.

The Characteristics of the upazilas of the study area appears in table-1. The respondents profile in table-2 shows some important household characteristics. It can be seen that about 98% of the respondents were affected by flood 2000. The housing characteristics, occupation, land ownership, economic status, health and cropping intensity of the study area have been shown in table-3, table-4, table-5, table-6, table-7 and table-8 respectively. The construction material of roof of most of the dwelling households of the study area is straw/bamboo and tiles/GI sheet. The primary occupation of 62% of the respondents is agriculture. Of the total respondents 75% have no secondary source of income, 20% have an additional source of income and 5% have two other income sources in addition to the primary one. About 24% of the respondents are land less in the study area. Of the landowning households in the categories of up-to 0.5 acre, 0.51-1.00 acre and 1.01-2 acres, 50% are found to be sharing-in some amount of land for cultivation, however, 20% are sharing-out some amount or all of their land 30% are neither sharing-in nor sharing-out any of their land. In the study area the average yearly income and expenditure of households are Tk. 51, 350 and Tk. 51, 830 respectively. It means Tk. 480 negative savings of the households as a whole. As to the availability of health care and the most common types of treatments applied, the figures in table-7 show the severe lack of modern medical services and major role of quack doctors in the study area. The cropping intensity in the study area as a whole is 196%.

Table 1: Characteristics of the Upazilas of the study area

Upazilas	Characteristics
Kalaroa, Satkhira	• Generally a flood free area • Low literacy rate • Fertile land and arsenic contaminated drinking water • Majority of the inhabitants are poor • Poor drainage facilities and lacks infrastructure development
Debhata, Satkhira	• Generally affected by low flooding • Low literacy rate and arsenic contaminated drinking water • Protected by flood control embankment • Main source of income is fish cultivation and agriculture • Poor drainage facilities and lacks infrastructure development
Satkhira Sadar, Satkhira	• Generally affected by low flooding • Low literacy rate and relatively good drinking water facilities • Fertile land and majority of the inhabitants are poor • Protected by flood control embankment
Sarsa, Jessore	• Generally a flood free area • Relatively high literacy rate • Arsenic contaminated drinking water • Main sources of income are agriculture and business • Business is relatively good • Poor drainage facilities • Fertile land • Not protected by flood control embankment • Middle class economic status of the people.
Mujibnagar, Meherpur	• Generally affected by low flooding • Relatively high literacy rate • Main source of income is agriculture • Better drinking water facilities • Fertile land • Better infrastructure development • Better communication facilities • Inhabitants mostly poor • Undeveloped slums

Continued Table-1

Upazilas	Characteristics
Jibannagar, Chuadanga	• Generally a flood free area • High literacy rate • Better drinking water facilities • Lacks infrastructure development • Poor drainage facilities • Fertile land • Inhabitants mostly poor • Not protected by flood control embankment • Main source of income is agriculture.

Table 2 : Respondents Profile

Household Characteristics	Respondents	Sd. Deviation
Average age (years)	41	12.9
Literacy rate (%)	68	
Household size	7	4.9
Household sex ratio (male/female)	1.28	0.594
Household dependent to income earning member ratio	3.65	1.35
Affected by flood 2000 (%)	98	
Landless to land owning household ratio	0.32	

Table 3: Construction Characteristics of the households

Locality	Material of Roof (%)			Row Total
	Straw/Bamboo	Tiles/G.I. Sheets	Cement	
Rural	44	52	4	100
Urban	10	60	30	100
Study area	37	54	9	100

Table 4 : Occupational involvement of the household heads

Types of Occupation	Percentage of respondents
1. Agriculture	62
2. Day labour	8
3. Business	15
4. Fishing	2
5. Driving	2
6. Salaried job	11

Table 5 : Land ownership pattern in the study area

Size of land ownership (acre)	Percentage of households
Landless	24
Up to 0.50	6
0.51-1.00	4
1.01-2.00	34
2.01-3.00	5
3.01-4.00	13
4.01-5.00	4
5.01-7.50	6
Above-7.50	4

Socio-economic impacts of the flood

Household economic loss

In the study area 98% of the total respondents reported that they had suffered household economic loss in varying degree. The lost properties include livestock, homesteads, crops, trees and other valuables. Table 9 shows the distribution of types of loss suffered by the homesteads in the study area.

Table 6 : Economic status of the Households in different Upazilas of the study area

Upazilas	Average yearly income (Tk.)	Average yearly expenditure (Tk.)	Net Savings (Tk.)
Sarsa, Jessore	78000	74000	+4000
Satkhira Sadar, Satkhira	48000	50000	-2000
Debhata, Satkhira	44000	45000	-1000
Kalaroa, Satkhira	42000	44000	-2000
Mujibnagar, Meherpur	39000	38000	+1000
Chuadanga, Jibannagar	65000	67000	-2000
Study area	51350	51830	-480

Table 7: Frequency of different types of treatments

Types of treatments	Percentages
Quack doctor	85
Trained / MBBS or hospital/clinic	15
Indigenous (tabiz /hakim)	0
No treatment	0
Total	100

Table 8 : Cropping intensity in different Upazilas of the study area

Upazilas	Cropping intensity (%)
Sarsa, Jessore	171
Satkhira Sadar, Satkhira	188
Debhata, Satkhira	200
Kalaroa, Satkhira	200
Mujibnagar, Meherpur	225
Jibannagar, Chuadanga	200
Study area	196

Table 9: Distribution of types of loss suffered by the households in the study area

Types of loss	Percentage of respondents
Only livestock (cattle, goat, poultry)	7
Homesteads and livestock	9
Only crops	7
Homesteads and crops	17
Homesteads, crops, fishes and trees	60

Employment and wage rate

In the study area employment problem as a consequence of flood is reported by about 90% of the total respondents. This problem resulted mainly from the disruption of economic activities due to flood. Trade and commerce almost came to a halt due to disruption of communication. The flood damage of crops dampened the wage rate. Moreover, about 30% of the households having land of their own had to keep all or some of their land fallow due to lack of capital to buy seedlings and water logging. About 90% of the total respondents reported about the migration of the people from their locality to urban areas in search of employment. It indicates that after the flood the extent of employment in the study area was insufficient.

Transfer of land

In the study area it is found that 30% of the respondents having land of their own were involved in land transfer after the occurrence of flood. The transfer of land was made both by selling and mortgaging-out of land. About 30% of the respondents involved in land transfer are found to have transferred their by selling out and the rest (70%) have transferred their land by mortgaging-out. As to land transfer it is revealed from the study that most of them who transferred land belonged to categories of marginal and small farmers. It is reported that all the sold-out and mortgaged-out land were accumulated in the hands of some rich people. It was revealed that the most prominent causes of land transfer were the purchase of food and meeting the farming expenses.

Sale of livestock and other properties

In the study area 83% of the total respondents were found to be involved in selling livestock during and after flood. However, most of them sold some of their livestock. The sold out livestock include cattle, goat and poultry. The reasons behind the selling of livestock in the study area as reported by the respondents were purchasing food, want of feed for livestock and meeting various family expenses. In fact the need for meeting emergency expenses was such that people had to sell out their livestock at a selling price which was about 30 to 50 percent lower than those of the prices that prevailed before the occurrence of the flood. Together with the selling of livestock people had to sell out other family properties like ornaments, trees, etc. It was found that 47% of the total respondents were involved in selling out properties other than land and livestock.

Indebtedness

In the study information on credit taken by the households in the study area both before and after the occurrence of flood from different sources were collected. It was found that 65% of the total respondents were indebted (Table 10). Of the total indebted respondents, 65% were indebted to only one source and 35% were indebted to more than one sources.

Table 10: Indebtedness of the respondents

Description	Respondents
Indebted respondents (% of the total)	65
Indebted to only one source (% of the total indebted)	65
Indebted to more then one sources (% of the total indebted)	35
Indebted respondents having land of their own (% of the total indebted)	75
Indebted landless respondents (% of the total indebted)	25
Indebted before the occurrence of flood (% of the total indebted)	35
Indebted after the occurrence of flood (% of the total indebted)	35
Indebted before and after the occurrence of flood (% of the total indebted)	30

Among the indebted households, 75% are land owning households and 25% are landless households. It is also found from the collected information that of the indebted households, 35% took credit before the occurrence of flood, 35% took credit after the occurrence of flood and 30% were involved in taking credit both before and after the occurrence of flood. It means that due to flood the number of indebted households was increased as compared to situation before the occurrence of flood.

Sources of credit

There were both formal and informal sources of credit. These sources were banks, friends, relatives, moneylenders, co-operatives and NGOs. Figure 3 shows the distribution of indebted households in relation to the sources. It can be seen from Figure that banks played the major role in providing the households with credit. The moneylenders follow it. It was found that the landless and small farm households had little access to the bank credit facilities. Most of them had to depend on moneylenders for taking credit.

Use of credit

The heads of using credit by the indebted households are shown in Table 11. It is revealed from the table that most of the indebted households used the credit for agricultural operations.

Table 11: Heads of using credit by the indebted households

Heads of using credit	Percentage of respondents
Agricultural operations	55
Purchase of food	9
Repayment of loan	3
Purchase of food and agricultural operations	17
Rebuilding of damaged houses	16

Relief operation

Respondents were asked about the receipt of relief materials both during and after the occurrence of flood. About 95% of the flood-affected respondents reported that they had received some amount of relief materials from different sources. These sources as reported by the respondents are government, NGOs, relatives, friends and local leaders. The distribution of households in relation to the sources of receiving relief materials is shown in figure 4.

Place of refuge during flood

Due to sudden onrush of flood many people had to leave their houses with some of their belongings in order to save lives and to reduce losses in goods and property. When asked about the place of refuge during the flood the respondents reported about different places such as own house, rooftop of the own house, rooftop of the neighbor's building, floodshelter, nearby road or embankment etc. Table 12 shows the distribution of households in relation to the place of refuge during the flood.

Table 12: Distribution of households in relation to the place of refuge during the flood

Place of refuge	Percentage of households
Own house	26
Rooftop of the own house	20
Rooftop of the neighbor's building	9
House of the friend/relative in safe area	19
Floodshelter	13
Nearby road or embankment	13

Diseases

In the study area there was incidence of diseases connected with flood. About 67% of the total respondents reported that at least one of their family members suffered from diseases during and after the flood. Figure 5 presents the type of diseases suffered by human beings during and after the flood. It is revealed from the table that most of the people.

Preparedness, awareness, adjustment measures and responses of flood affected people

The occurrence of the flood took everybody by surprise in the study area. The people were not at all ready to face the onslaught of the flood. Still they did not accept losses done by the flood without any response strategies. So long as they were not forced to accept losses passively and to abandon their households, people tried to reduce damage by adopting various strategies. The flood has awakened the people and the sense of security that was prevailing before the occurrence of flood is now non-existent. The people are now thinking of doing whatever they can to live with the floods.

Preparedness and perception of the risk

It was found that during the recent flood, the inhabitants of the flood-affected areas were more dependent on indigenous strategies to cope with the flood. There was little institutional support and the people undertook incidental rather than purposeful approaches to relieve themselves from flooding. In most of the cases they were seen to cut roads and dikes to release floodwater from their localities which in turn deteriorated the flooding situation in the neighboring localities. The other strategies they adopted were construction of dikes to prevent the propagation of flood, construction of temporary earthen barriers around the fishponds, selling out livestock and other properties, moving belongings etc.

It is revealed from the information collected during the study that the perception of the risk of occurrence of a future high flood is significant among the people in the flood-affected area. In this regard attention is drawn to the following table (Table 13).

Table 13: Perception of the risk of occurrence of a future high magnitude flood.

Respondents in	Percentage of "yes" answers
Protected area	75
Unprotected area	93
Study area	85

It can be seen from the table that 85% of the respondents in the study area as a whole perceive the risk of occurrence of a future high magnitude flood. However, the percentage of respondents in the unprotected area who perceive the risk is higher than that of the protected area. It may be due to the fact that despite the incidence of dike breaching during the recent flood some people still do not like to believe that such dike breaching can also occur in future. It was found that 76% of the respondents were thinking of doing something to face a future flood whereas 24% of them did not think of doing anything yet. Table 14 presents the nature of preparatory works the respondents were thinking of doing against flood damage. It can be seen from the table that most of the respondents (71%) were thinking of raising their houses to prevent the ground flood from being flooded.

Table 14: Nature of preparatory works for protection against flood damage

Nature of preparatory works	Percentage of respondents
Building pacca house	15
Raising house	71
Shifting to a safer place	10
Providing wall in brick or concrete around house	4

The sources of assistance expected by the respondents in case of a future flood have been shown in figure 6. It is important to notice from the information presented in figure 6 that 60% of the total respondents considered government as reliable source of assistance. On the other hand, a significant proportion (22%) liked to rely on God.

Awareness and perception

Perception and awareness of flood play a significant role in preparedness and adaptation behavior of the people living in flood-prone areas. Table 15 shows the views of the respondents regarding the causes of the recent flood. It can be fairly stated that the people of the study area perceived the causes of the flood rationally.

Table 15: Views of the respondents regarding the causes of the flood

Causes of the flood	% of respondents
Onrush of floodwater from across the border	37
Collapse of flood control embankment	32
Excessive rainfall before the onrush of floodwater from across the border Floodwater	12
Reduction in the transport capacity of the rivers and canals	7
Lack of drainage facilities	5
Do not know	4
Will of Allah	3

The percentage of respondents who were ignorant about the causes of the flood was found to be insignificant (4%). Only 3% of the total respondents were fatalistic and considered flood to be the will of God. The perception of the respondents regarding the reasons of delayed drainage was also found to be quite rational (Table 16). It can be seen that most of the respondents reported loss of transport capacity of the rivers/canals and unplanned construction of roads, bridges and culverts as main reasons for the delayed drainage of floodwater. The respondents who reported inadequate bridges and culverts as reason of delayed drainage were of the opinion that the existence of more bridges and culverts could facilitate safe passage of the floodwater. On the other hand, most of the respondents who reported construction of ring dikes, poor drainage facilities and shrimp enclosures as reasons of delayed drainage were from the polder areas.

Table 16: Reasons of delayed drainage as perceived by the respondents

Reasons of delayed drainage	Percentage of respondents
1. Loss of transport capacity of the river/canals	29
2. Unplanned construction of roads, bridges and culverts	15
3. Both of the above	26
4. Inadequate bridges and culverts	10
5. Construction of ring dikes	6
6. Poor drainage facilities	8
7. Shrimp enclosures	6

Adjustment measures

It was found that in the recent flood 98% of the respondents were affected but only 10% of them were thinking of shifting to a safer place. The rest were either rebuilding houses or repairing their damaged houses. However, it was revealed that the percentage of migrant people would likely to increase in case of a future high magnitude flood. Most of the farm households reported that they would continue to live with the floods. In this regard their expectation for necessary assistance from national government was found to be very high. They did not like to rely on social relationship assistance. It was found that most of the people were thinking to reduce flood damage by raising their houses. Only an insignificant proportion was thinking of building pacca house. However, whatever they intended to do could not be materialized without any external assistance.

It appeared from the study that the occurrence of flood would result in massive unemployment and the landless laborers and marginal farmers would migrate to the urban areas in search of employment. The job seekers and destitute women would likely to be involved in cross-border smuggling. The members of the farm dependent households would try to be involved in non-farm activities and it would cause major occupational change in the study area.

The landless and marginal farmers were found to be the most affected groups of people. Their houses were made of raw materials and therefore were more vulnerable to flood damage. In fact they had to lose almost everything whatever they had. It made them more dependent on money lenders and they were expected to lose their last possessions at the hands of the money lenders. It would ultimately create serious class divide.

Most of the medium and small farmers were in need of credit for agricultural operations. In this regard they were dependent on banks as source of credit. On the other hand, the poor and the marginal farmers did not enjoy the facility of bank credit. They had to depend on informal sources for taking credit.

As to the addition of family assets after the occurrence of flood it was found that 12% of the total respondents could not add any asset for want of money. Of the rest, 79% of the respondents invested for reconstruction and repair of houses, 9% were involved in purchasing cattle and 6% were involved in purchasing other properties (Table 17).

Table 17: Addition of family assets after the flood

Name of assets	percentage of respondents
Cattle	9
Goat	3
Poultry	3
Repair/reconstruction of houses	79
Others	6

Responses to the flood

It was found from the study that being perplexed by the sudden onrush of floodwater 15% of the total respondents virtually did nothing other than shifting their families with some belongings to a refuge area. Some of them reported that they had no option other than to do so while some others reported that they did not respond to the flood by adopting any control measure thinking that it would come to no effect. On the other hand, 85% of the respondents reported that they had applied various indigenous technologies and other measures to reduce the flood damage. The applied measures in response to the flood as reported by the respondents are stated below:

- Removal of obstructions hindering free flow of water
- Cutting dikes in order to release floodwater
- Blocking bridge opening to prevent floodwater from entering to non-protected area
- Reinforcement and repair of flood control infrastructures
- Closing gaps in dikes
- Cutting roads to release floodwater
- Clearing drainage canals
- Building temporary earthen barriers
- Helping in evacuation of people and property
- Selling out properties

Conclusions and recommendations

Conclusions

The following conclusions have been drawn from the study:

- There was no means to authorities to forecast the occurrence of such a flood. The flood originated outside the Bangladesh and no information was imparted to Bangladesh authorities by Indian authorities regarding the flood.
- In the flood-affected area the protection level against flooding was very limited. Moreover due to lack of any prior warning people of that area were not at all aware of flood risk. They had virtually no preparation to adopt any means to reduce flood damage. The concerned authorities also could not provide any realistic means to reduce flood damage due to lack of preparation.
- In the polder areas the restriction of tidal over-bank spill has caused the deposition of sediments at the upper end of the confined channels blocking the outlets of drainage sluices. It has caused drainage congestion in the polder areas for longer periods than designed.
- The natural drainage routes had not been maintained. As a result, people encroached upon these watercourses either to extend their agricultural lands or to cultivate fish causing hindrance to the free flow of water.
- In polder areas the shrimp enclosures built by the shrimp cultivators are acting as obstacles to the draining away of the floodwater.
- Many agencies were involved in the past development activities in the region and there was no co-ordination in the development activities of these agencies. Sufficient bridges and culverts were not built to allow the safe passage of floodwater during the construction of roads. Moreover, sufficient clearance was not kept under the constructed bridges and culverts to enable the floodwater to drain out quickly.
- There was no control of floodplain development. Floodplains were developed without any comprehensive plan. The infrastructures in the floodplains were barriers to the natural drainage of floodwater. Unplanned and uncontrolled floodplain development increased the potential for flood damage.
- The protected areas within the polders were flooded due to the dike breaching at Khaitala under Satkhira Sadar Upazila. Long duration of high stage might have weakened the dike and eventually caused the breach.
- About 98% of the people were affected by the flood in varying degrees
- Agriculture is the main occupation in the study area. Retail business and salaried jobs are also important means of livelihood.
- There is severe lack of modern medical services in the flood-affected region.
- The damage done by the flood resulted in massive unemployment for the landless laborers and small and marginal farmers. Many people migrated to the urban areas in search of employment.
- Many people transferred land and sold out livestock and other properties mainly for purchase of food and meeting the farming expenses.

- The number of indebted households had been increased due to the occurrence of flood. The main source of taking credit was bank. The poor and marginal farmers did not enjoy the facility of bank credit. They had to depend on moneylenders and other informal sources for taking credit.
- More than 50% of the people had to abandon their houses for safety. The major refuge areas were: house of the friend/relative in safe area, floodshelter and nearby road or embankment. There was no planning of evacuation.
- About two third of the households suffered from different diseases. The average size of the households suffering from the diseases was 7.16 and on an average 3.23 member of each household suffered from the diseases.
- Stoppage of local trade and commerce due to the flood triggered an increase in the cross-border smuggling.
- 76% of the people were thinking of taking preparatory measures to face a future flood comparable in magnitude with the recent flood and most of them liked to rely on government for assistance in this regard.
- After the occurrence of the flood most of the people invested for reconstructing and repairing the houses. The addition of other family assets was insignificant.
- Despite having no prior preparation people responded to the flood very well. In most of the cases the flood fighting measures deployed by the people came to no effect.

Recommendations

The following recommendations have been made based on the findings of the study:

- Establishment of a reliable flood forecasting and warning system
- Development of evacuation planning system
- Control of floodplain development
- Restoration of previous flow regime
- Removal of obstacles from natural drainage routes
- Coordination in the development activities of different agencies
- Strengthening and heightening of existing embankments
- Raising of houses and structures
- Flood assistance to the most affected households
- Creation of post-flood employment opportunities Improvement of women's situation
- Integrated water resources planning and management

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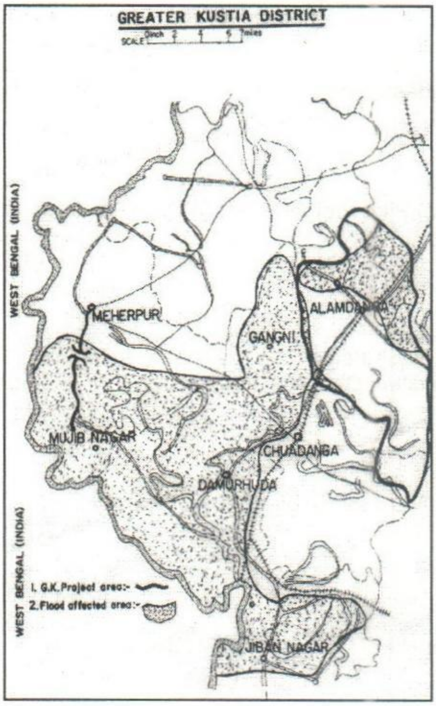

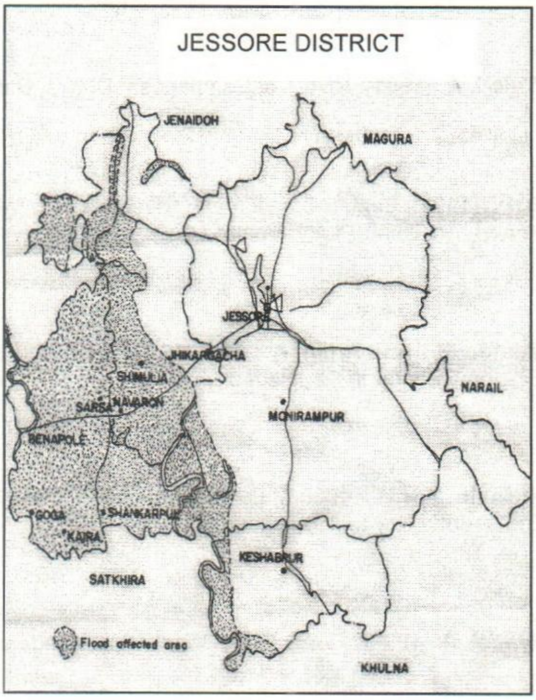

Figure 1: Flood affected areas of Greater Kushtia district

Figure 2: Flood affected areas of Jessore district

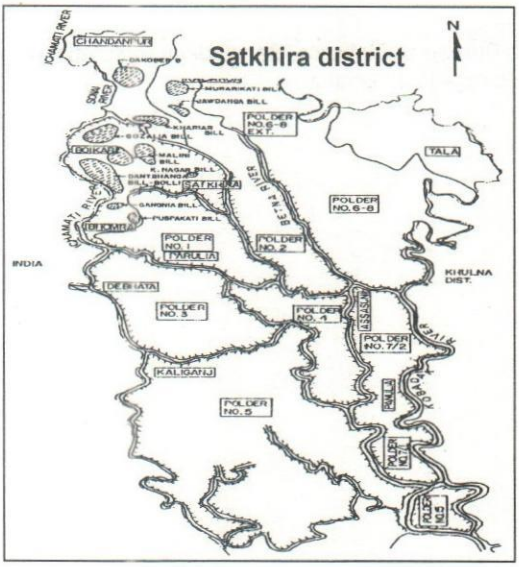

Figure 2a: Flood affected areas of Satkhira district

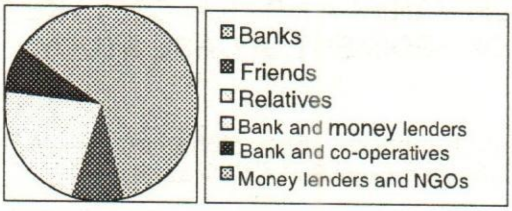

Figure 3: Distribution of indebted households in relation to the sources

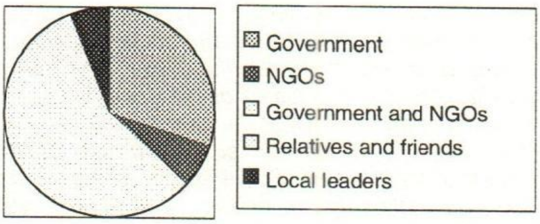

Figure 4: Distribution of households in relation to sources of receiving relief materials

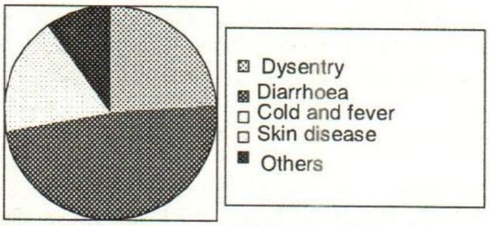

Figure 5: Type of diseases suffered by human beings during & after

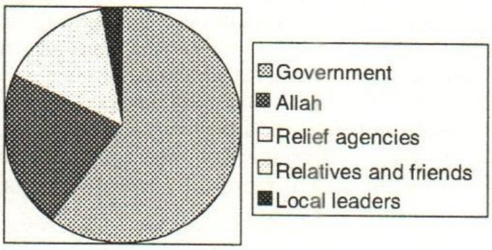

Figure 6: Expected sources of assistance in case of a future flood

Tech. j. River Res. Inst. 8(1): 20 - 29, 2001 (December)

EFFECTS OF BOTTOM VANES AT GORAI OFFTAKE ON DISTRIBUTION OF SEDIMENT: A CASE STUDY

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Abstract

Anti-sediment structures are used to divert the sediment movement in order to reduce sedimentation. In Bangladesh, most of the rivers carry huge amount of sediment load and causes sedimentation. The Ganges is a mighty river, which carries huge sediment load during rainy season. A part of that sediment load is transported through its distributaries also. The bed of the river and that of its distributaries are getting silted up since at the time of their genesis. As a result large sand bars are forming at the river bed as well as at the off-take position of some distributaries which can be seen during dry season. Some of these bars disconnect the distributaries from its parent river. Consequently very low or almost no flow situation occurs in these distributaries during dry season. This sedimentation has noticeable adverse impacts on navigation, agriculture and environmental quality of the region through which the river traverses. The Gorai is an important distributary of the Ganges that is now facing this type of problem. Under the framework of the Gorai River Restoration Project (GRRP) a physical model study was conducted to investigate the performance of Bottom Vane as anti-sediment structures along with Guide Bund and Flow Divider positioned at the off-take in reducing sediment transport through the Gorai. This paper presents the outcomes of model investigation. It is observed that the anti-sediment structures have marked impacts on sediment distribution through the Gorai.

Introduction

In our country, rivers carry huge amount of suspended load, which causes sedimentation in riverbed. As a result, many rivers and their distributaries are getting silted up. The Gorai, a distributary of the Ganges is facing shortage in the dry season flow due to siltation at its mouth. The Gorai River is an important source of fresh water supply to South West Region and it is the only remaining major spill channel of the Ganges flowing through the region. For last few decades the dry season flow (November-May) in Gorai River has been decreasing. The environmental impact on this decreasing flow is very serious in terms of increased salt-water intrusion in the coastal area, around Khulna and on Sundarbans. It is feared that further decrease in dry season flow will lead to the siltation of the off-take of Gorai River to an extent that the river may be permanently disconnected from the Ganges River. This will deprive the region of its most important source of fresh water supply. In order to mitigate this problem a physical model study is conducted under the framework of GRRP by constructing the Bottom Vane as an anti-sediment structure along with Guide Bund and Flow Divider at the Gorai off-take. The objectives of the model study are as follows.

- To investigate the impact of construction of interventions on the distribution of sediment transport at the off-take.
- To investigate the impact of construction of interventions on the discharge distribution at the off-take.
- To investigate the impact of construction of interventions on the flow field at the off-take.

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Methodology

The model was designed to investigate the flow and sediment distribution at the Gorai off-take in base condition and to observe the impact of introduction of Bottom Vane as an anti-sediment structures along with Guide Bund and Flow Divider on the sediment distribution. An open-air model bed of 63 m x 115 m has been used for setting up the model. The region included in the model is about 6 km reach of the Ganges 4.33 km of the Gorai. The layout of the model is shown in Figure-1 for the test T0 to T3 and Figure-2 for the test T4. It was an undistorted fixed bed model. The vertical and horizontal scale of the model was 1:70.

The dominant discharge of the Ganges is 37500 m^3/s was used in this model. Actually the model discharge was 45% of this dominant discharge and the boundary conditions for this discharge have been determined from the mathematical model. The bed geometry of the model was reproduced according to the bathymetric survey of March 2000, supplied by SWMC. The right boundary of the model extracted from the geo-corrected IRS map (March 2000) and the left boundary of the model corresponds to the flow line representing the 45% of the dominant discharge in the Ganges.

A sharp crested weir was used to measure the model discharge according to Rehbock's formula. A point gauge is installed upstream of the weir at a sufficient distance to avoid the effect of curvature during recording the water level. A stilling pond was constructed to dissipate the energy of incoming flow and hollow bricks and bamboo screens have been used to adjust the distribution of flow at the inflow section.

Polystyrene was used as a tracer material to investigate the sediment distribution at the Gorai off-take. The D_{50} and specific gravity of the tracer material were 0.35 mm and 1.025 respectively. During test run tracer material was released from three prefixed points along the selected cross section. Prior to the selection of three points dye was released from these points to make sure that flow from one point gets separated at the Gorai off-take and other two points lie at a same distance on both side of it. In the model the distance of these points from the right bank were 1.75 m, 2.5 m and 3.25 m. These three points were located at the cross section GAN-68. The trial runs are stopped when it is found that the tracer material movement has reduced so far that there is hardly any transport left. The time that was normally needed to reach such a state is about 20 minutes. Tracer material that was flowing out of the model has been collected by using the net that was fitted beneath the tailgate. After completion of the test the water from the model is drained and the tracer material has been collected from the bed and from the net. The collected material is then measured by volume. Several numbers of point gauges were installed in the model by which development of water levels at different locations were recorded.

The model study consisted of five tests of which T0 contributed to calibration and T1 to T4 was carried out as application tests. The test conditions are described below:

Test T0: Base run

Test T1: Guide Bund + Flow Divider

Test T2: Guide Bund + Flow Divider + Bottom Vanes-1

Test T3: Guide Bund + Flow Divider + Bottom Vanes- 2

Test T4: Guide Bund + Flow Divider + Bottom Vanes- 2

(changing the angle of attack of the flow)

The difference between Bottom Vane- 1 and Bottom Vane- 2 is shown in Table-1.

Table-1: Description of Bottom Vanes-1 and Bottom Vanes-2.

Bottom Vanes-1		Bottom Vanes-2	
Row no	Total no of vanes	Row no	Total no of vanes
1	8	1	6
2	8	2	6
3	10	3	8
4	11	4	9
5	14	5	11
6	17	6	14
7	20	7	17
8	24	8	19
9	26	9	19
10	27	10	19
11	29	11	19
12	30	12	19
		13	19

Tests

Test T0: Base run

In the first phase of the test the model was calibrated to meet the hydraulic similitude of the model with the prototype. After calibration of the model discharge was measured at the inflow section and flow velocity distribution was recorded at some selected cross-sections. Besides float tracks were measured to determine the flow lines. The layout of the model in test T0 to T3 is shown in Figure-1.

Discharge distribution

During the test, discharge flowing through the model at inflow section (Discharge Measuring Section-1) and at two outflow sections (Discharge Measuring Section -2 and Discharge Measuring Section -3) of the Gorai and the Ganges have been measured by adopting area velocity method. Point velocities have been measured at 0.6 depth from the water surface. The measured discharge at the downstream section of the Gorai shows that about 10.56% of the total Ganges water is flowing through the Gorai.

Tracer material distribution

In order to investigate the tracer material distribution through Ganges and Gorai at the Gorai off-take two trial runs are conducted. During each run tracer materiel is released from three prefixed points at cross section GAN-68. In the first run the total amount of released tracer material is 6000 ml. In the other test the amount of released tracer material is 9000 ml. Tracer material that is flowing out of the model has been collected by using the net that was placed at the beneath of tailgate. After completion of the test the water from the model is drained and the tracer material has been collected from the bed and from the net. The collected material is then measured by volume. The amount of tracer material lost from the system in the two trial runs is 11.8% of the total amount of released material. From the recovered amount the tracer material distribution into the Gorai is determined as 70%. The calculation is made excluding the tracer material deposited upstream of the flow separation zone, which is about 6% of the recovered material.

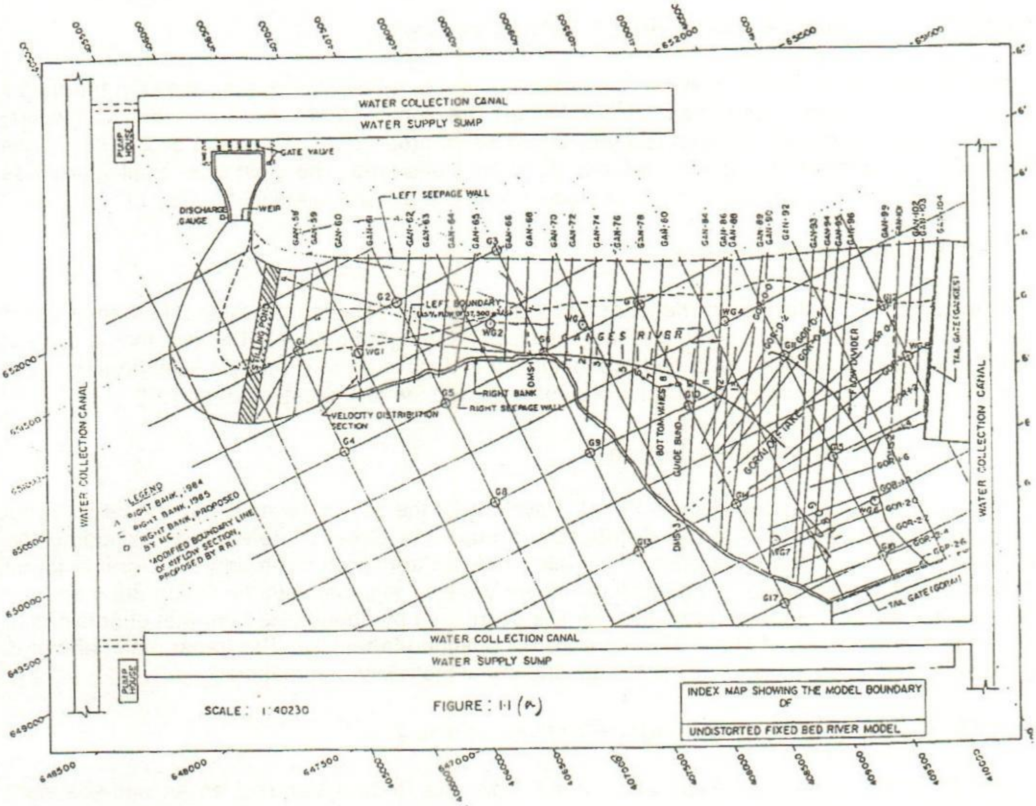

Figure-1: Layout of the model for test T0 to test T3

Test T1: Guide bund + flow divider

The objectives of this test are to investigate the impact of these structures on the overall flow pattern, discharge and tracer material distribution into the Ganges and the Gorai. The test procedure and objectives in this test are similar to that of test T0.

Discharge distribution

The outcome of the discharge measurements at three pre-selected cross-sections shows that about 10.86% of the total Ganges discharge is flowing through the Gorai. It signifies that introduction of Guide Bund and Flow Divider makes no significant difference in discharge distribution in comparison with test condition T0.

Tracer material distribution

To investigate the distribution of tracer material at the Gorai off-take two trial runs are performed. The loss of tracer material from the system in the two trial runs is about 6.4% of the total released tracer material. From the recovered material the tracer material distribution into the Gorai is determined excluding the material deposited upstream of the separation zone. The tracer material through the Gorai is found to be 59%. It indicates that due to introduction of Guide Bund and Flow Divider tracer material through the Gorai is decreased by about 11%. The tracer material that found to be deposited upstream of the separation zone is about 4.8% of the recovered material.

Test T2: Guide bund + flow divider + bottom vanes-1

In test T2 the Bottom Vanes-1 as an anti-sediment structure have been reproduced in the model in addition to the Guide Bund and the Flow Divider. The Bottom Vanes-1 are placed in 12 (twelve) rows. The number of vane in each row varies 8 to 30. In order to reproduce the design conditions the model bed is lowered to a level of 0 mPWD at the Vane area. The crest level of all vanes was set at 5.3 mPWD. The objectives and test procedure of this test are same that of test T1.

Discharge distribution

The outcome of the discharge measurements at three pre-selected cross-sections shows that about 10.80% of the total Ganges discharge is flowing through the Gorai. It means that in spite of introducing Bottom Vanes-1 and bed dredging at the Vane area to 0 mPWD level no significant change occurs in discharge distribution in comparison with the test situation T0 and T1.

Tracer material distribution

In this test the loss of tracer material from the system for the two trial runs is about 6.64 %. From the recovered tracer material the distribution through the Gorai is determined excluding the material deposited in the vane area. The tracer material transported through the Gorai is found 33%. It indicates that due to introduction of Bottom Vanes-1 together with the Guide Bund and the Flow Divider tracer material through the Gorai is decreased by about 26% from that of obtained in test T1 and a decrease of about 37% from that of obtained in test T0. The tracer material that is found to be deposited in the Vane area is about 9.4% of the recovered material.

Test T3: Guide bund + flow divider + bottom vanes-2

In test T3 along with Guide Bund and Flow Divider the Bottom Vanes-2 as an anti-sediment structure have been reproduced in the model. In case of Bottom Vanes-2 an additional row of vane is placed at the downstream of 12th number row of vane of test T2. Besides, the numbers of vanes in some rows of test T2 have been changed in test T3. The number of vane in each row varies from 6 to 19. For this reason the length of rows has been reduced compared to the condition of test T2. No change is made in the bed level of the vane area and also in the crest level of the vanes. The objective and test procedure of this test is same as that of test T2.

Discharge distribution

The outcome of the discharge measurements at three pre-selected cross-sections shows that about 10.95% of the total Ganges discharge are flowing through the Gorai. It means that in spite of introducing Bottom Vanes-2 and bed dredging at the Vane area to 0 mPWD level no significant change occurs in discharge distribution in comparison with the test situation T0 to T2.

Tracer material distribution

In this test the loss of tracer material from the system for the two trial runs is about 7.9%. From the recovered tracer material the distribution through the Gorai is determined excluding the material deposited in the vane area. The tracer material transported through the Gorai is found 27%. It indicates that due to introduction of Bottom Vanes-2 together with the Guide Bund and the Flow Divider tracer material through the Gorai is decreased by about 6% from that of obtained in test T2 and about 43% from that of obtained in test T0. The tracer material that is found to be deposited in the vane area is about 2.2% of the recovered material.

Test T4: Guide bund + flow divider + bottom vanes-2 (changing the angle of attack of the flow)

In test T4 interventions are kept similar to that of test T3. But this test is planned to investigate the impact of the change in the angle of attack of the Ganges flow towards the off-take and existing vanes on the discharge and tracer material distribution. The possibilities of such change in the angle of attack are sought from the satellite images of the Ganges river at that location. It is observed from the satellite images that the situation in 1984 and 1985 represents such possibilities. Considering the space constraint and position of the other modeling facilities in the model area the situation of 1985 is found to be suiTable to reproduce in the model. The layout of the model for test T4 is shown in Figure-2. The test objective and procedure followed in this test is similar to that of T1, T2 and T3.

Discharge distribution

At first the model is calibrated for the given discharge in order to have a uniform flow distribution over the width of the approach channel. The outcome of the discharge measurements at three pre-selected cross-sections shows that about 11.7% of the total Ganges discharge is flowing through the Gorai. It is a noticeable increase in the discharge distribution into the Gorai compared to the distribution observed in other test conditions. This increase in the Gorai discharge seems to have caused by the change in the upstream boundary conditions.

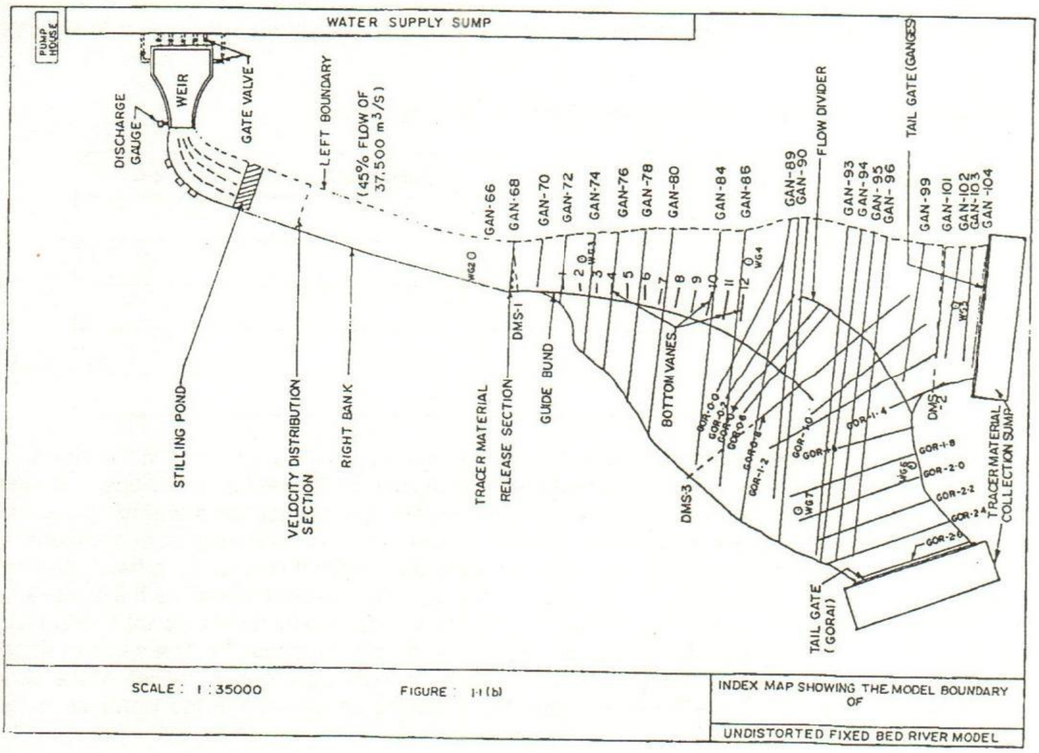

Figure-2: Layout of the model for test T4

Tracer material distribution

The loss of tracer material in this test from the system for the two trial runs is about 8.3%. From the recovered tracer the material distribution through the Gorai is determined excluding the material deposited in the vane area. The tracer material transported through the Gorai is found to be 26%. It indicates that due to change in the angle of attack no significant change in the tracer material distribution is occurred in comparison with the test T3. The tracer material that is found to be deposited in the Vane area is about 2.3% of the recovered material.

Result and discussion

Interpretation of the test results

In this model different tests have been conducted with and without intervention. The test conditions have been discussed in methodology section. During the tests different measurements have been carried out in a systematic manner so that the impact of the different interventions on flow pattern, discharge and tracer material distribution could be identified and a comparisons could be made. The following interpretation of the test results has been made based on the analysis of the recorded data of discharge distribution and tracer material distribution.

Discharge distribution

During each test the discharge has been measured at three pre-selected cross sections from which it is possible to determine the discharge through the Gorai as percentage of the total Ganges discharge. Table-2 shows the percentages of discharge through the Gorai in different tests.

Table-2: Discharge distribution into the Gorai for different tests.

Test No.	Discharge through the Gorai as percentage of Ganges flow
T0	10.56
T1	10.86
T2	10.80
T3	10.95
T4	11.70

It is clear from the information presented in the Table-2 that no significant change in the discharge distribution into the Gorai has been occurred after introduction of different interventions. It is seen in test T1 that at the upstream the Guide Bund some part of flow has attracted towards Gorai that is supposed to be discharged through the Ganges in test T0. Due to removal of bed material in test T2 and T3 by dredging (upto 0 mPWD) in the vane area more flow is seen to have attracted towards the Gorai. But the Bottom Vanes direct the bottom flow that enters to the vane area towards the Ganges. The surface flow remains unaffected. That is why no significant change was observed in case of discharge distribution during tests from test T0 to test T3. The angle of attack of the flow is changed due to change in the arrangement of the upstream condition of the vane area in test T4 and from Table-2 it is revealed that it causes an increase in the Gorai discharge compared to the other tests.

Tracer material distribution

During different tests tracer material is released from three pre-selected points of cross section

GAN-68. In test T0 and T1 a part of the tracer material is found to have deposited at upstream of flow separation zone, as well as Gorai bed and Ganges Bed. The material that has settled at the Gorai and the Ganges bed is considered to be finally transported through the respective outlet in the model. In tests T2, T3 and T4 a part of the material is deposited in the vane area in lieu of upstream separation zone. In every test a part of the material is lost. The percentage of material transported through the Gorai is determined in the following way.

Percentage of material through the Gorai = $\{G_m / (R_m - D_m)\} * 100$

Where, G_m = Material transported through the Gorai (ml)

R_m = Material recovered in total (ml) and

D_m = Material deposited upstream of flow separation zone or within Vane area (ml).

Based on the above relation the percentages of tracer material transported through the Gorai in various tests are determined and are shown in Table-3.

Table-3: Distribution of Tracer Material into the Gorai in different tests

Test No.	Material transported through the Gorai (%)
T0	70
T1	59
T2	33
T3	27
T4	26

It is seen from the above Table-3 that the Gorai conveys 70% of the released material in test T0. The introduction of the Guide Bund and the Flow Divider (T1) have reduced the tracer material transport to the Gorai by about 11%. The Bottom Vanes-1 together with Guide Bund and Flow Divider (T2) has caused remarkable changes in the tracer material distribution. And in this test the tracer material transport through the Gorai is 33% that is 37 % less in comparison with the test T0. It can be seen from the results of test T3 and test T4 no significant change occurs in the tracer material distribution into the Gorai. Therefore, it can be fairly concluded that the effect of the Bottom Vanes-2 in combination with the Guide Bund and Flow Divider is remarkable in reducing the tracer material transport through the Gorai even the angle of attack flow is changed.

It is important to note here that the percentages of tracer material transport through the Gorai found in different test conditions do not at all means that those percentages of the Ganges transport will be conveyed to the Gorai if such interventions are made. The observed distribution is found from the model test by releasing the material from three pre-selected points and the found distribution is mainly dependent on the location of the selected injection points. The test results are indicative to the fact that the proposed interventions will bring about reduction in the Gorai transport and the interventions tested in test T3 will be more effective in this regard. However, in order to provide a prediction of the actual distribution of the sediment over the Gorai and the Ganges branches some additional analyses have been carried out in the following way.

The fixed locations for injection of tracer material in cross-section GAN-68 have been chosen carefully around the locations where the discharge separation line for the Gorai and the Ganges discharge is located. It is assumed that the tracer material added to the model represents the sediment transported in the prototype over a width of 186 m. It is also assumed that the sediment transported in the 60 m width between the sediment path of 186 m width and the actual bankline will be transported into the Gorai. It is furthermore assumed that the sediment transported further that the (60+186=) 246 m will be transported totally into the Ganges branch downstream the Off-take. From the above analysis the distribution of discharge and sediment transport in the model is shown in Table-4 and Figure-3.

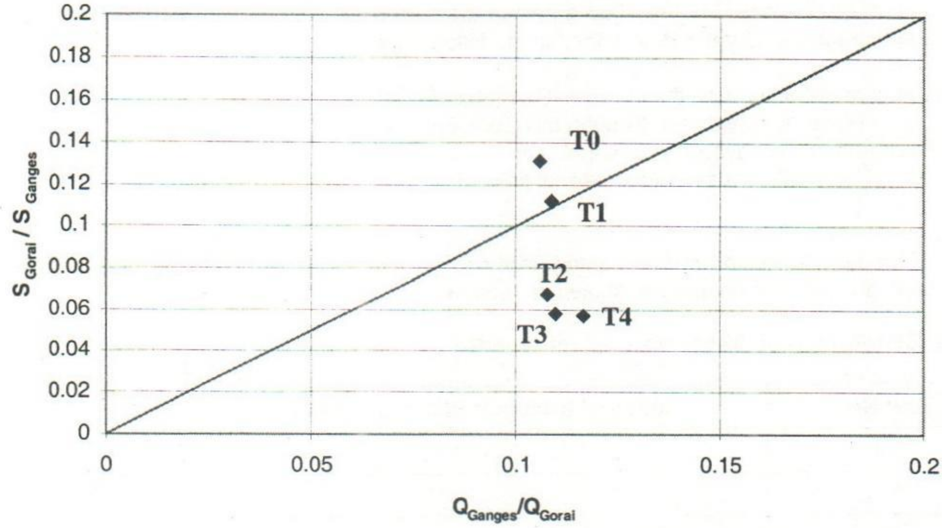

Figure-3: Discharge and sediment distribution for different Tests.

Table-4: Distribution of discharge and sediment transport in the model.

Test	Q_{Gorai} / Q_{Ganges}	S_{Gorai} / S_{Ganges}
T0	0.106	0.131
T1	0.109	0.112
T2	0.108	0.068
T3	0.110	0.058
T4	0.117	0.057

Based on the test results of the model the improvement in the sediment distribution into the Gora in response to different interventions are summarized in the Table-5.

Table-5: Improvement in the sediment distribution into the Gorai in different test conditions.

Test	S_{Gorai} / S_{Ganges}	Improvement from T0 situation
T0	0.131	-
T1	0.112	15%
T2	0.068	48%
T3	0.058	56%
T4	0.057	56%

Conclusion

In the model investigation different options of Bottom Vanes as an anti-sediment structures along with Guide Bund and Flow Divider have been tested. It is seen from the test results that the structures have impacts on the distribution of the sediment transport through the Gorai although no noticeable change occurs in the distribution of flow. The study reveals that in without structure situation 10.56% of the Ganges flow enters into the Gorai whereas for sediment distribution it is 13.1%. The introduction of Guide Bund and Flow Divider is seen to have reduced the sediment transport through the Gorai to some extent. However, marked improvement in the Gorai sediment transport is seen when Bottom Vanes have been introduced in addition to the Guide Bund and Flow Divider. It is to be mentioned here that within the frame work of the model study program only two different layout of the Bottom Vanes have been tested. The outcomes of both the tests are satisfactory but varying in degree in terms of percentage of sediment transport through the Gorai. The other important aspect of the study is to examine the influence of the angle of attack of the incoming flow on sediment distribution for a given layout of the Bottom Vanes. In this respect two likely situations have been identified from the satellite images of the river Ganges at that location. Of the two one represents the situation of 1984 and the other of 1985. In this model study the 1985 situation is simulated in consideration of space constraint and position of the modelling facilities in the model area. The outcomes of this test T4 shows an increase in the Gorai discharge (11.7% of the Ganges flows) but no significant change in the sediment transport through the Gorai. However, it is not certain that the introduction of 1984 situation or some other extreme cases would be of same consequence. From the observations of the limited number of tests in single bathymetry and based on the above mentioned facts the following inferences can be fairly drawn:

- The Bottom Vanes as anti-sediment structures would work well in combination with Guide Bund and Flow Divider for reducing the sediment transport through the Gorai without resulting any significant change in the discharge distribution.

- The distribution of sediment transport largely depends on the number of rows of the vanes, position of the vane rows and orientation of the vanes. The Gorai sediment transport could be further improved by testing some other options.
- When angle of attack of the flow is changed with existing vanes condition of test T3 the discharge through the Gorai has been increased to some extent but almost no change occurred in the sediment distribution. Some other extreme cases should be tested in this regard to have a conspicuous impression with respect to flow and sediment distribution.

- The spacing between two vane rows seems to have great impact on sediment distribution. Therefore, an optimum solution should be sought with respect to the number of rows required for obtaining desired results and the cost involvement for the construction.

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Tech. j. River Res. Inst. 8(1): 34 -44, 2001 (December)

SIMULATION OF LITHOLOGS TO STUDY THE GROUNDWATER POTENTIALITY IN KUMARKHALI UPAZILA, KUSHTIA

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Abstract

This paper investigates the feasibility of groundwater development in the northern part of Kumarkhali Upazila under Kushtia district. In this regard 28 borehole and 10 water well observatory data of this area have been analyzed and interpreted. A panel diagram has been prepared which clearly shows that the area is mainly consists of two sub-surface layers, namely a top clay layer and a sandy layer of different grain sizes. Computer aided groundwater maps have been prepared for the quantitative and qualitative assessment of the aquifer system. The Interfacing surfaces and cross-sectional views have been prepared for the necessary assessment of the variation of individual sub-surface stratum in different parts of the area. The transmissivity and specific draw down maps prepared with their estimated values, support the area almost favorable for well development. From the analysis of natural groundwater flow direction and flow rate, it is observed that the groundwater system of the area influxed from the east and outfluxed to the north, south and west sides are found unequal but positive which indicates the presence of transient flow within the system. It is also observed that the river channels of the Gorai and Padma receive water from the groundwater reserves of the area in dry of 2000. However, from the overall analysis it is found that the area is favorable for groundwater exploration. Finally, a few more groundwater potential zones have been identified for well development.

Introduction

Bangladesh endows with a massive supply of readily accessed surface and groundwater from outside the country's political boundaries providing enormous opportunities for development. This coupled with a soil that is generally fertile and has a good structure, and with a climate that permits year round cultivation provides an industry potential for a highly productive agriculture. But the availability of water presents severe constrains and problems (Rahman et al, 2000).

Despite the annual threat of flooding, agriculture in Bangladesh is dependent mainly on Deep Tube Well (DTW) irrigation during the dry eight months from mid October to mid June when rainfall is minimum. Groundwater supplies about 75% of dry season irrigation and almost all municipalities' water supplies. Groundwater, used for irrigation, is becoming increasingly important for food production since floods often damage rainfed crops. Groundwater has been the backbone of the green revolution, which has made Bangladesh virtually self-sufficient in rice production since mid 1990s (Asaduzzaman and Rushtom, 1998).

With the phenomenal increase in the use of groundwater in recent years, the need has arisen for the better understanding and functioning of groundwater reservoirs in response to natural and man made conditions. Groundwater resource, although with the phenomenal increase in the use of groundwater in recent years, the need has arisen for the better understanding and functioning of groundwater reservoirs in response to natural and man made conditions. Groundwater resource, although replenishable, is not inexhaustible. The wide and uneven distribution of groundwater thus necessitates detailed study in specific areas for the conservation of this vital resource. It is highly desirable to have a clear idea about the variation of surface elevation,

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hydraulic head position and flow direction, the thickness of the composite sand for the better understanding of aquifer system. It is needed to present the above parameters in the form of contour map and surface view with respect to a datum plane for delineating groundwater potential zones. In addition, it will be absolutely nice to have vertical sectioning by varying different parameters of interest. The development of groundwater system required the knowledge about the behavior of the system due to various stresses. The objectives of this investigation are:

(i) to study the subsurface geology as well as the hydrogeological parameters of the subsurface water system,
(ii) to determine the groundwater flow directions and flow rates in different parts of the study area,
(iii) to delineate the groundwater potential zones.

General features of the study area

The floodplains of the Ganges, the Brahmaputtra, and the Meghna cover approximately 40% of Bangladesh. The Ganges built up, by far, the largest area of the delta. The Ganges delta includes several districts of West Bengal and the districts of Kushtia, Jessore, Khulna and western part of the districts of Faridpur and Barishal (Khan, 1991).

The southwest of Bangladesh consists of three physiographic units; namely the Ganges river floodplain, the Ganges tidal floodplain, and the Gopalganj-Khulna beels, is now facing water crisis due to the water shortfall in the Ganges and its tributaries, Gorai in dry months. The study area lies in the northern side of the Ganges River flood plain. The area is intensively used for agricultural crops by the utilization of groundwater. The intensity of irrigation is 52.95 % (Aktar et al, 2000). The agricultural practices and productions inherent to the area are largely governed by the areas' hydrologic, topographic and soil characteristics. But there are natural hazards that affect agricultural production as well. These are mainly drought and flood. The flood is not so frequent. The moderate degree of draught is observed in the area studied (Das, 2000).

Geography

The study area is located in the northern part of Kumarkhali Upazila (Longitude 89°08′ E to 89°20′ E and Latitude 23°45′ N to 23°50′ N) as shown in Fig.1. The area is almost plain land. But there is a gentle slope towards the south and southwest direction from the north and northeast corner of the study area. The minimum and maximum elevation vary between 14 m and 15 respectively. The main river, Padma and its tributary, the Gorai are sustaining the environmental balance and socio-economic development of the area. The Padma is flowing by the northern side. The alluvium is composed of mostly clay, silt and fine sand, and are gray and brown in color.

Geology

The sub-surface geology and the aquifer system of the study area, in general can be described as : (i) an upper surface layer made up of primarily clay which is moderately thick, (ii) an intermediate layer made up primarily of fine sand and (iii) a deeper layer comprising mainly sand, ranging from medium to coarse in size and known as the main aquifer of high porosity and moderate to high permeability. This three units are generally in hydraulic continuity and function as semi-confined to unconfined storage (BWDB, 2000).

Socio-economics

The population density of the area studied is 2174 per square mile in 1989-91 (Aktar, 2000). The average household size of 5.6 is found to vary with land ownership. The land-poor household categories have predominant number of young members among their populations. Females tend to be mostly engage in household work. In examining the nutritional intake of the population, it is found that starchy food are available to all of the house holds on a daily basis, other food items are not common in the daily diet. Water for drinking purposes is mostly procured from tube-wells. However, water for other purposes is procured from various sources including ponds (BWDB, 2000). There are about 4362 weaving machines in this Upazila and about 13925 people are engaged with these industries (Bangladesh District Gazetteers of Kushtia, 1991).

Climatic conditions

The study area, like the rest part of Bangladesh, enjoys monsoon climate with seasonal wind reversal. Based on rainfall, temperature and pressure, a yearlong cycle can be broken down into the four seasons: winter (December to February), summer or pre-monsoon (March to May), monsoon (July to September) and autumn or post monsoon (October to November). The annual average rainfall varies between 1500 mm to 1750 mm. The average wind speed of the area is 6.3 Knots. The area has high relative humidity. The mean annual relative humidity is of 77 percent. The lowest and highest temperatures are of 6^oC and 43^oC respectively (BWDB, 2000).

Materials and methods

Lithological log is one of the major sources of valuable data for hydrogeological studies. About 28 borehole and 10 water well observatory data of the study area collected from Bangladesh Agricultural Development Corporation (BADC), Kushtia, have been processed, analyzed and interpreted with the aid of available Computer Software for quantitative hydrogeological studies to determine the groundwater potentiality. The Kumarkhali Upazila is divided into two parts, southern and northern, by the river Gorai (Fig.1). There is no borehole data in the southern-half of this Upazila due to Ganges-Kobadak (G-K) Project. An effective study area has been drawn considering the sufficient data points within the area studied. The rectangle constituted by the doted and continuous line is considered as analytical area and different maps of interpretation have been presented in this rectangular area.

Sub-surface formation distribution

The distribution of aquifers and aquitards in a geological system is controlled by lithology, stratigraphy and structure of the geologic formations. If water-bearing materials were uniformly pervious and homogeneous, groundwater problems could easily be solved by hydraulic data. The materials underground, however, heterogeneous and their hydrologic characteristics are varied. These variations control the quantity and distribution of groundwater.

Panel diagram

Borehole lithological data is an important source of information for obtaining the sub-surface formation distribution. It is customary to present borehole lithologs in a vertical section so that the formation distribution as they actually occur would be reconstructed but it is not feasible to effectively present all the vertical section in a single diagram. The sub-surface geology of the area investigated has been studied upto 91 m on the basis of lithological logs of 7 locations covering the whole effective study area (Fig.1). The stratigraphic panel diagram is shown in Fig.2. The panel diagram is extremely useful in predicting three-dimensional distribution of the sub-surface formations. This diagram represents an over all view of the sub-surface geological formations delineating the major aquifer zones.

As in the above figure, the area mainly consists of two sub-surface layers, namely a top clay layer and a sandy layer of different grain size. The sandy layer is clearly divided into two parts, one below the top clay which is fine in grain and another is consist of medium to coarse sand generally termed as 'Composite Sand'. This composite sand formation is the only usable groundwater source in the area. The overall thickness of this formation is suitable. This layer is overlying an unknown formation.

Formation thickness

The development of underground water requires knowledge of the characteristics of sub-surface formations, of which the composition and thickness are of importance. From the panel diagram it is clearly observed that the thickness of fine sand is less thicker as compared to top clay and composite sand. Quantitatively the groundwater yield is expressed in terms of formation transmissivity. This parameter does not show much difference in clay and fine sand. So the combined thickness of top clay and fine sand may be considered as non-aquifer materials. The shaded contour map of the combined thickness of top clay-fine sand has been illustrated in Fig.3(a). The regions of less thick bed of this combined formation would be economical to drill wells.

An aquifer performs two important functions, it stores water serving as reservoir and release it for extraction by pumping. So, grain size distribution plays an important role in the properties of the aquifer. In the investigated area, medium to coarse sand termed as 'Composite Sand' underlain by the top clay-fine sandy layer is the only productive aquifer. So, the assessment of the thickness of this unconfined aquifer is of great importance in groundwater exploration. The thickness of composite sandy layer of the study area has been estimated using the lithological information and presented in Fig.3(b). This figure gives a clear quantitative understanding of the presence of usable aquifer in different regions of the area studied. The existence of composite sandy formation in the area is good and varies between 29 m and 65 m.

Sub-surface configurations

The geologic structure has a marked influence on the lateral and vertical extent of aquifers. So the stratigraphy is an essential tool in the search for water in areas of wide spread sedimentary rock. The position and thickness of water bearing horizons and the continuity of confining beds are of particular importance in the development of groundwater exploration zones. In order to represent the interfaces between different sub-surface formations a datum has been considered 91.4 m below Mean Sea Level (m.s.l.) covering the maximum depth of borehole information. The interbeded views along with earth surface have been presented in a single view as in Fig.4 for the comparative study.

To observe the cross-sectional views in different parts of the effective study area, six representative vertical sectionings along the profiles of both east-west (3 profiles) and north-south (3 profiles) directions have been prepared with the indication of water head position in dry, 2000. The east-west profiles are oriented at latitudinal distances of 15 Km, 17 Km, 19 Km, whereas the north-south profiles are oriented at the longitudinal distances of 7 Km, 10 Km, 13 Km from the (0,0) origin (Fig.1). The sectional views clearly distinguish the earth surface elevation, thickness of top clayey layer, fine sand, composite sand and the position of unknown formation along the profiles. Fig.5(a-c) and Fig.5(d-f) represent the vertical divisions of sub-surface formations along the profiles oriented in the east-west and north-south directions respectively. These sectional views would definitely play an important role for selecting suitable well sites and its designing. The locations of more thick composite sand formation may be used as the better locations for well sites.

From the above figures it could be concluded that the sub-surface geology of the area studied is favorable for groundwater exploration in medium scale provided the other conditions are satisfied.

Transmissivity

The value of transmissivity (T) all over the study area has been estimated from the borehole information. In this investigation, transmissivity of water saturated formation i.e. below the water table has been taken into account only. Considering the thickness of the layers of different grain size as obtained from the borehole data and the corresponding co-efficient of permeability, the transmissivity in different layers have been calculated. Then the individual values are added to get the transmissivity (T) value of that location. The permeability of clay, fine sand, fine-medium sand, medium sand, medium-coarse sand and coarse sand of the area studied has been considered as 0.000001 m/day, 0.003 m/day, 0.00525 m/day, 0.0075 m/day, 0.03125 m/day and 0.055 m/day respectively. The value of transmissivity in the area has been estimated and presented in the form of shaded contour map with interval of 400 m^2/day as shown in Fig.6(a). It is observed from the figure that the transmissivity value lies between 180 m^2/day to 2329 m^2/day. In most part of the area this value covers 980 m^2/day to 2180 m^2/day whereas in other parts it is recorded below 980 m^2/day and above 2180 m^2/day. In conclusion it could be said that the estimated value of transmissivity of the non-artesian aquifer of the area is favourable for groundwater exploration.

Specific draw down

When water is pumped from a well or discharges from an artesian boring, a cone of depression is created which spreads to the outer limit of the aquifer. It is extremely important to bear in mind that while the cone of depression is still spreading that is to say until the limits of the aquifer reached no new water cycle equilibrium becomes established for the groundwater outside the cone of depression. All that is actually happening is that withdrawals are being made from the aquifer water reserves. The new equilibrium only occurs when the cone of depression reaches the zones of recharge and natural discharge. The productivity of a well is usually indicated by the specific capacity, which is given by the ratio of discharge to draw down, i.e., discharge per unit draw down. In well hydraulics the parameter, specific draw down inverse of specific capacity, is widely used for studying the aquifer properties. The specific draw down map of the area studied has been illustrated in Fig.6(b). The low draw down regions of the area may be considered as more favourable.

Flow net analysis

Groundwater is in constant motion from a point of recharge to a point of discharge, in accordance with laws governing flow of fluids in porous media. The volume of groundwater in motion changes with time and distance according to the principle of conservation of mass (Karanth, 1990). In general terms, this could be expressed as;

Mass inflow rate = Mass outflow rate + change of mass storage with time.

A flow net consists of two families of curves — one of equipotential lines and the other of flow lines or stream-lines intersecting at right angles to form an orthogonal pattern of small squares in isotropic aquifers. A line joining points of equal head on the potentiometric surface is an equipotential line. At right angles to the tangent of the equipotential line is the flow line, defined as a line such that the macroscopic velocity vector is everywhere tangent to it (Todd, 1980). Flow lines indicate the direction of movement of groundwater. The flow net analysis of the effective study area has been made using Software. The model area has been subdivided into 28 (7 columns and 4 rows) rectangular blocks each of 1.95 Km^2 in size. This software requires porosity, horizontal and vertical conductivity of each block and hydraulic head of the edges. The horizontal and vertical conductivity have been calculated with the formula:

horizontal conductivity, $K_{hor} = \Sigma(kd) / \Sigma d$, and
vertical conductivity, $K_{vert} = \Sigma d / \Sigma(d/k)$

where, k is the hydraulic conductivity of individual layers and d is the corresponding thickness. After simulation, the nature of groundwater flow in dry, 2000 of the study area has been depicted in Fig.7(a). The figure shows that the stream-lines are directed towards the Gorai river (south and southwest of the study area) and the Padma river (north of the study area) originating from the eastern side. It is also important to calculate the net flow rate of the study area. The estimated rate of each block of the effective study area in dry of 2000 is shown in table-1. The net flow rate in details is shown in Fig.7(b). The shaded area is the effective study area. The groundwater system of the area is influxed from the east and outfluxed to the north, south and west sides. But the flux densities are found unequal, which indicates the presence of transient flow within the system. The change in storage in the study area is found positive which is favorable phenomenon for groundwater abstraction.

From the flow direction and flow rate it could be concluded that the river Gorai (mainly) and Padma receive water from the groundwater reserves of the area in dry of 2000.

Groundwater potential zone

In areas where surface water bodies are very limited, the groundwater is the only source of water supply. The amount of water extracted depends on the storage and yield capacity of sub-surface water saturated formation, and the continuous and steady water supply is established, if the natural groundwater flow direction is directed towards the point of discharge. In previous sections, groundwater potentialities in different parts of the area investigated have been identified considering only the singular parameter. Finally, the analysis of all individual potentialities has resulted some more groundwater potential zones as marked in the Fig.8.

Table-1 : Estimation of flow rate in each of the blocks of the effective study area.

Block (Row,Column)	Flow rate from north in m^2/day	Flow rate from west in m^2/day	Flow rate from east in m^2/day	Flow rate from south in m^2/day	Net flow rate in each block In m^2/day
1,1	0.0002818	0.8840	0.1165	-0.0003085	1.0004733
1,2	-0.0025000	-0.1165	0.8830	0.0003190	0.7643190
1,3	-0.0053600	-0.8830	2.0440	0.0008610	1.1565010
1,4	0.0000028	-2.0440	2.0890	-0.0002673	0.0447355
1,5	0.0024750	-2.0890	1.1590	-0.0006050	-0.9281300
2,1	0.0003085	-1.0310	1.1150	-0.0008120	0.0834965
2,2	-0.0003190	-1.1150	1.1460	-0.0017120	0.0289690
2,3	-0.0008610	-1.1460	1.1250	-0.0019440	-0.0238050
2,4	0.0002673	-1.1250	1.0350	-0.0017140	-0.0914467
2,5	0.0006050	-1.0350	0.9090	-0.0007410	-0.1261360
3,1	0.0008120	-0.5580	1.5420	-0.0011510	0.9836610
3,2	0.0017120	-1.5420	1.4560	-0.0018700	-0.0861580
3,3	0.0019440	-1.4560	1.4430	-0.0011630	-0.0122190
3,4	0.0017140	-1.4430	1.5320	-0.0001428	0.0905712
3,5	0.0007410	-1.5320	1.7300	0.0000537	0.1987947
3,6	0.0008610	-1.7300	1.8600	-0.0003300	0.1305310
3,7	0.0009240	-1.8600	3.8700	-0.0009630	2.0099610
4,1	0.0011510	-1.8630	0.8990	-0.0006030	1.8623970
4,2	0.0018700	-0.8990	3.7100	-0.0038700	2.8090000
4,3	0.0011630	-3.7100	4.7100	-0.0007320	1.0004310
4,4	0.0001428	-4.7100	2.5720	0.0019710	-2.1358862
4,5	-0.0000537	-2.5720	0.6020	0.0017800	-1.9682737
4,6	0.0003300	-0.6020	-0.2084	0.0013870	-0.8086830
4,7	0.0009630	0.2084	-2.9860	-0.0011640	-2.7778010

Conclusion

Utilization of groundwater reservoirs for greater benefit is dependent on adequate hydrogeological data, from which the full potential of development is determined. So, to assess the sustainability of the groundwater yield it is necessary to examine carefully the nature of the aquifer system. For this purpose, borehole and water well observatory data have been processed, analyzed and interpreted for reliable estimates of the location and areal extent of aquifers and realistic estimates of the aquifer properties. The results of this work can be summarized as follows:

(i) The exploitable aquifer is unconfined in nature.
(ii) Water bearing materials, chiefly medium to coarse sand, are being used as productive aquifer. The overall thickness of this composite sandy formation is suitable.
(iii) Transmissivity and specific draw down maps indicate that the whole area is almost favorable for well development.
(iv) The transient groundwater flow has been observed within the system of the area studied. The change in the storage is positive which is a favorable phenomenon for groundwater abstraction. It is also observed that the river channels of the Gorai and Padma receive water from the groundwater reserves of the area in dry of 2000.

From the overall discussion it could be concluded that the area is hydrogeologically favorable for groundwater development. It is also remarkable that the usable aquifer is unconfined in nature. So the large-scale abstraction of groundwater should be avoided otherwise ecological imbalance would affect the environmental system. Therefore, a continuous monitoring is essential to overcome this problem.

Acknowledgment

The authors are grateful to the authority of the Bangladesh Agricultural Development Corporation (BADC), Kushtia, for their assistance during this work.

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KUMARKHALI UPAZILA

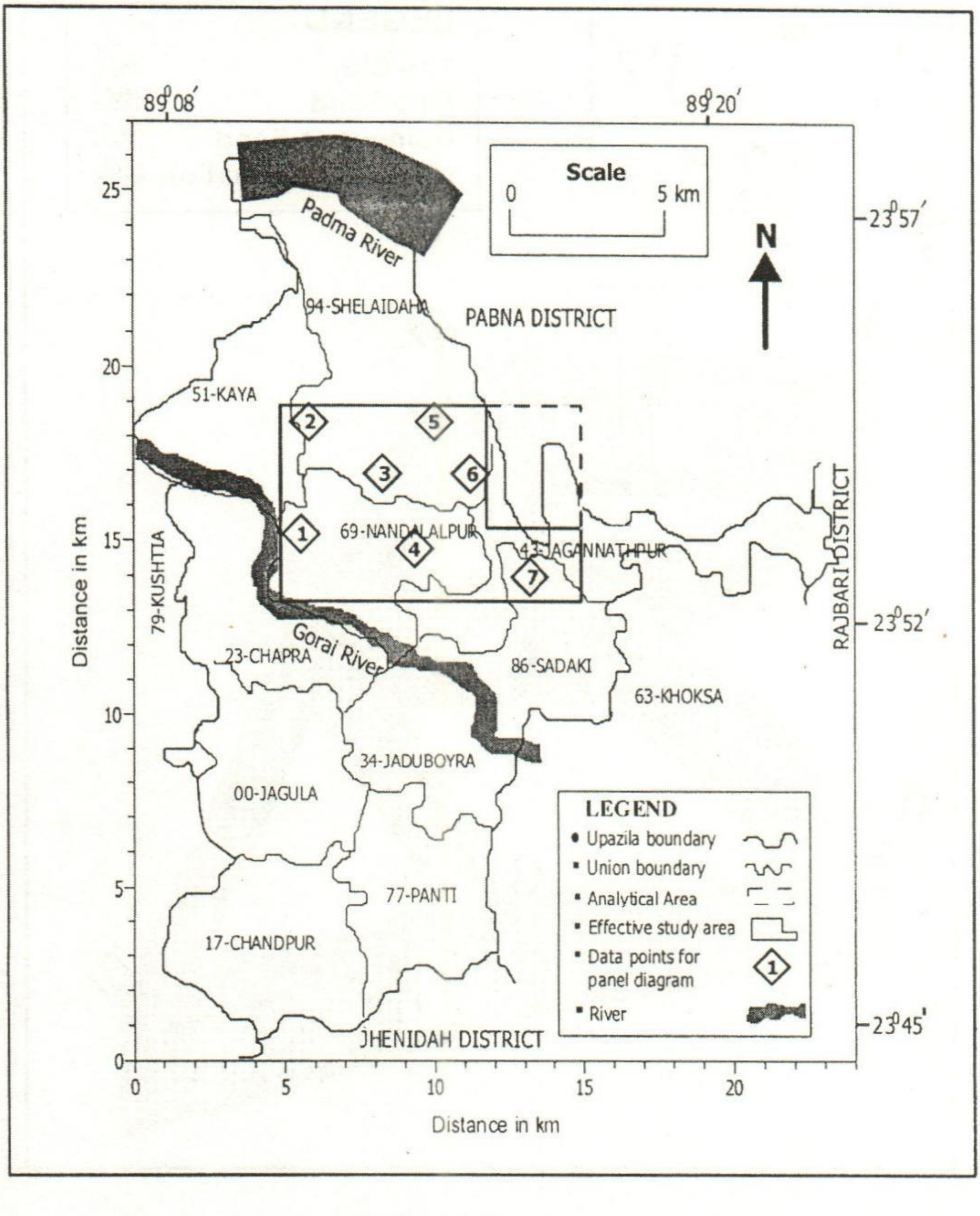

Fig.1 Location map showing effective study area.

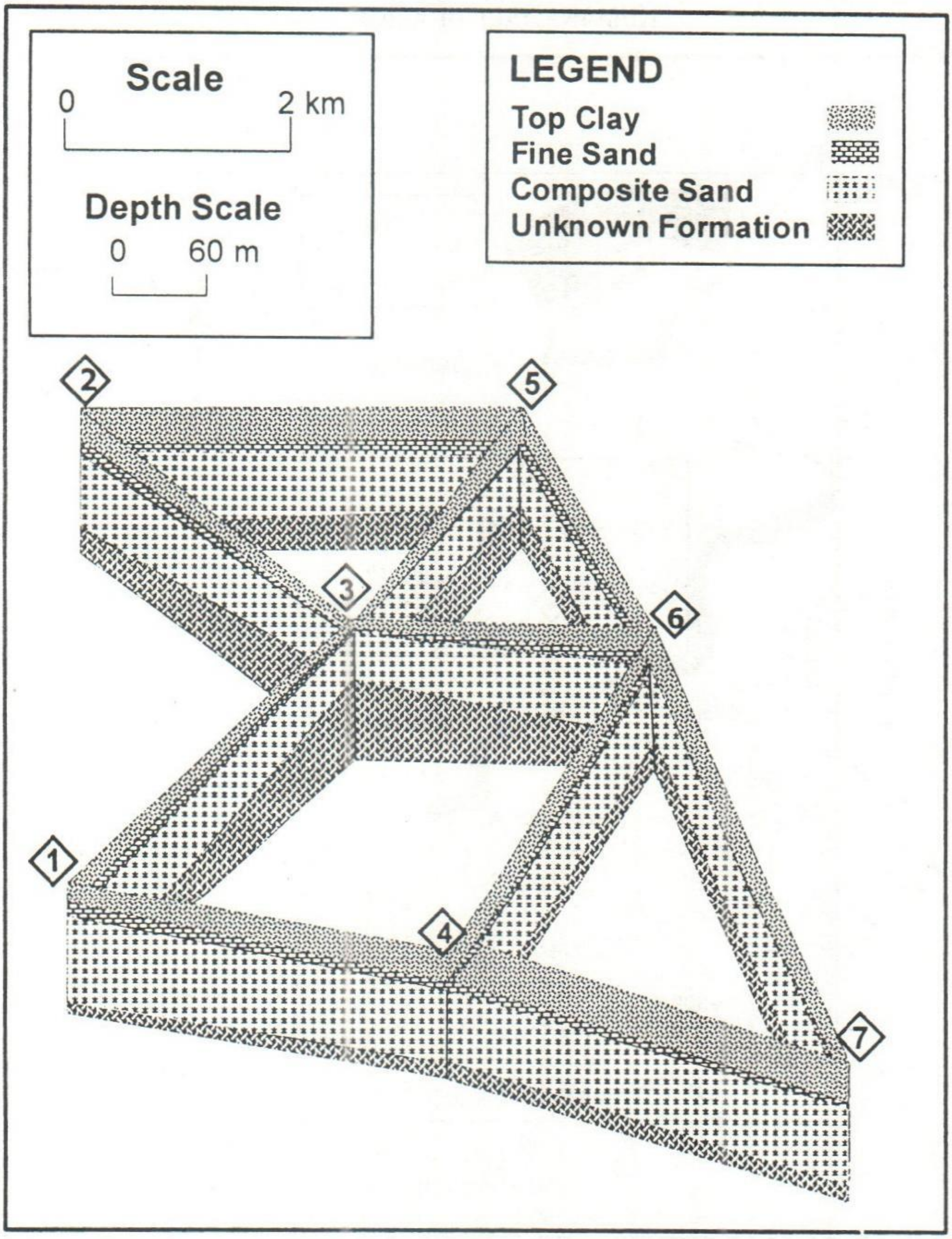

Fig.2 : Panel diagram of the effective study area.

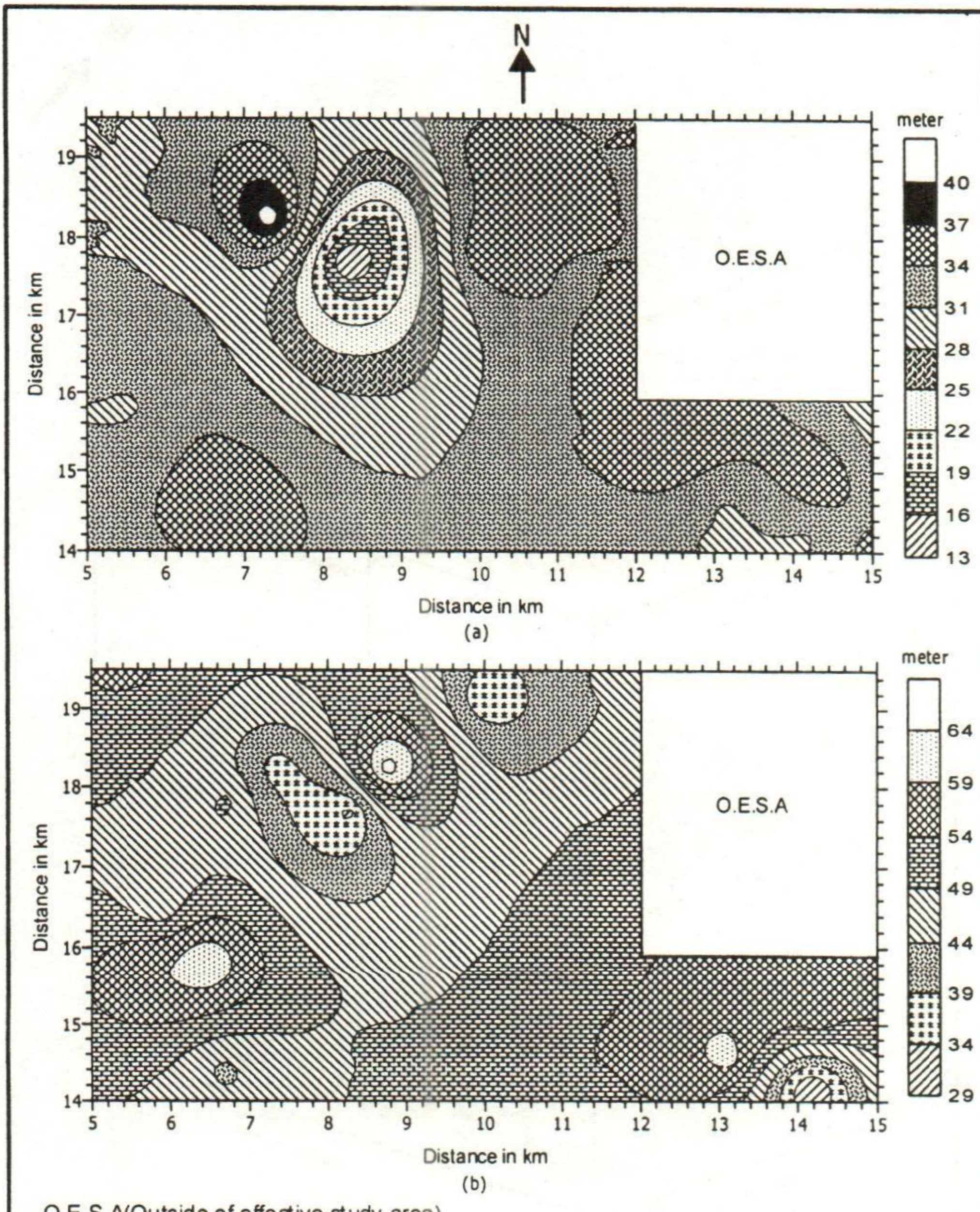

Fig.3 : Contour map with shade of the thickness of (a) Top clay-fine sand and (b) Composite sand.

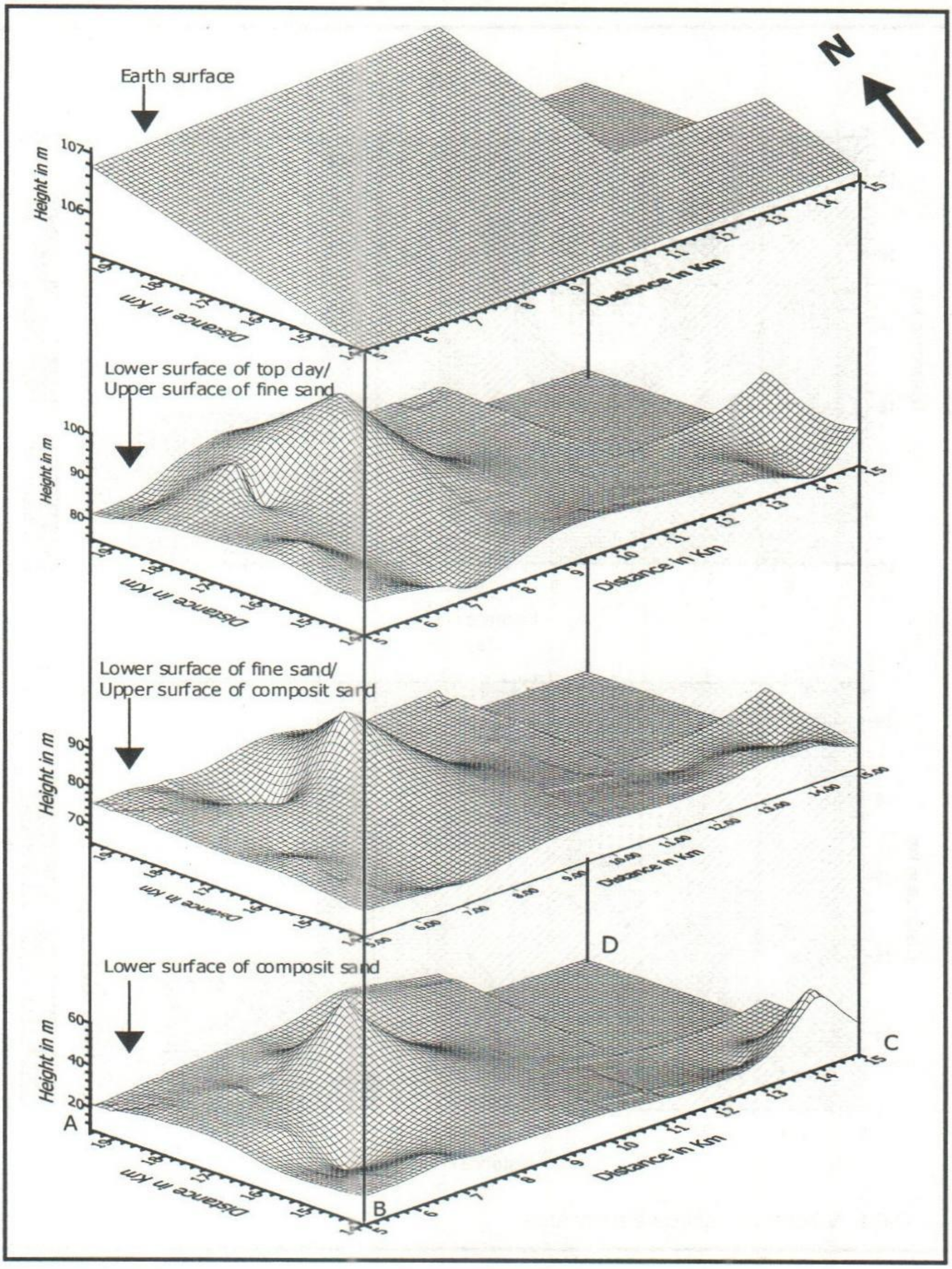

Fig.4 : Surface views of different interfaces of sub-surface formations (a view from the south-west corner).

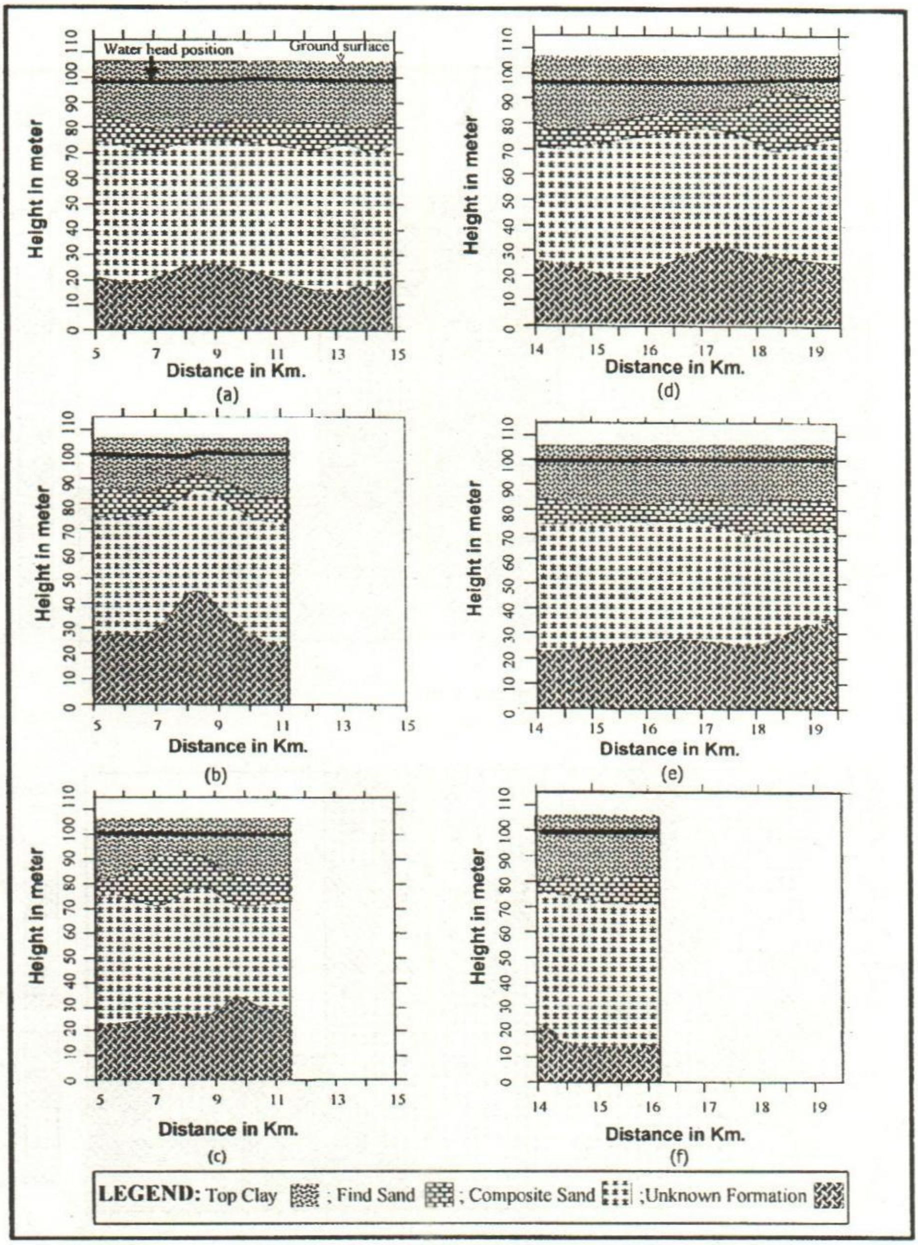

Fig.5 : Cross-sectional views at latitudinal distance of (a) 15 Km, (b) 17 Km, (c) 19 Km and at longitudinal distance of (d) 7 Km,(e) 10 Km, (f) 13 Km from the (0,0) origin.

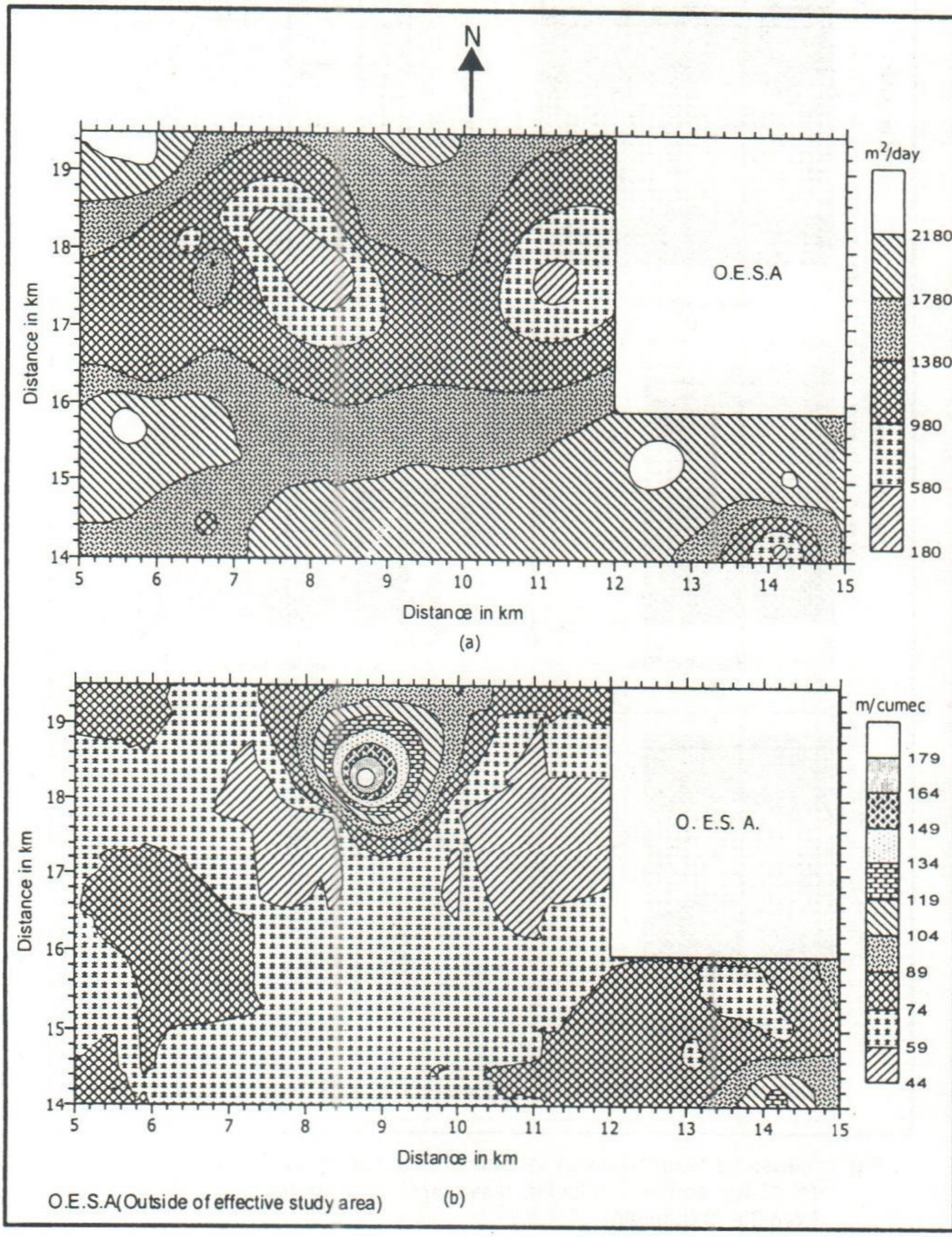

Fig.6 : Contour map with shade of (a) Transmissivity and (b) Specific Draw Down.

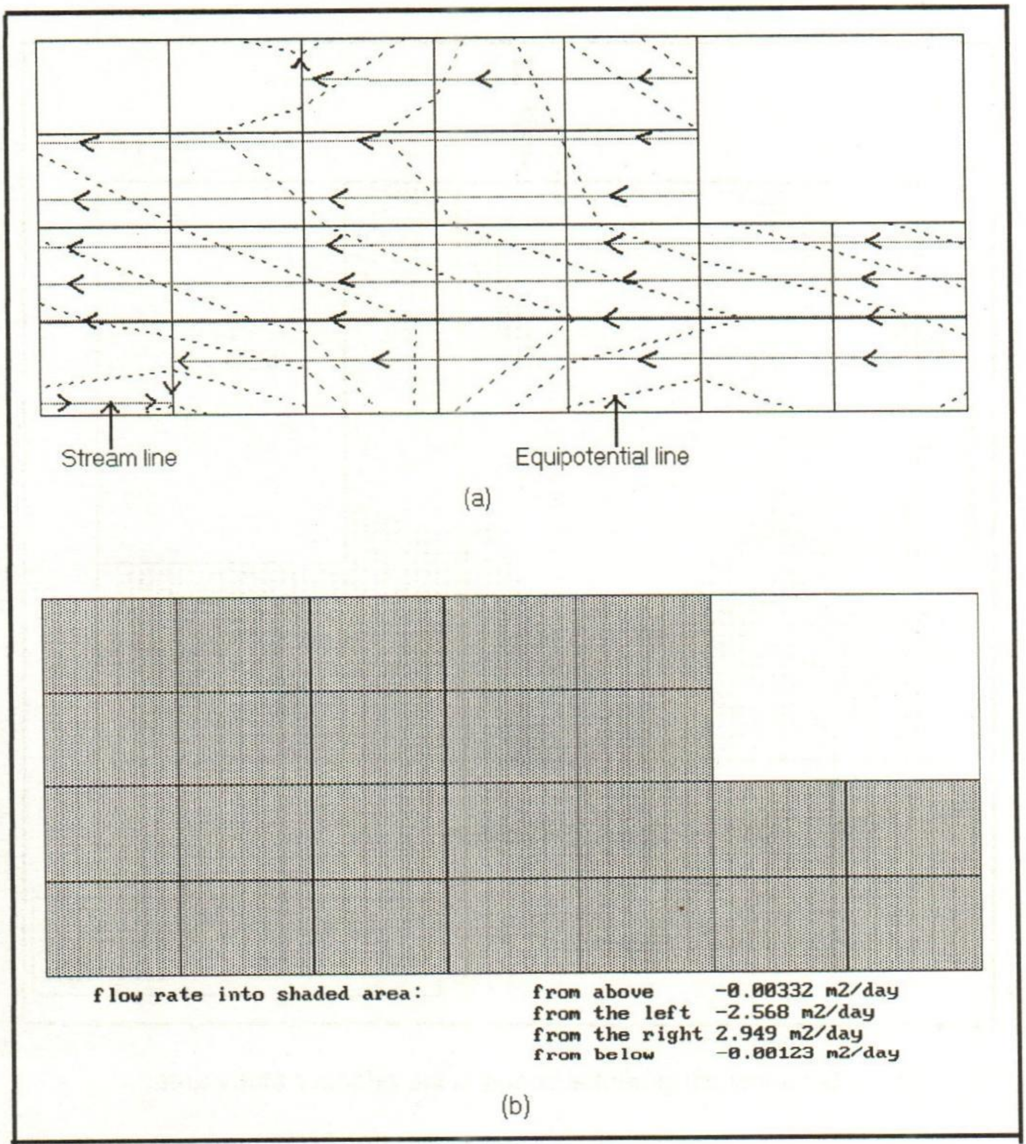

Fig.7: Groundwater (a) flow pattern and (b) flow rate of the study area in dry, 2000.

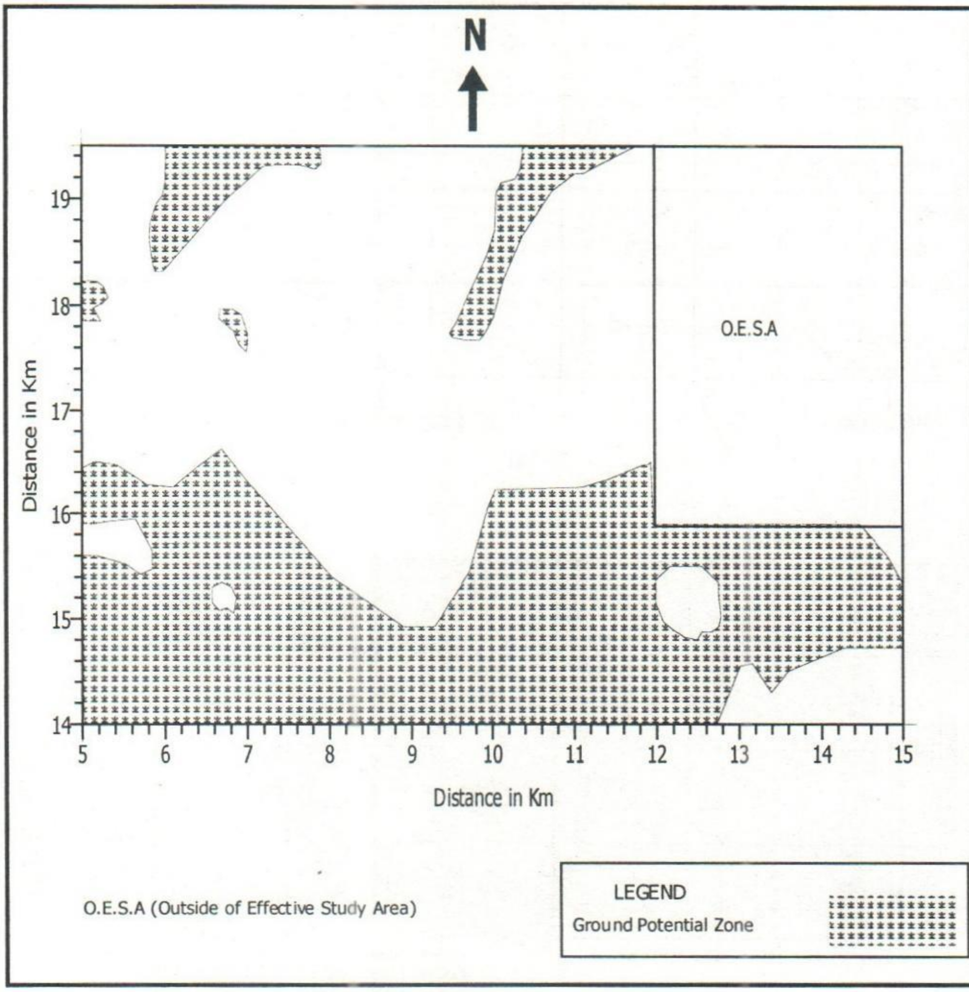

Fig.8 : Groundwater potential zones in the effective study area.

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DETERMINATION OF LOCAL SCOUR AND VELOCITY FIELD AROUND GROYNE BY PHYSICAL MODELLING: A CASE STUDY OF GORAI RIVER RESTORATION PROJECT

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Abstract

This paper illustrates the determination of local scour and velocity field around groynes. It also describes the effectiveness of the groyne in terms of local scour. Local scour is defined as the interaction between the structure and flow velocity and also the turbulance intensity at the transition between the fixed and the mobile bed. A rectangular flume bed was constructed to investigate the local scour and the flow field around the groynes. The model was designed based on Froudian condition, having an undistorted model scale of 1:100. The flume bed was filled up with fine sand whose mean diameter was about 0.08mm. Before starting the application test, the model was calibrated firstly. Development of scour around the groynes was found by analyzing soundings. This study would be very effective for taking important decision as well as designing of the groyne.

Introduction

The bathymetry and planform of the Ganges and Gorai have been studied by Main Consultant, Gorai River Restoration Project (GRRP) and identified several elements that have a positive impact on flow resulting the formation of char at the mouth of the Gorai river. One of the elements is bank erosion along the right bank of Ganges river upstream of the Gorai off-take. To combat the erosion along this reach, a series of groynes have been tested in the overall distorted morphological Ganges-Gorai model carried out by River Research Institute (RRI). The groynes were constructed along the right bank and their positions were different with the flow angle. In overall morphological model, the overall performance of the groynes was investigated qualitatively with respect to flow diversion towards the mid channel. The effectiveness of the groyne in terms of local scour can be quantitatively predicted only by constructing an undistorted local scour model. Having considered this situation, a straight flume was constructed using indoor modelling facilities of RRI with a view to investigate the local scour around the groynes. To get more confidence level about the forecast of local scour, the groynes were tested in the flume with three different angle of attack with the flow.

Model design

The investigation of local scour and flow field around the structure is the main objective of this model study. To meet these objectives, the different parameters for the scale condition are estimated and summarized in **Table 1**. In a physical model, the same local scour holes can be reproduced as in the prototype when certain scale laws and scale conditions are fulfilled. So the water depth, the velocity etc. should be scaled according to the basic scale laws and scale conditions and also the bed material in case of local scour model (Draft Final Report, Planning Study, FAP 21/22, Volume VI, January 1993).

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In case of undistorted model, the sediment transport rate can be reproduced in the model at a scale if the D_{50} is reproduced at the length scale. The sediment in the Ganges-Gorai system is fine sand. If this fine sand is scaled according to the length scale then the diameter of the sediment in the model will be equal to the silt or clay. Moreover, the sediment transport characteristics of the silt or clay is completely different from the sand. One of the solutions for this problem is to select proper lightweight materials. It has also some disadvantage and difficulties. For these reasons the scale condition for the representation of the sediment transport intensity in the model is not taken into account. For the reproduction of the scour hole precisely, the scale condition followed in this model is that the average velocity in the model should be at least twice the critical velocity for sand movement in the model. In this situation the scour hole characteristics will not be influenced by the size of the bed material or approach velocity. But, like on the prototype, it will be influenced only by the flow pattern, the geometry of the structure and cross section (Draft Final Report, Planning Study, FAP 21/22, Volume VI, January 1993).

To reproduce the flow field in the model as in the prototype, Froude's similitude is essential and for this reason model is designed based on Froude's model law.

The model was run with a discharge of 280.0 l/s corresponding to the average velocity 0.22 m/s and average water depth of 0.116 m for calibration test as well as application tests. The average velocity 2.2 m/s is selected from the output data of mathematical model studies of 1998 peak discharge and this value is chosen around the location of groyne no.5 (Because groyne no. 5 was worsely affected as observed in overall morphological model study).

Model set-up

This model was constructed in the indoor facilities of RRI. A rectangular flume having effective mobile bed dimensions 11m X 40m along with fixed bed in the upstream and downstream was constructed. Twenty cross-sections were indicated in the mobile bed portion for the convenience of different measurements in the model. The layout of the model can be seen in **Figure 1**. The model bed cross sections were uniform rectangular section and the longitudinal slope of 22.5 cm/km. The reason behind this set-up of the flume was with a view to investigate the local scour of different structure in a simplified way. The bed was filled with fine sand of D_{50}= 0.08 mm.

Required discharge in the model was measured by the sharp crested weir, which was installed at the upstream of the inflow section. Six point gauges were constructed to measure the water level in the model of which three point gauges are along the left bank and the other three along the right bank of the flume. Tailgates were constructed at the downstream of the model to maintain the required water level in the model.

Systems for filling up of the model slowly at the beginning of each test run as well as the drying up of the model bed after each test run were also constructed. The sediment feeding in the model was done manually at the upstream of the inflow section.

Test description

Test runs

Test runs includes the calibration and three application tests with the groyne considering different approach flow angle. In calibration test the model was calibrated with some boundary conditions. The application tests were carried out to determine the local scour around the intervention and also to observe the flow field due to the intervention proposed by the Main Consultant.

Test set-up and objectives

The set-up of different tests including calibration test and its objectives are described in this section. A summary of the test objectives and scenarios is shown in **Table 2.**

Calibration test

Test T0

Test T0 contributed to the calibration of the model. The objectives of the calibration test were as follows:

- Adjust the roughness elements in the inflow section to maintain a uniform velocity throughout the section
- Maintain a uniform water depth all over the model length
- Assessments of the sediment feeding rate during the model run

Application tests

Test T1

This is the first application test carried out on the existing set-up of the calibrated model plus a single groyne having length of 3.40 m (i.e., 340 m in prototype) placed at 90-degree approach flow angle.

Test T2

This is the second application test carried out with the groyne at 74-degree approach flow angle.

Test T3

This test is carried out with the groyne at 106-degree angle of attack.

Measurements carried out in the model

- Scour around the structure at an interval of 0.5m in the model
- Water level at all the point gauges at every one hour interval
- Velocity around the structure after equilibrium condition of the model
- Water depth at all cross section after equilibrium condition of the model

Interpretation of the test results

Local scour

The velocity measured in the model around the structure is shown in **Table 3, 4** and **5**. Three tests have been carried out with the groyne of length 340 m and approach flow angle with 90, 74 and 106-degree. The maximum scour (i.e., from bed level to scour level) is observed 50 m, if the model value is translated to prototype value. This maximum scour occurred during the tests with 90-degree approach flow angle. But the location of 50 m scour is not on the structure, its location is about 32 m away from the toe of the structure. The maximum scour around the toe of the groyne obtained in different tests is shown in **Table 6.**

From the observed scour depth, the value of K-factor is determined as follows:

$$K = H_s / H_0 \qquad (1)$$

Where,

K = K-factor, H_s = Scour depth (m)

H_0 = Undisturbed water depth (m)

The K value calculated in different tests are presented in **Table 7.**

Velocity

The velocity measured in the model around the structure is shown in **Table 8, 9** and **10.** The maximum point velocity measured around the structure is about 4.6 m/s in test T2. The maximum velocity around the structure is increased 1.9 to 2.1 times from the average velocity at the upstream inflow section. The recorded average and maximum velocity in different tests is shown in **Table 11.**

Conclusions

Three application tests were conducted with single groyne considering approach flow angle 90,74 and 106-degree. It is revealed from the test results that the maximum scour on the structure is 44, 41 and 40 m for 90,74 and 106-degree respectively. But 50m scour is observed during the test with 90-degree angle of attack, and its location is about 32 m away from the toe of the structure towards down stream. So it can be concluded that maximum depth of scour occurred with the condition of 90-degree angle of attack.

Recommendations

Single groyne was tested in a straight flume with three different approach angle with the flow. All tests were carried out with constant discharge and varying approach flow angle. The results obtained from this study were quantitative in nature with respect to local scour. The maximum scour and velocity value was recommended to finalize the design of the groyne. In addition the measured prototype scour value around any structural interventions in the Ganges river may be compared.

Acknowledgement

This study was carried out by the authors with the financial support of BWDB. The flume was designed at RRI and finalized by BUET and WLIDelft Hydraulics. All supports and cooperation in the study are highly acknowledged.

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Table 1 Scaling of the flume

SL. No.	Parameter	Unit	Prototype	Model	Scale
1	Width of the flume	m	1100	11	100
2	Length of the flume	m	4000	40	100
3	Discharge	m^3/s	-	0.28	-
4	Average Water depth	m	11.6	0.116	100
5	Velocity	m/s	2.2	0.22	10
6	Chezy's Roughness Co-efficient	$m^{1/2}/s$	84	28	-
7	Median Diameter (D_{50})	m	0.00016	0.00008	-
8	Acceleration (g)	m/s^2	9.81	9.81	-
9	Relative Density (Delta)	-	1.65	1.65	-
10	Kinematic. viscocity, (Neu)	m^2/s	0.000001	0.000001	-
11	Dimensionless particle Diameter (D_*)	-	-	2.024	-
12	Shields critical	-	-	0.119	-
13	Critical Velocity	m/s	-	0.111	-
14	Required Scour velocity	m/s	-	0.222	-
15	Froude number	-	0.206	0.206	1
16	Length of Groyne	m	340	3.40	100

Table 2 Summary of test scenarios

Tests	Objective	Scenarios
T0	Calibration of the model	Uniform bathymetry throughout the model
T1	To determine local scour depth in the vicinity of perpendicular groyne as well as velocity field	Equilibrium bathymetry obtained from T0 plus a groyne having length 340 m at 90-degree angle of attack with the flow
T2	To determine local scour depth in the vicinity of attracting groyne as well as velocity field	Equilibrium bathymetry obtained from T0 plus a groyne having length 340 m at 74-degree angle of attack with the flow
T3	To determine local scour depth in the vicinity of repelling groyne as well as velocity field	Equilibrium bathymetry obtained from T0 plus a groyne having length 340 m at 106-degree angle of attack with the flow

Table 3 Net scour (cm) in Test T1

Distance (cm)	-340	-325	-300	-275	-250	-225	-200	-175	-150	-125	-100	-75	-50	-25	0	25	50	75	100	125	150	175	200	225
-200																								
-175																								
-150																								
-125																								
-100																								
-75																								
-50																								
-25																								
0	Groyne Axis																				24.3	19.7		
25																						28.7	21.0	
50																						33.4	26.2	
75																							32.8	21.8
100																							42.3	29.0
125																							47.2	32.0
150																						49.0	49.5	
175																					41.5	50.0		
200																					37.8	47.7		
225																					38.5	43.2		
250																					35.5	36.0		
275																				22.5	31.0			

Table 4 Net scour (cm) in Test T2

Distance (cm)	-340	-325	-300	-275	-250	-225	-200	-175	-150	-125	-100	-75	-50	-25	0	25	50	75	100	125	150	175	200	225
-200																								
-175																								
-150																								
-125																								
-100																								
-75																								
-50																								
-25	Groyne Axis																							
0																								
25																						23.0	12.0	
50																						33.5	23.5	
75																							31.5	14.5
100																						41.0	32.0	
125																							33.0	19.0
150																					29.5	38.8	30.0	
175																					24.5	31.4	26.5	
200																						24.0	21.0	
225																						20.0	16.5	
250																						12.0	10.5	

Table 5 Net scour (cm) in test T3

Distance (m)	-340	-325	-300	-275	-250	-225	-200	-175	-150	-125	-100	-75	-50	-25	0	25	50	75	100	125	150	175	200
-200																							
-175																							
-150																							
-125																							
-100																							
-75																							
-50																							
-25																							
0	Groyne Axis																						
25																							
50																					23.5	17.0	
75																						21.3	10.0
100																					28.6	25.5	
125																					31.3	28.5	
150																					36.0	28.5	
175																					37.5	27.5	
200																				40.0	37.3	24.0	
225																				39.0	32.0	19.5	
250																			32.7	34.0	26.0		
275																			28.5	22.3	18.0		

Table 6 Maximum scour in different tests

Tests	Maximum scour, m	Maximum scour on the structure, m
T1	50	42
T2	41	41
T3	40	40

Table 7 K-factor in different tests

Tests	Undisturbed water depth (H_0), m	Scour depth(H_s), m	K-factor
T1	11.00	50.00	4.55
T2	10.93	41.00	3.75
T3	10.96	40.00	3.65

Table 8 Velocity (m/s) in test T1

Distance (m)	-3.5	-3.0	-2.5	-2.0	-1.5	-1.0	-0.5	0.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0
-2.0																
-1.8																
-1.5																
-1.3																
-1.0																
-0.8																
-0.5								0.36	0.39	0.38	0.28	0.34	0.26	0.23	0.28	0.28
-0.3								0.42	0.42	0.40	0.31	0.30	0.26	0.26	0.28	0.29
0	Groyne Axis								0.00	0.44	0.39	0.25	0.25	0.26	0.23	0.26
0.3								0.00	0.00	0.28	0.33	0.33	0.28	0.26	0.26	0.24
0.5								0.00	0.00	0.00	0.41	0.32	0.27	0.31	0.27	0.24
0.8								0.00	0.00	0.00	0.32	0.33	0.29	0.27	0.28	0.28
1.0								0.08	0.19	0.16	0.23	0.37	0.24	0.25	0.25	0.22
1.3								0.00	0.13	0.13	0.19	0.37	0.27	0.26	0.25	0.23
1.5								0.00	0.21	0.14	0.15	0.35	0.19	0.25	0.26	0.27
1.8								0.00	0.00	0.13	0.11	0.39	0.26	0.24	0.32	0.29
2.0								0.00	0.00	0.00	0.17	0.34	0.24	0.24	0.28	0.25
2.3								0.00	0.00	0.00	0.21	0.27	0.28	0.26	0.25	0.29
2.5								0.00	0.00	0.00	0.28	0.30	0.28	0.26	0.27	0.27
2.8								0.00	0.00	0.18	0.33	0.33	0.28	0.26	0.28	0.26
3.0								0.00	0.00	0.17	0.28	0.34	0.28	0.28	0.30	0.26
3.3								0.17	0.23	0.24	0.32	0.36	0.33	0.24	0.26	0.26
3.5								0.19	0.19	0.28	0.32	0.36	0.31	0.24	0.26	0.27
3.8								0.23	0.28	0.32	0.33	0.34	0.35	0.28	0.31	0.27
4.0								0.18	0.27	0.33	0.34	0.31	0.28	0.27	0.31	0.27

Table 9 Velocity (m/s) in test T2

Distance(m)	-3.50	-3.00	-2.50	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00
-2.00																
-1.75																
-1.50								0.16	0.24	0.27	0.26	0.27	0.32	0.30	0.28	0.30
-1.25								0.21	0.28	0.27	0.26	0.29	0.30	0.29	0.31	0.28
-1.00								0.22	0.23	0.25	0.26	0.28	0.26	0.27	0.30	0.29
-0.75								0.30	0.29	0.28	0.28	0.28	0.23	0.25	0.29	0.26
-0.50								0.46	0.43	0.32	0.28	0.29	0.29	0.27	0.26	0.25
-0.25								0.00	0.43	0.40	0.28	0.30	0.28	0.25	0.26	0.27
0.00	Grovne Axis								-0.09	0.42	0.29	0.30	0.26	0.28	0.27	0.28
0.25								0.00	0.00	0.12	0.30	0.26	0.28	0.27	0.26	0.27
0.50								0.00	-0.11	-0.08	0.31	0.27		0.26	0.29	0.27
0.75								0.00	-0.15	-0.13	0.28	0.29	0.27	0.28	0.25	0.27
1.00								0.09	0.12	-0.13	0.18	0.29	0.28	0.26	0.30	0.24
1.25								0.13	0.23	-0.11	0.13	0.32	0.27	0.23	0.26	0.27
1.50								0.11	0.24	-0.14	-0.07	0.30	0.25	0.23	0.25	0.26
1.75								0.09	0.18	-0.16	0.11	0.29	0.28	0.26	0.27	0.25
2.00								0.08	0.17	0.15	0.22	0.28	0.29	0.27	0.24	0.24
2.25								0.18	0.20	0.16	0.28	0.29	0.29	0.26	0.25	0.24
2.50								0.11	0.13	0.11	0.24	0.29	0.29	0.27	0.27	0.27
2.75								0.09	0.19	0.19	0.25	0.30	0.28	0.26	0.23	0.28
3.00								0.13	0.17	0.19	0.25	0.29	0.27	0.29	0.26	0.29
3.25								0.11	0.19	0.21	0.23	0.30	0.28	0.26	0.25	0.29
3.50								0.15	0.14	0.21	0.27	0.31	0.29	0.25	0.23	0.25
3.75								0.16	0.14	0.18	0.27	0.28	0.27	0.29	0.26	0.23
4.00								0.13	0.14	0.23	0.27	0.26	0.32	0.26	0.29	0.23

Table 10 Velocity (m/s) in test T3

Distance (m) (m) (m)	-3.50	-3.00	-2.50	-2.00	-1.50	-1.00	-0.50	0.00	0.50	1.00	1.50	2.00	2.50	3.00	3.50	4.00
-2.00																
-1.75																
-1.50								0.24	0.23	0.26	0.28	0.28	0.29	0.25	0.27	0.24
-1.25								0.24	0.24	0.24	0.28	0.31	0.31	0.24	0.26	0.26
-1.00								0.22	0.24	0.23	0.27	0.31	0.35	0.28	0.28	0.26
-0.75								0.24	0.25	0.28	0.29	0.29	0.32	0.27	0.27	0.26
-0.50								0.31	0.33	0.28	0.28	0.29	0.31	0.25	0.27	0.26
-0.25								0.29	0.41	0.34	0.26	0.27	0.29	0.25	0.27	0.27
0.00	Grovne Axis								0.00	0.37	0.28	0.32	0.29	0.31	0.26	0.27
0.25								0.00	0.00	0.32	0.30	0.30	0.31	0.27	0.26	0.25
0.50								0.00	-0.07	0.24	0.32	0.31	0.31	0.27	0.26	0.24
0.75								0.00	-0.08	0.27	0.28	0.26	0.31	0.26	0.27	0.27
1.00								0.00	-0.11	-0.09	0.34	0.27	0.29	0.26	0.27	0.26
1.25								-0.08	-0.12	0.08	0.35	0.28	0.33	0.26	0.27	0.27
1.50								-0.13	-0.27	0.10	0.42	0.29	0.28	0.27	0.27	0.28
1.75								-0.08	-0.12	-0.10	0.33	0.30	0.28	0.26	0.28	0.25
2.00								-0.09	-0.13	0.11	0.34	0.27	0.27	0.27	0.31	0.26
2.25								-0.17	-0.10	0.20	0.31	0.31	0.26	0.27	0.29	0.25
2.50								0.12	0.11	0.25	0.28	0.29	0.29	0.27	0.29	0.28
2.75								0.15	0.19	0.31	0.28	0.28	0.27	0.26	0.27	0.26
3.00								0.20	0.24	0.28	0.26	0.29	0.28	0.30	0.29	0.24
3.25								0.21	0.25	0.28	0.26	0.26	0.25	0.28	0.27	0.28
3.50								0.26	0.27	0.31	0.27	0.32	0.25	0.29	0.30	0.27
3.75								0.22	0.24	0.28	0.29	0.26	0.23	0.29	0.28	0.30
4.00								0.22	0.24	0.29	0.32	0.30	0.31	0.32	0.26	0.30

Table 11 Average and maximum velocity in different tests

Tests	Average velocity, m/s	Maximum velocity, m/s
T1	2.2 m/s	4.4
T2	2.2 m/s	4.6
T3	2.2 m/s	4.2

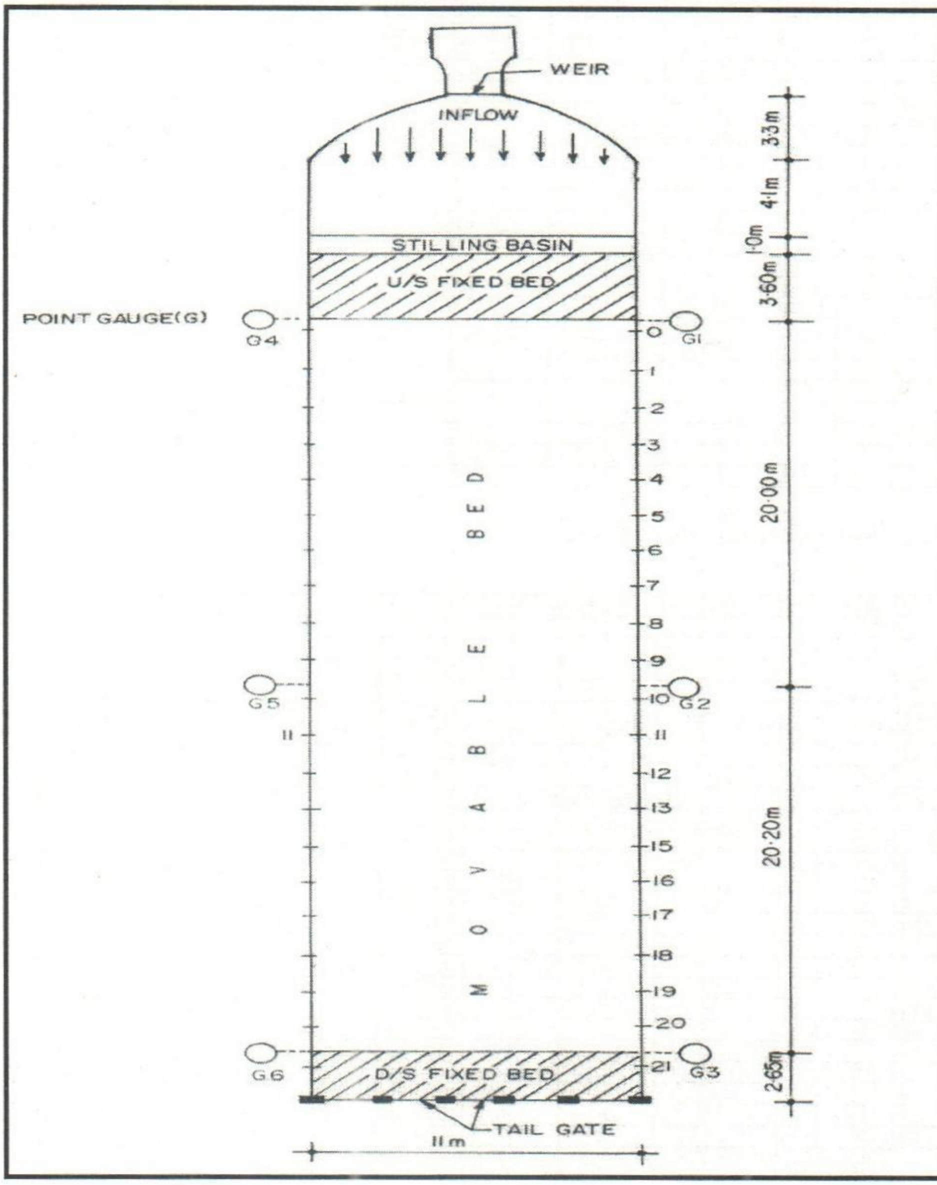

Figure 1 Layout of the model

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A STUDY FOR THE PROTECTION OF FARIDPUR TOWN AND ITS ADJACENT AREAS FROM THE EROSION OF PADMA RIVER

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Md Kayser Habib [3], Gius Uddin Ahmed [3] and Md. Rafiqul Alam [1]

Abstract

A study was undertaken by the River Research Institute (RRI) to protect the Faridpur Town and its adjacent areas from the erosion of Padma river. The study area starts from Decreer Char Union under Faridpur Sadar Upazila to Zajirtek Union under Char Bhadrason Upazila in the District of Faridpur covering around 10 km long reach along the right bank of Padma river. Many permanent important installations such as High School, Primary School, Hat, Bazar, Post Office, Food Godown, Family Planning Centre, Ghat, Homesteads and Agricultural lands are affected due to the devastating bank erosion of Padma river. Every year the right bank of Padma river is shifting toward the right side at these areas. To save these areas and its agrarian economy from the devastating bank erosion of the Padma, this paper suggests retired embankment parallel to the existing banklines and also a series of spurs extending from the embankment upto this bankline. As an alternative to spur, river bank can also be protected by providing revetment.

Introduction

The location of the study area can be seen in **Figure 1.** Faridpur Town and its adjacent areas such as Decreer Char Union under Faridpur Sadar Upazila and Gazirtek Union under Char Bhadrason Upazila in the District of Faridpur are located on the right bank of Padma river. The present right bankline of Padma river recently surveyed in February, 2001 at the study area with existing embankment is shown in **Figure 2**. The overall objectives of the present research project was to find out a viable solution from technical standpoint to protect Faridpur Town and its adjacent areas from the erosion of Padma river by constructing protective structures. However, in short, the objectives were: (i) to conduct a detailed literature review in the field of river bank erosion, river bank shifting and river bank protection. (ii) to determine the geometric as well as bank shifting characteristics of the river at the study area and (iii) to suggest possible bank protective structures to combat river bank erosion.

The Padma river

The combined flows of Jamuna and Ganges rivers constitute the flow of the present Padma river. Before the avulsion of Jamuna river, the flow was a continuation of Ganges river only, and Rennel's map shows that the river passed further south than the resent course. The annual mean discharge is 28,000 m^3/s, and the bankfull discharge is about 75,000 m^3/s. The average size of the bed material is about 0.10 mm.

Geo-morphologically, the river is still young. A flow regime analysis by the FAP4 study shows that it is now in a dynamic equilibrium. A reach of about 90 km is almost straight and the planform of the river is a combination of the meandering and braiding type, indicating a wandering river.

The variation of the total width of the river is quite high, ranging from 3.5 km to 15 km. The slope

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and the bed material sizes of the rivers vary within a range of 8.5 to 5 cm per km, and 0.20 to 0.10 mm, respectively. Bankfull discharges are within the range of 43,000 m^3/s to 75,000 m^3/s. With respect to planform, the Jamuna is distinctly a braided river, while the Ganges and Padma rivers fall in between braided and meandering rivers, i.e. wandering rivers. The bank erosion rates of the rivers are almost the same.

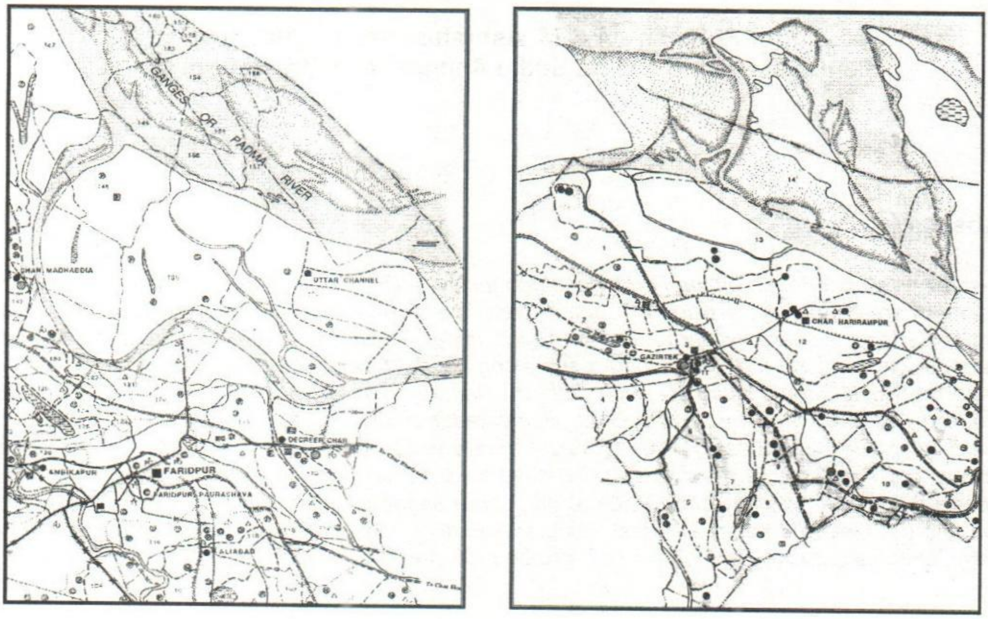

Figure 1 Location of problem area under Faridpur district

Methodology

Eight standard BWDB cross-sections (from downstream to upstream) were selected in the present study under the study region. These were CS P3, P3.1, P4, P4.1, P5, P5.1, P6 and P6.1. The spacing between successive cross-sections was 6.436 km. The cross-sectional map was produced for each of the cross-sections for 1992 and 2000.

Area-elevation relationships were developed for selected BWDB cross-sections to determine the variation of cross-sectional area with elevation for the years 1992 and 2000.

The thalweg level was determined as the deepest point from the cross-sectional map for each of the selected cross-sections for the years 1992 and 2000 to observe the variation of thalweg level along the river reach.

The MBL at selected cross-sections was determined by subtracting average depth from average bank level of each cross-section and plotted for the years 1992 and 2000 to observe the variation of MBL at these cross-sections. Change in MBL was also determined at selected cross-sections during 1992 to 2000. Assuming linear variation of change in MBL, the amount of sediment deposited throughout the study reach was calculated for a period of eight years.

The Baruria Transit Station is the nearest station to the study area. The stage-discharge relationship was developed at that station using water level and discharge data for the years 1966

-1994 and the trend was also determined.

The satellite imageries for the years 1973 and 1999 were traced and superimposed. These were then utilized to observe the lateral bankline movement i.e. to determine the bank erosion and deposition with respect to 1973. The bankline shifting at the study area (Decreer Char Union under Faridpur Sadar Upazila, Zajirtek Union under Char Bhadrason Upazila) was determined from 1999 to 2001 from the index map provided by BWDB. It was done in order to determine the trend and amount of bankline movement.

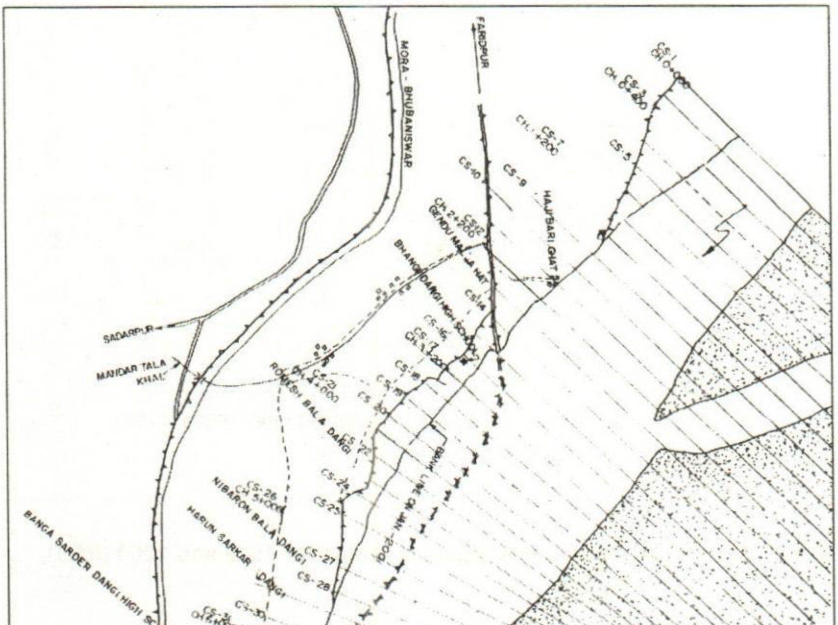

Figure 2 Present right bankline of Padma river with existing embankment

Results and discussion

Variation of cross-sectional area

Each of the cross-sectional map was superimposed for the years 1992 and 2000 which clearly shows the shifting of thalweg, change of top width as well as the location of the deepest point. A typical plot is shown in **Figure 3** (P5.1).

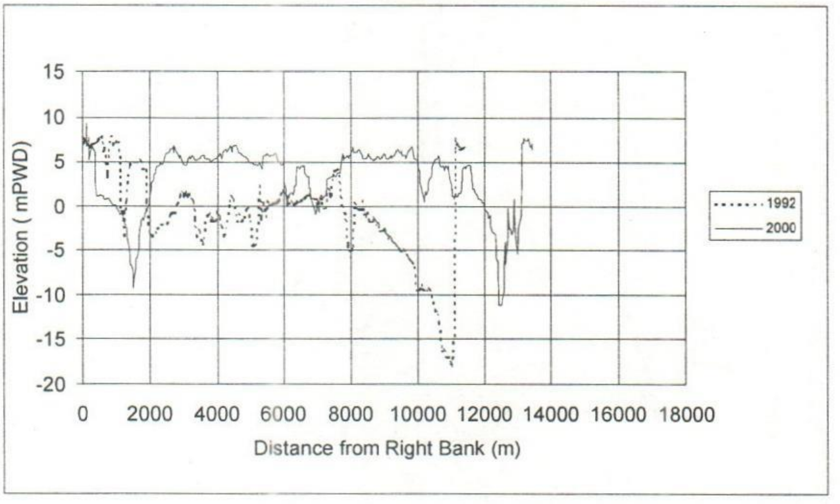

Figure 3 Superimposed cross-sectional maps for 1992 and 2000 (P5.1)

The variation of cross-sectional area, average depth, top width against the selected standard BWDB cross-section is also shown in graphical form in **Figure 4, 5** and **6.** The cross-sectional area at cross-sections P3, P4 and P5.1 had a decreasing trend while there had an increasing trend at cross-sections P3.1, P4.1, P5, P6 and P6.1 during the period from 1992 to 2000. This indicates aggradation and degradation of these cross-sections respectively. The cross-sectional area at cross-section P5.1 in 1992 was reduced to 0.7 times the corresponding cross-sectional area in 2000. The cross-sectional area at cross-section P6.1 in 1992 was increased to 1.34 times the corresponding cross-sectional area in 2000. The cross-sectional areas calculated were 660387.0 m^2 and 676235.0 m^2 in 1992 and 2000 respectively and the increase in cross-sectional area was about 2.4%. The average depth in 2000 is less than 1992 while the average width increases.

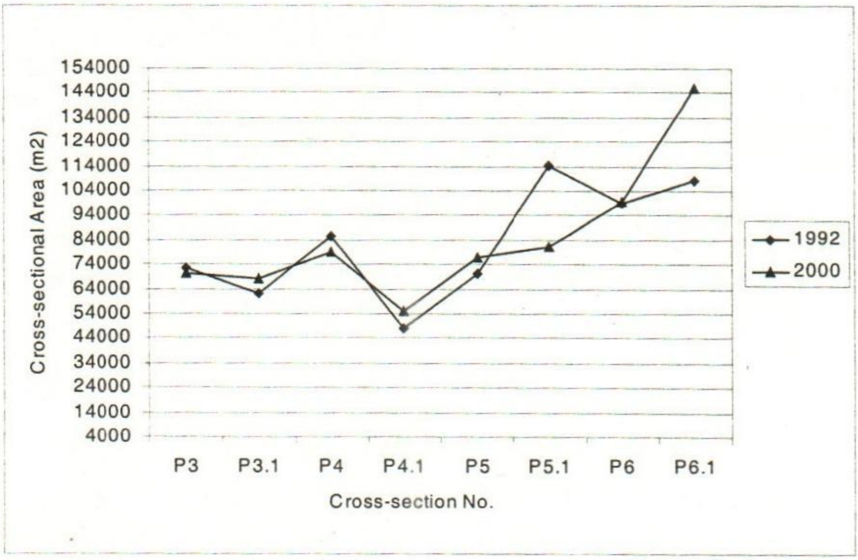

Figure 4 The variation of cross-sectional area

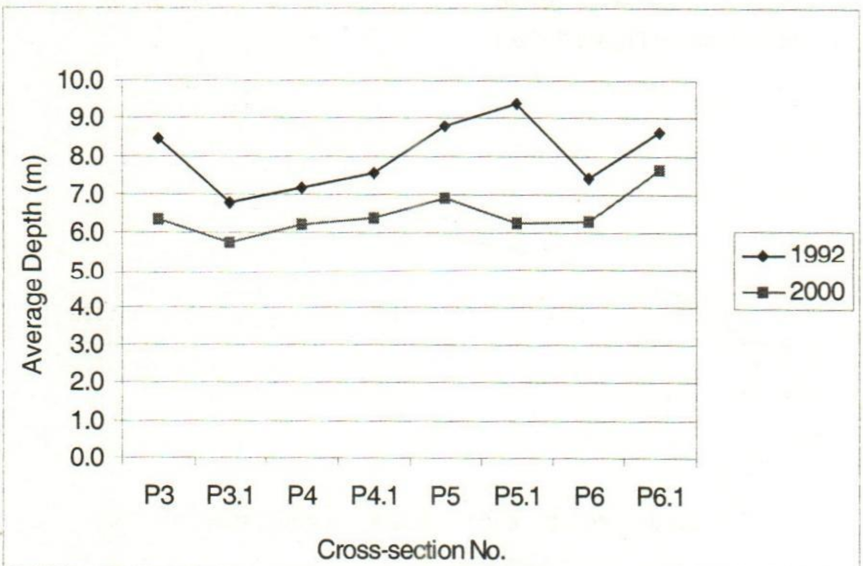

Figure 5 The variation of average depth

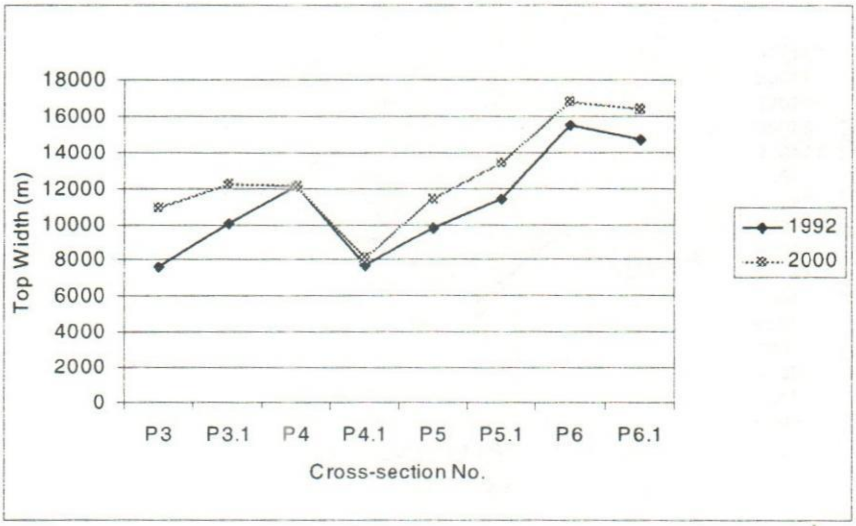

Figure 6 The variation of top width

Area-elevation relationship

Area-elevation relationships showing the variation of cross-sectional area with elevation (with respect to PWD datum) were developed for various standard cross-sections for 1992 and 2000 and a typical plot is shown in **Figure 7** (P5.1).

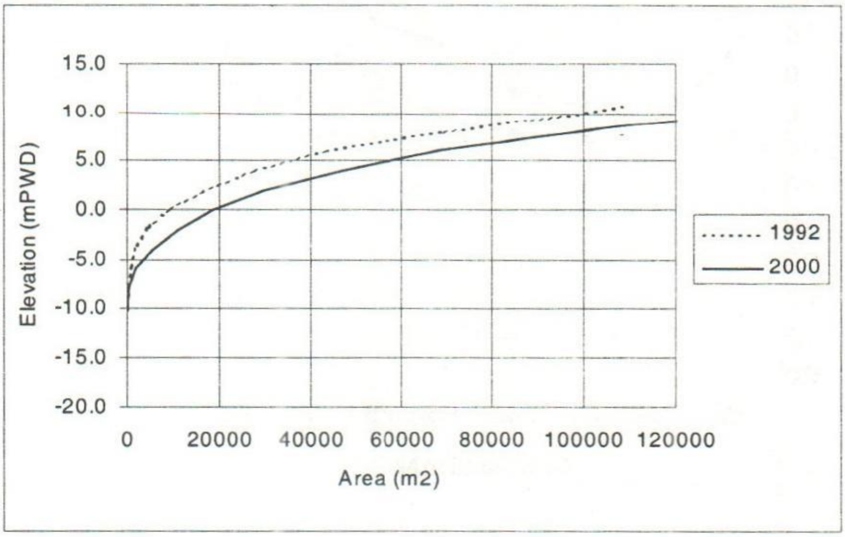

Figure 7 Area-elevation relationship

Such type of analysis was done with a view to observing the effect of aggradation or degradation on cross-section. At sections P3, P3.1, P4 and P5.1 it was observed that at the same elevation, less area was obtained in 2000 in comparison to 1992. This may lead to the aggradation. On the other hand, at sections P4.1, P5 and P6.1 it was observed that at the same elevation, more area was obtained in 2000 compared to 1992. This may be the result of degradation. At section P6, no considerable change was observed.

Variation of thalweg level

Table 1 shows the position of thalweg measured from left or right bank of river for the selected cross-sections over a period of eight years. The variation of deepest point for the selected standard BWDB cross-sections is also shown in graphical form in **Figure 8.** The thalweg of cross-section P3, P4.1 and P6.1 shifted to the right and P3.1, P4, P5, P5.1 and P6 shifted to the left. The average thalweg level in 2000 was 1 m above relative to 1992. An exceptional deepest point was found in P5.1, which was 18 m below the PWD datum. The MBL in 2000 was higher relative to 1992 indicating channel bed had rising tendency. The maximum bed level rises at cross-section P5.1 that was about 3.4 m.

Table 1 Position of thalweg measured from left or right bank for the standard BWDB selected cross-sections

BWDB	1992	2000	Measured from	Shift	Shifting Direction
CS	m	m		m	
P3	720	3030	LB	-2310	right
P3.1	9134	2590	LB	6544	left
P4	3850	11055	RB	-7205	left
P4.1	6725	4494	RB	2230	right
P5	9293	5053	LB	4240	left
P5.1	11024	12531	RB	-1506	left
P6	4390	15685	RB	-11295	left
P6.1	6294	3540	RB	2754	right

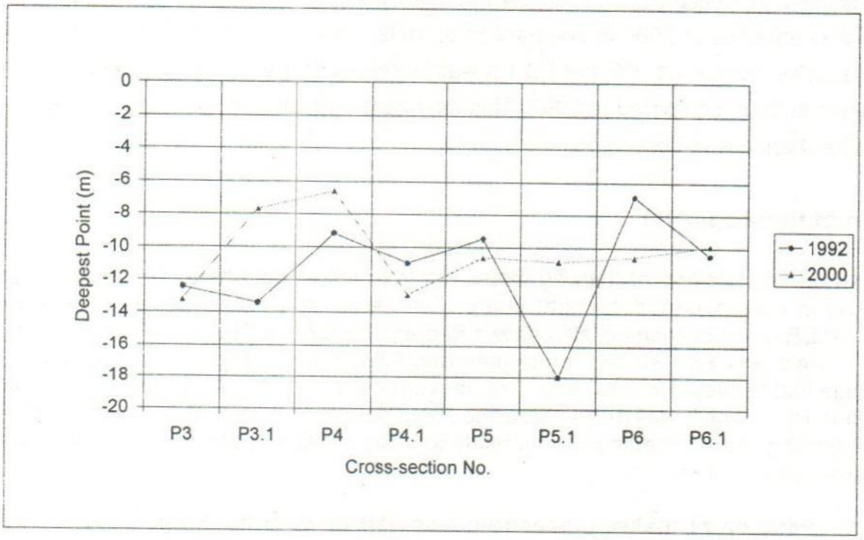

Figure 8 The variation of deepest point

Variation of mean bed level (MBL)

The variation of MBL for the selected standard BWDB cross-sections is also shown in graphical form in Figure 9. It was observed that at all the selected BWDB standard cross-sections considered in the present study reach, the MBL rises in 2000 relative to 1992 situation.

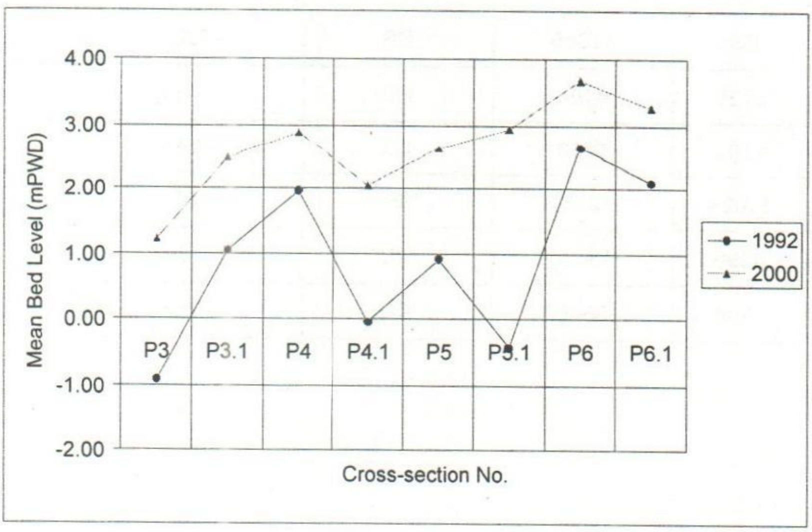

Figure 9 the variation of MBL

Calculation of sediment deposition from the change in variation of MBL

The variation of change in MBL was also shown in **Figure 10.** From this figure it was revealed that sediment was deposited at all cross-sections within the study reach. Assuming linear variation of change in MBL, the calculated net sediment deposition was found as $9.4\times10^{8}\,m^{3}$ during 1992 to 2000. It corresponds to about 22.0 cm sediment deposition each year throughout the study reach (P3 to P6.1) of Padma river during the period from 1992 to 2000.

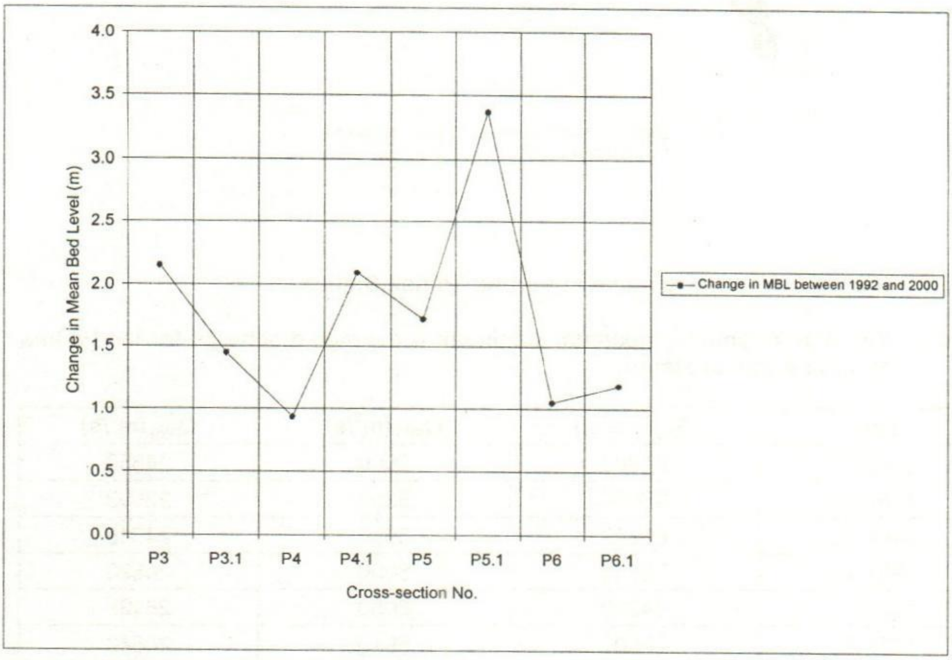

Figure 10 The variation of change in MBL

Variation of water level and discharge data

A rating curve or stage-discharge relationship was also developed at Baruria Transit Station for the years 1966-1994, which is shown in **Figure 11.** Using the above figure, it is also possible to determine roughly the water level with known discharge and vice versa for the problem area.

The variation of annual maximum, minimum & average discharge for the Padma river at the same station shows in **Table 2**. From this table it can be seen that the annual average discharge had an increasing trend. As a result, cross-sectional area had increased and fall of water level had occurred at Baruria Transit Station.

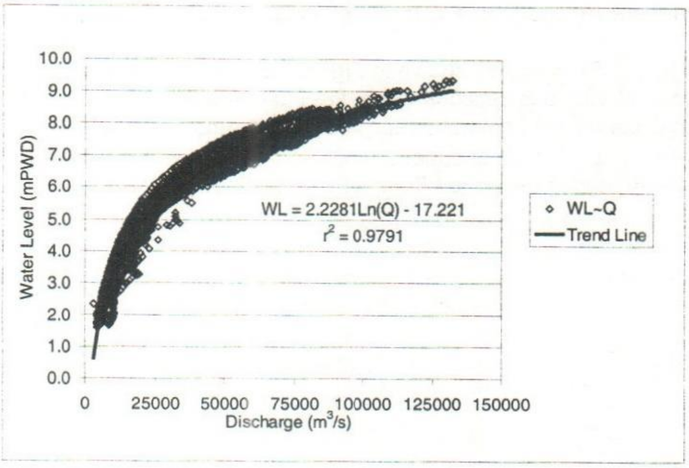

Figure 11 The rating curve at Baruria Transit Station

Table 2 Variation of annual maximum, minimum & average discharge for the Padma river at baruria transit station

Year	Q_{max} (m^3/s)	Q_{min} (m^3/s)	Q_{avg} (m^3/s)
1966-67	81300	5600	24352
1967-68	63600	5350	22593
1968-69	80200	5090	24546
1969-70	72700	6000	24820
1970-71	84200	6080	28135
1972-73	76600	5910	24643
1974-75	113000	5660	33501
1980-81	109000	4490	31261
1981-82	88200	4250	26085
1982-83	89600	4760	27366
1983-84	101000	4440	29335
1984-85	107000	5010	31611
1985-86	90200	5430	31470
1986-87	81100	3040	27645
1987-88	113000	5120	30530
1988-89	132000	5200	33583
1989-90	79800	5300	29505
1990-91	83700	4570	31766
1991-92	100000	4610	31779
1992-93	72500	4750	23759
1993-94	84700	4120	31683

Bankline shifting from Satellite imagery supplied by EGIS

The bankline of Padma river from satellite image was plotted and superimposed on the same map for the years 1973 and 1999 as shown in **Figure 12**. From the superimposed plan maps it was seen that the river bankline at 1999 along the study reach became wider relative to bankline at 1973. **Table 3** shows lateral bankline shifting along grid lines (Easting) of Padma river at the study area. From the table it can be seen that the maximum left bank erosion was 9.15 km and the maximum right bank erosion was 3.95 km. Only upstream of study reach near C & B Ghat, 3.35-km deposition at the right bank was occurred. Especially near the Hazi Bari Ghat under Faridpur Sadar Thana, the right bank of river was shifted towards the right side, which causes unmitigable losses of properties and sufferings to the people.

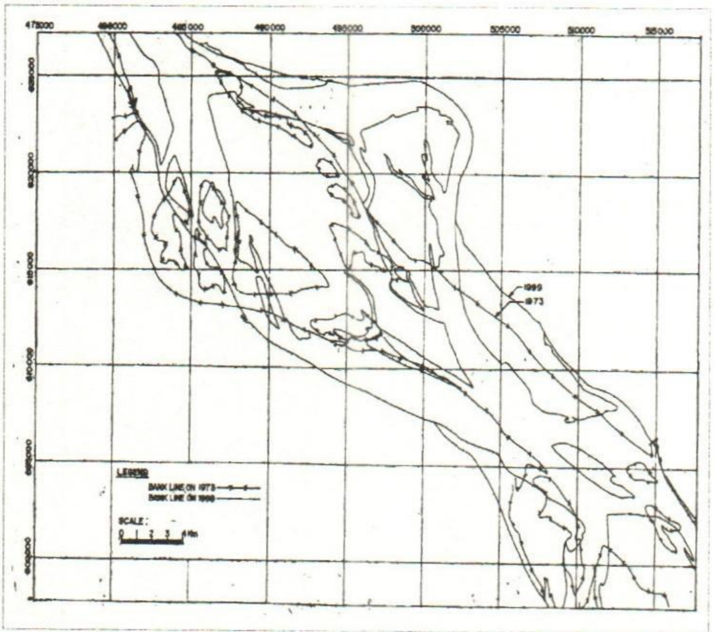

Figure 12 Superimposed bankline from satellite imagery at the study area for the years 1973 and 1999

Table 3 Lateral bankline shifting along grid lines (along Easting) of the Padma river from Satellite imageries with respect to 1973

Grid Line	m Easting	Right Bank (km)	Left Bank (km)
1	485000	+3.35	-0.55
2	490000	-1.45	-1.40
3	495000	-1.90	-4.50
4	500000	-2.75	-9.15
5	505000	-3.95	-1.55

NB: (+) means sedimentation and (-) means erosion.

Bankline shifting from index map supplied by BWDB

Figure 13 shows the bankline shifting of Padma river which cover some parts of Faridpur Sadar Upazila and some parts of Char Bhadrason Upazila for the period of 1999, 2000 and 2001 from which one can easily visualize the nature of devastation of bank erosion. The trend of right bank shifting is towards the right side. **Table 4** shows the amount of right bankline shifting of Padma river for various cross-sections (shown in index map) of the river. The maximum shifting was occurred along cross-section No. 21, which was about 1005 m for a period of only 2 years (from 1999 to 2000) so the maximum rate of bankline shifting is 1005/2=502.5 m/year. This erosion was occurred at Romesh Bala Dangi under Char Bhadrason Upazila.

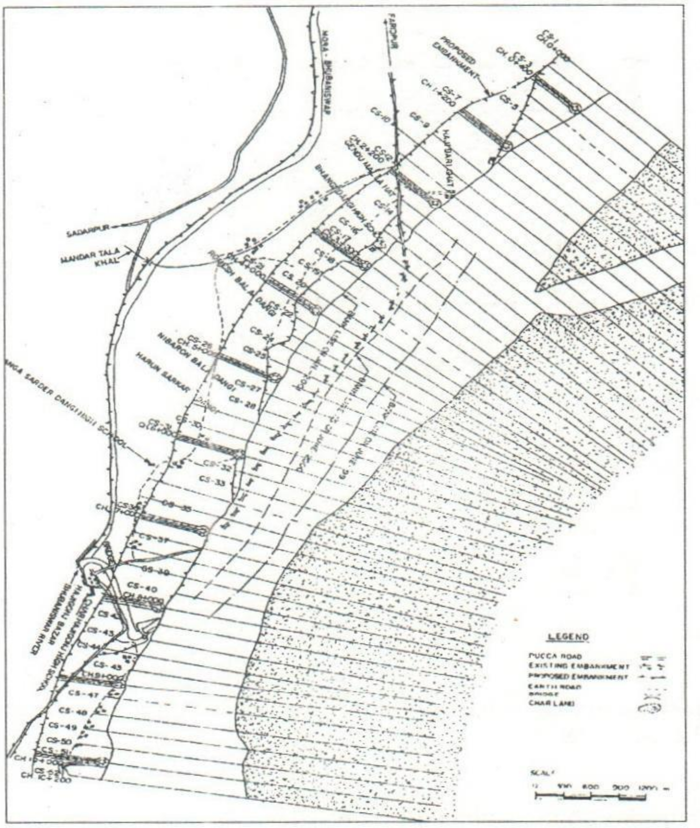

Figure 13 Bankline shifting of Padma river and location of proposed embankment and proposed spurs at the study area

There was a pucca road between cross-section No. 43 and 15 from Lohertek regulator toward Faridpur Town which was already drowned under water within one year due to the devastating bank erosion. The embankment downstream of cross-section No. 8, 28 and 33 was also drowned under water. The embankment between cross-section No. 29 and 31 merged with the bankline. All these cause unmitigable losses of properties and unbearable sufferings to the people.

Table 4 Amount of right bankline shifting of Padma River at the study area from index map

Cross-section No.	Shifting from 1999 to 2000 (m)	Shifting from 2000 to 2001(m)
12	240	315
13	225	420
14	262.5	450
15	315	495
16	360	465
17	397.5	480
18	412.5	525
19	405	577.5
20	592	330
21	420	585
22	450	517.5
23	450	525
24	450	525
25	450	495
26	450	495
27	450	495
28	420	510
29	405	510
30	390	510
31	360	480
32	337.5	427.5
33	322.5	375
34	285	360
35	285	397.5
36	300	420
37	315	360
38	322.5	298.5
39	330	255
40	300	217.5
41	285	172.5

Protection of Faridpur Town and its adjacent areas

A proposed embankment parallel to river bankline can be suggested as a temporary and low cost alternative to protect the affected areas from flood. If bank erosion continuously increases toward the countryside then a series of spur or revetment must be constructed. In **Figure 13**, it can be seen that the existing retired embankment is very close to the present bankline. An this moment, another embankment parallel to the present bankline from cross-section No.1 to 52 can be proposed as shown in the above figure. In addition to this, a series of solid RCC/earthen spurs can be introduced from proposed embankment upto bankline for the protection of these areas. Due to this, the river bankline can not extend toward the countryside without disturbing the existing condition of river. As a result river is not affected naturally and no environmental impact has been occurred. The number, length and spacing of spur also depends on river reach to be protected and the distance between proposed embankment and bankline. As an alternative to spur, riverbank can be protected by providing revetment. But it is too much expensive to protect such a long reach. The optimum number, length, spacing, orientation of spur and block size of revetment should be determined by physical model investigation.

Conclusions and Recommendations

Conclusions

The following conclusions can be drawn on the basis of the present research study:

- Over a period of eight years (2000-1992), the cross-sectional area varies randomly. The cross-sectional area at cross-section P3, P4 and P5.1 has a decreasing trend whereas CS P3.1, P4.1, P5, P6 and P6.1 has an increasing trend indicating aggradation and degradation of these cross-sections respectively during 1992 to 2000. The net increase in cross-sectional areas is about 2.4% in 2000 in comparison to situation in 1992. The study also reveals that the average depth in 2000 is less than that of 1992 while the average top width increases.

- The thalweg of the river moves from one bank to another in a random fashion. The thalweg of cross-section P3, P4.1 and P6.1 moves to the right whereas P3.1, P4, P5, P5.1 and P6 move to the left. The average thalweg level in 2000 is 1.0 m above than that of 1992.

- The MBL at all cross-sections rises in 2000 compared to 1992 situation which represents the channel bed has a deposition tendency during the period from 1992 to 2000. Assuming linear variation of change in MBL, the calculated sediment deposition was 9.4×10^8 m^3 over eight years period i.e. from 1992 t0 2000 which corresponds to about 22.0 cm sediment deposition each year throughout the study reach of Padma river.

- The general equation of rating curve obtained in the present study using data from 1966-94 is given by: WL = 2.2281Ln(Q) - 17.221 from which one can roughly estimate the water level with known discharge and vice versa for the study area

- From the index map supplied by BWDB, the trend of right bankline shifting towards the countryside. The maximum amount of shifting at right bankline is around 1005 m near Romesh Bala Dangi under Char Bhadrason Upazila. During the period from 1999 to 2001 i.e. bankline is shifted towards the countryside at a rate of 502.5 m per year which is dangerous if appropriate protective measures have not yet been taken. If bank erosion is continues with this rate, the affected area with homesteads will be engulfed into the river within a very short period of time.

- From the superimposed satellite imagery supplied by EGIS, the river bankline has been extended both toward the left and right countryside in 1999 relative to 1973 situation at the study area.

Recommendations

The following recommendations can be made on the basis of the present research study:

- A series of spurs having tentative number, length, alignment and spacing from proposed embankment to bankline can be recommended to protect the study area. The optimum number, length, spacing, orientation of spur and block size of revetment should be selected by adopting physical model study.

- As an alternative to spur, continuously double layer revetment (by placing 2 layer RCC blocks) along the bankline for the study reach can be suggested. But for the long reach, it will not be economical in practice. For localized problematic reach, it can be constructed.
- All the suggested spurs to be constructed in one year so as a consequence of joint hydrodynamic effect to combat bank erosion.

The research work was conducted on the basis of recent bathymetry of February, 2001. After this period bankline and morphology will be changed. For this reason, due care should be given to assess these changes before construction of any river training structure in the field.

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Tech. j. River Res. Inst. 8(1): 72 - 81, 2001 (December)

HYDROGRAPH SIMULATION IN A PHYSICAL MODEL: A CASE STUDY

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Abstract

This paper presents the findings of the physical model investigation of the Gorai River Restoration Project with schematized hydrograph. In this contribution an attempt was made to discuss the techniques of simulating hydromorphological process and findings of the investigation with schematized recession hydrograph in a distorted morphological model. In the framework of the Gorai River Restoration Project modeling, a test was conducted with a falling hydrograph in a distorted morphological model. The key interest of the study was to simulate retarded scour in the model. The findings of the test presented in this paper are based on the measurements carried out in the model and the visual observation made during the test run. Extent of retarded scour could not be investigated comprehensively because a base hydrograph test without any structural intervention (present condition) was not available. Such a test could be recommended to investigate the retarded scour.

Introduction

In the aftermath of the establishment of the Ganges Water Sharing Treaty, the Government of Bangladesh initiated studies for the project preparation, feasibility analysis and detail design of the Gorai river restoration. Within this framework of the study, River Research Institute has been assigned to conduct the physical model investigation of the Gorai River Restoration Project (GRRP). This modeling study is a component of the main study to reproduce the overall as well as the local morphology of the Ganges-Gorai system at and around the off-take to support the development of engineering options.

Retarded scour is a phenomenon which develops over time, and it is caused by the fact that the bed topography adapts to changes in discharge only with some time delay. Retarded scour is in particular observed during the erosion process of the depositions in the upper part of the Gorai originating from the previous flood. It is observed that during the fall of the flood the highest point of the channel connecting the Gorai with the Ganges is lowering continuously due to continued scour. If this retarded scour would not have been present the connection between the Gorai and the Ganges would have been lost. Thus it was understood from past studies that retarded scour plays a vital role in keeping the Gorai mouth open in the dry season.

In the framework of the physical model investigation a distorted morphological model was developed at RRI to investigate the hydromorphological impact due to structural interventions proposed to restore the Gorai flow. Several number of tests were conducted with constant discharge to find out a set of structural intervention along the Ganges and Gorai channel especially at the Gorai offtake. From the test results, it was revealed that the Ganges-Gorai revetment and flow divider at the offtake, a series of groynes at the upstream of Talbaria, the advanced revetment and series of spurs at the upstream of Gorai Railway Bridge were the best combination of structural interventions for augmenting the dry season flow into the Gorai channel. Under such intervention, a hydrograph test was carried out in this model to simulate the retarded scour at the off-take.

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It is the first time a hydrograph test in a scale model is carried out in Bangladesh. In the following section the modeling area and setup, boundary conditions, schematization and scaling of hydrograph, applied hydrograph, simulation and fine tuning, result and discussion, conclusion and recommendations are discussed.

Study area and set up

The study area is located at about 55 km downstream of the India- Bangladesh boarder on the Ganges river. The latitude and longitude of the study area lies between 23°52′ N to 24°7′ N and 89°2′ E to 89°12′ E. The Eastern part of the Ganges area is located under Sirajgang and Pabna district and Western part under Kushtia district. The area comprised of flood plain and unstable islands. Area reproduced in the model is about 25 km, which includes Hardinge Bridge in the upstream, 2 km downstream of Gorai Railway Bridge in the Gorai and up to 10 km downstream from the off-take in the Ganges downstream. The model layout can be seen in **Figure 1**.

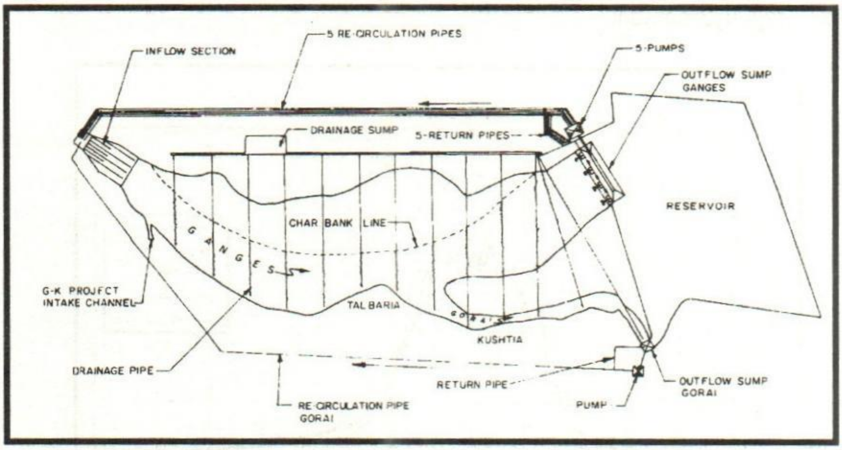


Figure 1 Layout of the model

A distorted morphological model was set-up using the existing and developed facilities at RRI. An open-air model bed of 30 m × 125 m long have been used for setting up the model. The length scale have been selected as n_L=300 and the vertical scale has been primarily selected as n_h=60 by making comparison between different possibilities. Initially the model have been constructed with geometric scales of n_L=300 and n_h=60. Finally during calibration the vertical scale for this distorted morphological model have been found to n_h=52.

Boundary condition

In the present investigation three boundary conditions were employed in the model as :

- Upstream discharge
- Downstream water level
- Sediment transport

Upstream discharge boundary

As the key objective of the test was to simulate the retarded scour the recession limb of a flood hydrograph was intended to provide an upstream boundary.

It is not completely obvious which (prototype) hydrograph has to be used during the model study to investigate this retarded scour phenomenon.

There are different possibilities:

an average hydrograph or the hydrograph of a particular year ; and pre-Farakka or post-Farakka.

The use of one particular hydrograph might yield results, which are not representative. The use of an average hydrograph might result in too optimistic results, as in general it might be expected that the falls of particular hydrographs are steeper than the fall of the average hydrograph. To study this phenomenon **Figure 2** was prepared which compares the average 1977-1997 hydrograph with the hydrographs of three consecutive years (1995-1996, 1996-1997 and 1997-1998).

The starting date of the hydrographs is 1st April. As can be observed the differences between these specific years and the average hydrogrpah are only marginal and hence it can be proposed to use the average hydrograph.

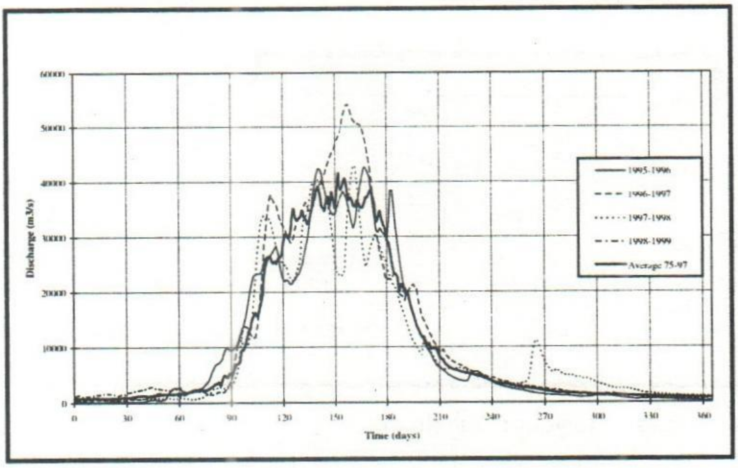


Figure 2 Comparison of average 1977-1997 hydrograph with three specific years

Regarding the choice between pre and post-Farakka hydrographs there are less doubts. In the post-Farakka period the fall of the hydrogrpahs is quicker than in the pre-Farakka period (FAP-24,1996). Hence the post-Farakka hydrographs are preferred for the model simulation as these are more critical (less time for the retarded scour to develop) and as they are more realistic for the present conditions. **Figure 3** shows the average hydrographs for both the pre and post-Farakka period.

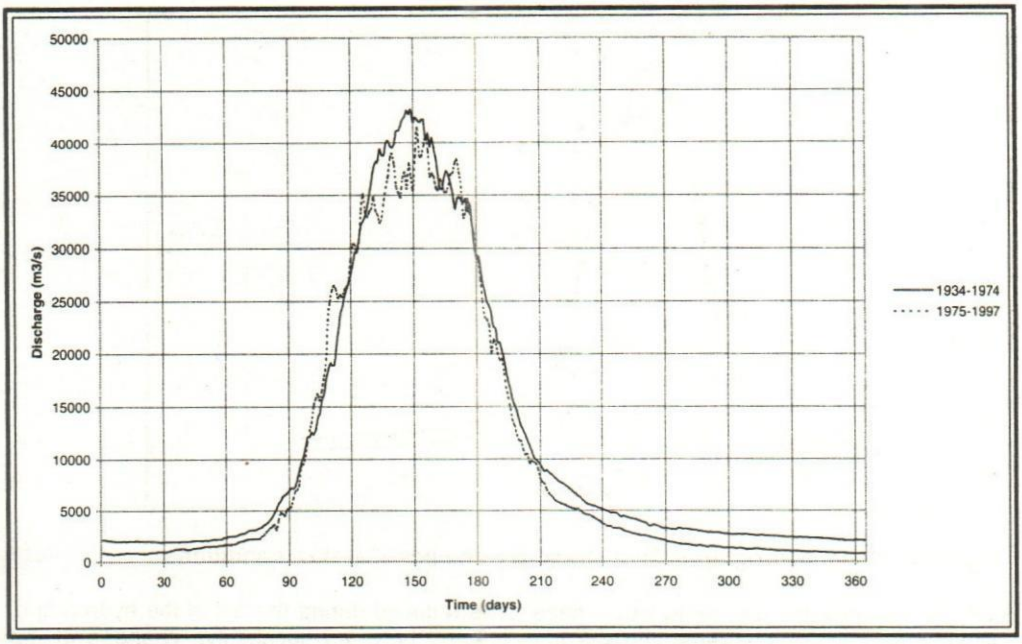


Figure 3 Average pre and post-Farakka hydrographs

As dealing with retarded scour, which essentially is a 1D phenomenon, it is appropriate to use the 1D continuity of the sediment for the determination of the time scale given by:

$$\frac{\partial z_b}{\partial t}+\frac{\partial s}{\partial x}=0 \qquad (1)$$

From this equation the following *scale condition* for the time can be derived:

$$n_t=\frac{n_h n_L}{n_s} \qquad (2)$$

$$n_Q = n_u n_L n_h \qquad (3)$$

By applying the above scale factors for the discharge and the time, model hydrographs have been determined. These are given in **Figure 4**. Simulation of a whole year takes about 15 days, and the discharge in the model varies between 0.01 and 0.4 m^3/s (10 to 400 l/s).

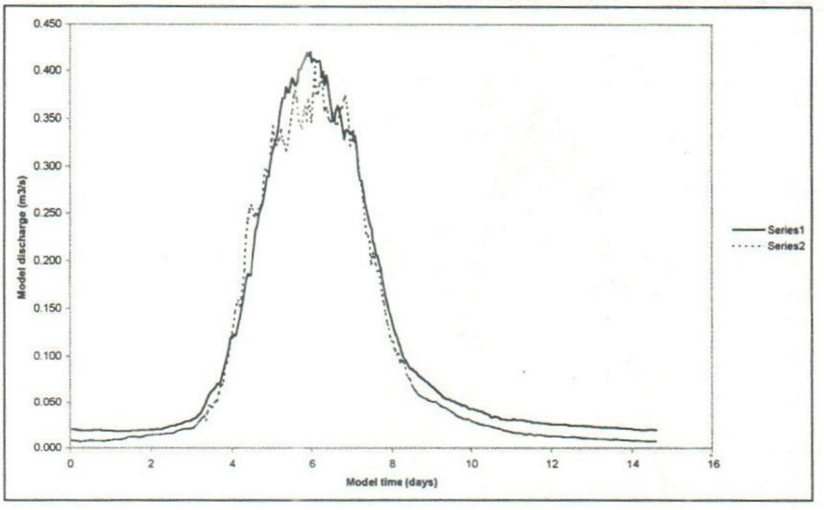


Figure 4 Model hydrographs for average pre and post-Farakka conditions

To study how quickly the discharge would have to be reduced during the fall of the hydrograph, two assumptions are made regarding the time interval between successive changes of the discharge, notably 12 and 6 hours. The changing discharge is hence averaged over either 12 or 6 hours.

Only the recession part of the hydrograph was considered to be simulated in the model. Because only in that period retarded scour will occur. The recession hydrograph is made stepwise to apply in the model conveniently. The starting discharge of the simulation corresponds approximately to the peak of the flood. Some values were slightly adjusted to obtain a smoother hydrograph. The proposed hydrograph is shown in **Figure 5**.

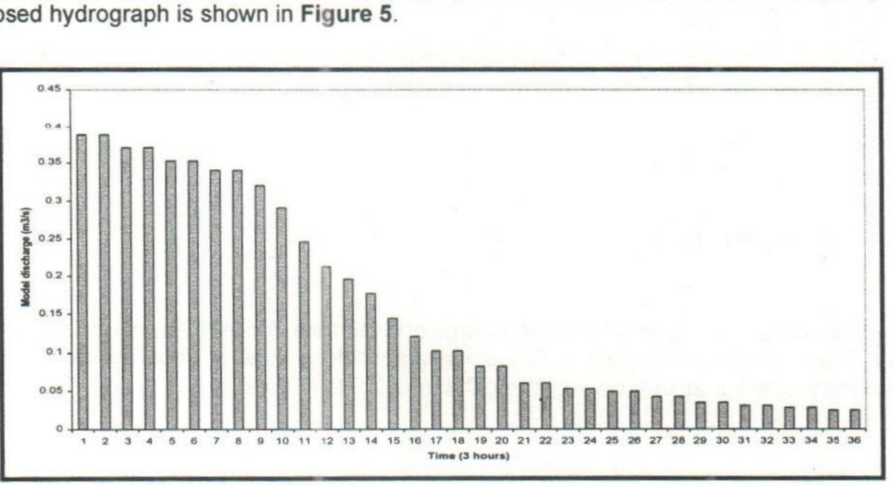


Figure 5 Proposed recession hydrograph for the model

All the discharges proposed in the above step hydrograph was not possible to provide in the model because the pumping capacity of the Ganges and Gorai pumps is limited. So necessary further adjustment was done according to the pumping capacity in the proposed hydrograph. The stepwise discharge in different time steps employed as an upstream boundary in presented in **Figure 6.**

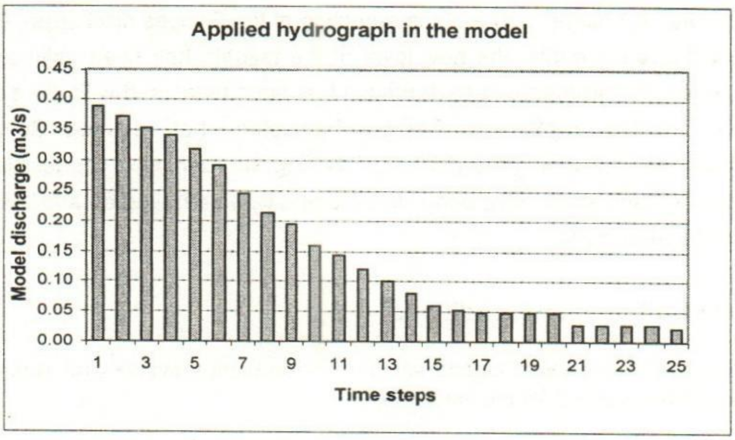
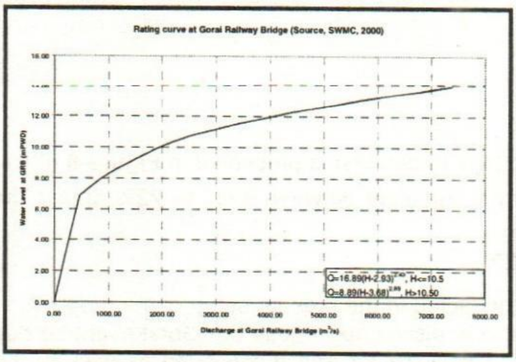


Figure 6 Hydrograph applied in the model

Downstream boundary conditions

In addition to the upstream hydrograph also the downstream boundary conditions have to be specified for these tests with a hydrograph. In the case of a bifurcation and a varying discharge the discharge distribution over the two downstream branches was not exactly known in advance, as it depends (in addition to the regulation of the downstream tailgates) also on the retarded scour phenomenon itself. Rapid scour results in an increased inflow at the off-take and further into the Gorai branch.

For the Gorai River this was the rating curve for Gorai Railway Bridge. For Gorai River rating curve produced by SWMC (Second Technical Report, SWMC, 2000) has been used. For the Ganges downstream boundary a prototype rating curve has been derived based on the rating curve produced by SWMC for the Hardinge Bridge. The rating curves derived for the downstream boundary conditions are shown in **Figure 7**.



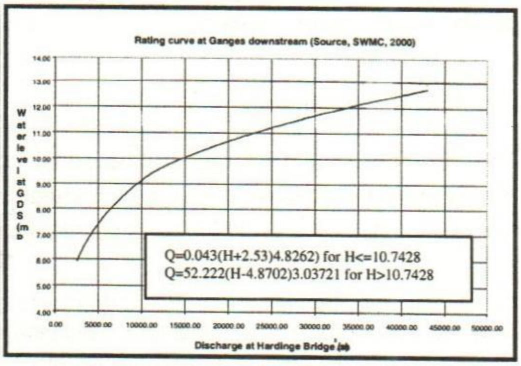


Figure 7a. Ganges downstream rating curve

Figure 7b. Gorai Railway Bridge downstream rating curves

The derived prototype rating curves have been scaled down to model values using the appropriate discharge and vertical scale. When reducing the discharge in the model during the test, an estimate is made (based on the measured discharge in a branch before the change in discharge) of the new discharge in each of the branches (e.g., using the assumption that the reduction of the Gorai discharge is 10% of the reduction of the Ganges discharge). By reading the model level from the rating curve, the new level of the tailgate has been estimated. Once the discharge is changed, the discharge in each branch has been measured with the electromagnetic discharge meters and the tailgate level has been adjusted when required. Some iteration is needed immediately after changing the discharge. During the running of the test (e.g., every 60 minutes) the discharge and stage have been checked and when required an additional adjustment of the tailgates have been made.

Sediment transport boundary conditions

As the model has been tested with closed sediment recirculation system, no separate sediment transport boundary was required for the simulation.

Adjustment of the boundary conditions and fine tuning

The upstream boundary conditions in the model were provided in the model by the pumps. The discharges were reduced stepwise according to the hydrograph schematized. The downstream water level was provided in the model by adjusting the tailgate level. When a discharge is reduced to its next step in the applied hydrograph then the previously recorded discharge through the Gorai was taken into account to decide the amount of discharge to be started with the Ganges pump. Then the corresponding downstream water level was provided at the downstream boundary of the Ganges. The discharge in the Gorai branch was measured by electromagnetic discharge meter.

Analysis of results

The analysis of the results are mainly based on the measurements carried out in the model, the observations made during the model study. However the analysis here is focussed on the discharge distribution between the Ganges and the Gorai and the development of retarded scour due to receding water levels.

Discharge distribution

The development of discharge distribution during hydrograph test is presented in **Figure-8.** It can be said that the discharge distribution varied approximately between 12% to 22% during the period of model run with different stepped discharge.

This is significantly higher than any other tests conducted in the present setup of the model (and with permanent discharge condition). This increase in discharge through the Gorai might be due to the combined effect of the construction of the flow divider and guide bund as well as the development of retarded scour. The enhanced scour at the off-take resulted in significant increase in discharge in the Gorai branch. The Gorai construction may also have some impact on the increase in discharge. Although some caution should be taken into account with these high discharge values through the Gorai (due to limitations of the morphological model). It is concluded regarding the discharge distribution between the Ganges and the Gorai that the model has shown that a considerable discharge could be maintained in the Gorai in the present setup of the model (boundary conditions, bank lines and constructions tested).

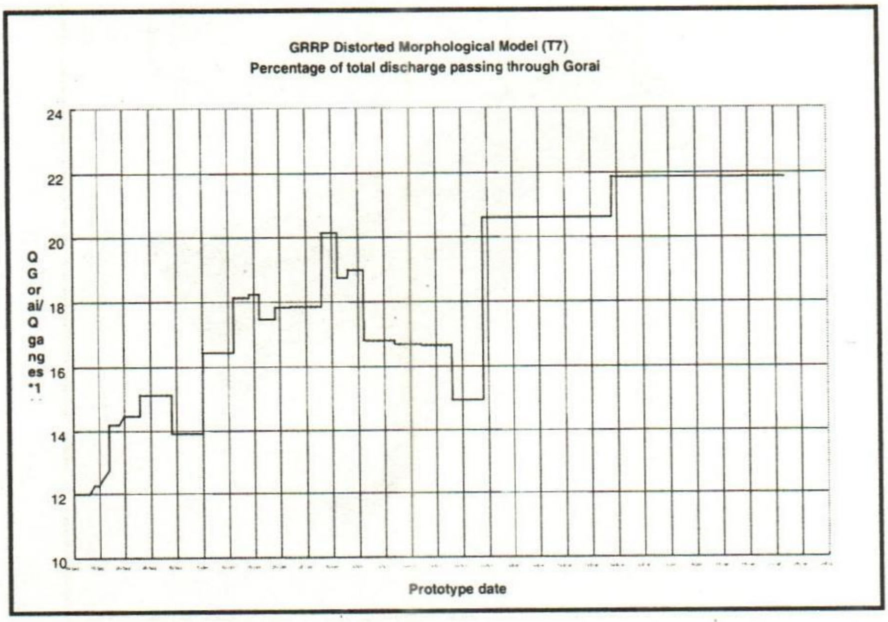


Figure 8 Development of discharge distribution in hydrograph test

Morphology

The morphological situation in hydrograph test at the upstream of the Talbaria scour hole was more or less similar to that in other tests. A channel was found to be formed along the Gorai side of the flow divider probably due to the local scour. But at the off-take the channel along the divider was more pronounced than any of the previous tests. Retarded scour was also found to be occurred in the model. The combined effect of the local scour and the retarded scour kept the channel open and became deeper with the falling water level at the off-take. The retarded scour was quite successfully simulated in the model, which is shown in **Figure 9**.

It was observed during model tests that a local scour hole developed at the head of the flow divider. In hydrograph test the local scour hole at the downstream of flow divider is observed to be diminished with the reduction of the discharge in the falling stage of the hydrograph, which is called as breathing of a local scour hole. This is due to the reduction of flow velocity resulting in the lowering of the sediment carrying capacity and consequently depositing in the scour hole.

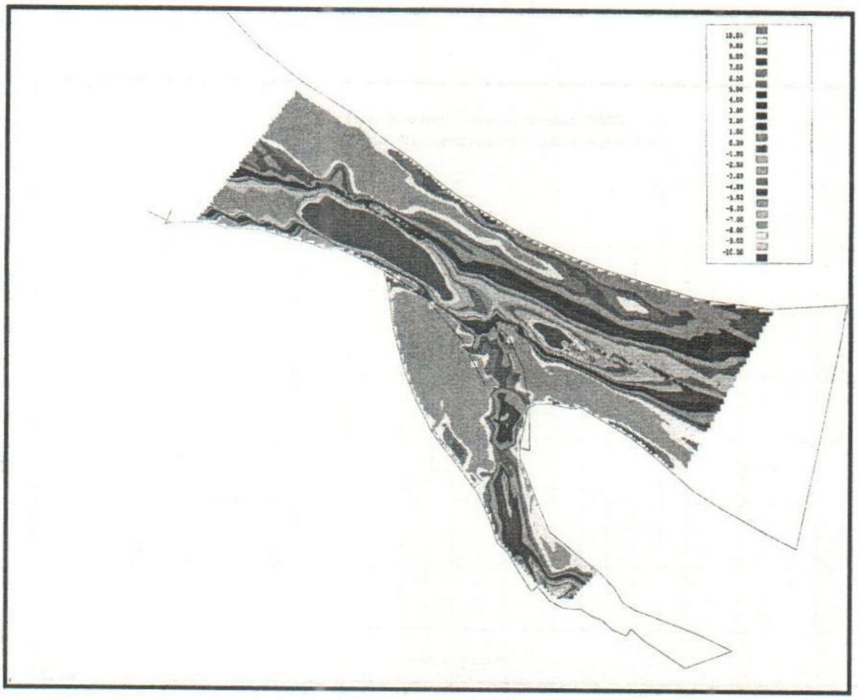


Figure 9 : Simulated retarded scour in hydrograph test

Limitation of the model

As in the model heavier sand as bed material has been used to simulate the sediment transport and bed topography, the critical flow velocity for the initiation of motion might be higher than the flow velocity at the off-take. So the actual sediment transport in the model was less than the actual transport and thus the retarded scour simulated would have been more pronounced if the sand would have been possible to scale down or lighter material were used. On the other hand due to the scale effects in reproduction of the direction of sediment, more sediment is entering into the Gorai and due to low flow velocity it was depositing at the off-take. Thus the scale effects due to the initiation of motion has a positive influence on the retarded scour at the off-take. So it is expected that retarded scour is even under estimated due to the scale effects

Conclusions and recommendations

For the first time a hydrograph test was possible to conduct in a physical model in Bangladesh for modelling a large braided sand bed river like Ganges. Through this hydrograph test a new technique of simulating river process with any hydrograph has been developed at RRI which can be successfully used in any other modelling activities. The hydrograph test improved our understanding in simulating a hydrograph in a physical model. The test provided better insight into the physical process of retarded scour. The retarded scour was successfully simulated at the off-take of the Gorai bifurcation. The retarded scour was simulated in the model quite satisfactorily and it was revealed that this retarded scour if happens in the prototype will help the mouth to open to flow significant amount of discharge to the Gorai. It has been found that the retarded scour initiated at the mouth and continued rightward in the Gorai channel thus creating well defined flow passage during the lean period. However the extent of retarded scour could not be investigated because a base hydrograph test without any structural intervention (present condition) is not available. Such a test could be recommended to investigate the retarded scour comprehensively.

Acknowledgement

This study was conducted at RRI, Faridpur by the authors with the financial support from BWDB. The model was designed at RRI and finalized by WL | Delft Hydraulics and BUET. All supports and co-operation in this regard are highly acknowledged.

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CAUSES OF NAVIGATION PROBLEM IN THE ARICHA NOTAKHOLA-DAULATDIA ROUTE

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Abstract

The river system of Bangladesh played a vital role for waterway transportation in the recent past, but the situation has aggravated due to reduced flow and excessive deposition of the rivers. During the monsoon a lot of sediment is transported through these rivers and significant amount of sediment is also deposited during the falling stage of the discharge. Due to this indiscriminate deposition of sediment the morphology of the river is changing and some times the riverbed level is rising, causing the reduction of the draft for the navigation route. The river training is required to mitigate the siltation problem at the said area. The effectiveness of the required structure is very difficult to assess ahead for such a complicated problem. Therefore, the type of structure to be adopted here and its effectiveness should be studied in depth.

Introduction

Bangladesh is a riverine country consisting of several hundred rivers and their tributaries. It is located at the lower part of the basins of the three major rivers, the Ganges, the Brahmaputra and the Meghna. The extensive flood plain of these rivers and their numerous tributaries and distributaries is the main physiographic feature of the country. The river systems have played an important role in shaping the landscape of the flood plain, nursing its soil and sustaining its production system. The economy of this country is greatly influenced by the morphological and hydraulic behavior of the river systems. Bangladesh have a unique geographical set-up due to the existence of great Himalayan Mountains at its North and Bay of Bengal at its South. For topographical position many of these rivers and channels originated outside Bangladesh flowing through it to find passage to the Bay of Bengal. About fifty-four rivers coming from India and three rivers from Mynmar.

Bangladesh is located in the World's largest delta at the confluence of the three great rivers the Brahmaputra-Jamuna, the Ganges-Padma and the Meghna. The first two have the most dynamic morphology. The basins of the three rivers cover a total area of approximately 1.55 million square kilometers, spanning China, Nepal, India, Bhutan and Bangladesh. The downstream areas within Bangladesh account for only 8% of this total area and most of the flow in Bangladesh consists of water that entered into the rivers from outside of Bangladesh territory.

The Rivers of Bangladesh are characterized by severe bank erosion, silting up of the riverbed, scouring and the courses of the rivers are extremely unstable both laterally and longitudinally. The main cause of this is the geological tilting movement of the ground, the extremely flat and low-lying topography of the plains, the fact that riverbanks consist of mainly sand, the large volume of flood flows and the sparseness of vegetation along riverbanks. The socio-economic life of the people of Bangladesh is significantly influenced by the characteristics of the rivers. It is, therefore, essential to have an understanding of the problems caused by the river erosion and siltation of

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specific area of interest. So, in this paper an endeavor has been made to investigate the silt problem at important Ferry route Notakhola - Aricha - Daulatdia.

Objectives of the study

The objectives of the study are:

- To identify the probable causes of siltation at the Notakhola, Aricha and Daulatdia navigation route
- To evaluate the socio-economic impact of dredging
- To make recommendation for the mitigation of the siltation problem

Literature review

Bank migration through erosion-deposition process in an alluvial river is a characteristic feature and one of the most conspicuous changes affecting fluvial landscapes. At a meander bend high velocity occur in the outer bend causing recession of the bank and also the spiral flow tends to deepen the outer bank. In a river, rate of such bank erosion can be rather high. Generally, the rate of bank migration is determined by the strength of the bank as well as the fluid forces. Due to effects of river flow fluctuations, regular pattern of bank migration can not survive. The problem in analyzing any aspect of riverbank erosion is to find a method, which adequately demonstrates the properties of the course, and plan form, especially where stable banks are poorly defined or irregular. In the recent past a number of important studies have been done by various researchers to develop insight into the bank erosion process as well as rate of bank erosion. Wolman (1959), Osman and Thorne (1988), Hickin and Nanson (1984), Klaassen and Masselink (1992) and Hughes (1976) played a notable role in this regard. Klaassen and Masselink studied the bank erosion of the braided the Jamuna river of Bangladash and found that in most of the cases erosion rate along the curved channel is between 0 and 500 m/year. The bank erosion rates analyzed within the framework of Hickin and Nanson revealed that low relative curvatures lead to relatively fast erosion rates and vice versa.

The flow through the Padma and the Jamuna confluence largely depends upon the hydrodynamic and morphological conditions of the river. The wandering pattern of the major boundary rivers has particular implications for the hydrology, hydraulics and morphology of the regional rivers, which are distributary channels. The amount of water sediment spilled into the distributary depends primarily on the position of the mouth within the pattern of the wandering river. In turn, the channel characteristics and morphology of the distributary depend on the inputs of water and sediment and their annual variation are controlled firstly by channel dynamics in the parent river and secondly by condition of the off-take mouth. Recognizing the morphologically dynamic nature of a wandering pattern river, it is to be expected that large variations in inputs to distributaries will occur, to which the size and the morphology of the distributary river constantly adjust (Navera, 1996).

Confluence scour represents critical components of drainage system geometry and the point at which river morphology and hydrology can be changed drastically. It was found that scour depth was a function of confluence angle, relative tributary discharge and relative sediment discharge through the confluence. Confluence angle was found to be the major control of scour depth. Tributary discharge and sediment loads were found to have less influence on scour depth. Scour depth increased rapidly as confluence angle increased from 15 to 75-degree and more slowly up to 120-degree. Scour depth was found to be maximum when the angle of incidence of the tributaries were symmetrical and discharge in the tributaries were equal. Scour depth decreased as the relative discharge in the tributary or sediment discharge in the tributaries increased (R.B. Rezaur et, al.)

After severe floods on the River Meuse in 1993 and 1995, one of the proposed measures to reduce the flood risk was dredging 120 kilometres of river bed by 3 metres. In order to gain experience first, a pilot project of 20 Km was carried out in 1996. The monitoring results show that the reduction of water levels at the upstream end of the dredged reach is as expected. In addition however, a scour hole has developed with a depth of 2 metres and a length of 1 kilometer, due to erosion of a layer of fine sediment. The rate of expansion of the scour hole after two minor floods seems to have decreased. Partly as a result of this experience, widening the river bed instead of deepening it has been chosen at a second location, where the sediment composition directly under the top layer was even finer, (Max Schropp & Ard Wolters *et, al.*)

Methodology

The cross-sectional data, hydrographic chart, spot image, hydrological data are collected from the Morphology division of BWDB, BIWTA, SPARRSO, EGIS and Hydrology division of BWDB. The cross-sectional data and hydrographic chart which are collected are not sufficient, consistent and regular. However, these data have been analyzed and attempt has been made to develop an understanding about the siltation and erosion process in this area. Spot images are also analyzed to have idea about the bank shifting or bank erosion. The hydraulic parameters such as width, average depth, cross sectional area, mean bed level etc. are calculated from the cross sectional data with reference to the bank level.

Data analysis

Data collected from different organizations such as BWDB, BIWTA, SPARRSO, EGIS etc. are analyzed and discussed in this chapter.RRI collected the satellite image data from SPARRSO and EGIS for the year 1990, 1991,1992,1993,1995 & 2000, 1993 &2000, hydrographic chart from BIWTA for the year 1990-2000, the cross sectional data from BWDB for the year 1880-81,1882-83, 1884-85, 1885-86, 1990-91, 1992-93, 1995-96 & 1998-99, dredging information for the year 1990-99 etc. Some of the consistent data have been analyzed and interpretations of results have been made, which is discussed in this section. In addition to these, the analysis and information obtained from the FAP-20 study were also incorporated and discussed here for better understanding of the morphological process of the rivers at the study area.

Planform analysis

The Notakhola is at the right bank of the Jamuna river upstream of the Aricha confluence and the other two Ferry Ghat i.e. the Aricha and Daulatdia is in the Padma river at the downstream of the confluence. It is observed from the plan form analysis that the Notakhola Ferry Ghat experiences severe bank erosion, where as the Aricha is comparatively less. But these two Ferry Ghats are mainly located on the erodable bank for a couple of years if the main flow is analyzed. On the other hand at Daulatdia mainly deposition is observed (Table 3). But the dredging becoming essential to maintain the navigational route between these Ferry Ghats.

The planform studied for the year 1990,1991,1992,1993,1995 & 2000 obtained from the satellite image and a summary of erosion and deposition estimated thereof is shown in Table 1 to 3 respectively. The planform changes of 1991 and 2000 is also shown in Fig.2 and Fig.3 respectively.

Table1 Erosion deposition estimated from satellite image at Notakhola

Year	Erosion/deposition	Magnitude (m)	Remarks
1990-`91	Erosion Very little deposition	150	At Notakhola Upstream and downstream
1990-`92	Erosion Erosion Deposition	300 300 400	At 850 m u/s of Notakhola At Notakhola At 2.5 Km d/s of Notakhola

Table1 (continued)

Year	Erosion/deposition	Magnitude (m)	Remarks
1990-`93	Erosion	150	At Notakhola
1990-`95	Erosion	450 250 850	At 850 m u/s of Notakhola At Notakhola At 7.5 Km d/s of Notakhola
1990-2000	Erosion	600 300 2100	At 850 m u/s of Notakhola At Notakhola At 7.5 Km d/s of Notakhola

It is observed from the table1 that the bank erosion is prominent compared to the amount of deposition. From 1990 to onwards there is always a tendency of bank erosion. The maximum bank erosion is observed about 2100 m compared to the 1990 bankline.

Table 2 Erosion/deposition estimated from the spot image (Aricha)

Year	Erosion/Deposition	Magnitude (m)	Remarks
1990-91	Little erosion No erosion No erosion	100 m Nil Nil	At Aricha At 7 .5 Km u/s to Aricha Aricha to 8.5 Km d/s
1990-92	Very little erosion No erosion No erosion	50 m Nil Nil	At Aricha At 7.5 Km u/s to Aricha Aricha to 8.5 Km d/s
1990-93	Erosion No erosion No erosion	150 m Nil Nil	At Aricha At 7.5 Km u/s to Aricha Aricha to 8.5 Km d/s
1990-95	Erosion No erosion No erosion	200 m Nil Nil	At Aricha At 7.5 Km u/s to Aricha Aricha to 8.5 Km d/s
1990-2000	Erosion No erosion Erosion	100 m Nil 500 m	At Aricha At 7.5 Km u/s to Aricha Aricha to 8.5 Km d/s

The erosion or deposition at Aricha is not so indicative from the table. On the other hand from the spot image it is seen that main channel flows along the left bank, i.e. along the Aricha. In principle, there should be bank erosion, but due to the bank protection works, the bank erosion is restricted. But, some distance downstream of Aricha the bank erosion is significant, because there is no bank protection works. Big char developed very near to the Aricha can also been observed from the satellite image.

Table 3: Erosion/deposition estimated from satellite image (Daulatdia

Year	Erosion/Deposition	Magnitude (m)	Remarks
1990-'91	Deposition Deposition Deposition	500 250 900	At Daulatdia At 3 Km u/s of Daulatdia At 3 Km d/s of Daulatdia
1990-'92	Deposition Deposition Deposition	350 Nil Nil	At Daulatdia At 3 Km u/s of Daulatdia At 3 Km d/s of Daulatdia
1990-'93	Deposition Deposition Deposition	800 Nil 1500 m	At Daulatdia At 3 Km u/s of Daulatdia At 3 Km d/s of Daulatdia
1990-'95	Deposition Deposition Deposition	1000 Nil Shallow char	At Daulatdia At 3 Km u/s of Daulatdia At 3 Km d/s of Daulatdia
1990-2000	Deposition Deposition Deposition	800 1200 2500	At Daulatdia At 3 Km u/s of Daulatdia At 3 Km d/s of Daulatdia

Table 3 shows the gradual sedimentation at Daulatdia Ghat area. This is because of the fact that, at this region, the main flow is along the left bank of the Padma. The maximum deposition estimated from the spot image plan form is about 2000 m from 1990 and 2000.

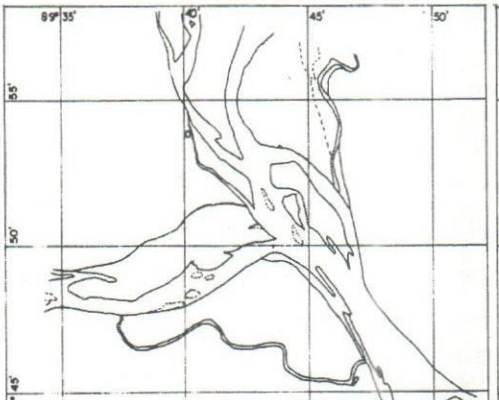

Figure 1 Planform of Notakhola, Aricha and Dautdia area, 1991

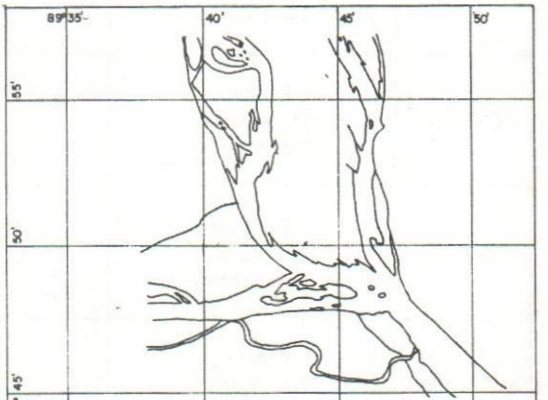

Figure 2. Plan form of Notakhola, Aricha and Daulatdia area, 2000

Hydrographic chart

The hydrographic chart collected from the BIWTA was analyzed and some selected sections were plotted. But, the problem faced during the analysis of hydrographic charts is that, the soundings are not taken along the full width of the river. As a result, it is not possible to analyze the data for the estimation of erosion or siltation purposes. However, it can be visualized from the bathymetric plotting about the variation of the cross sectional geometry. Therefore, it can be stated here that the cross-sectional geometry of the river is changing randomly with time, which indicates that the river is very active and unstable.

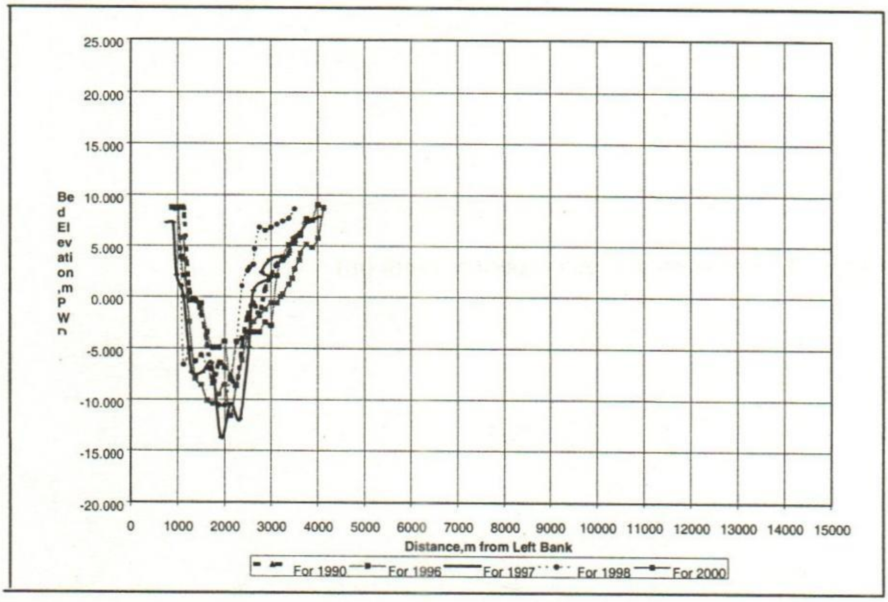

Figure .3 Bed profile from hydrographic chart

Cross-section

Cross sectional data collected from the BWDB are processed and some of the selected years have been analyzed. Because the data for different sections were not available for the same year. Attempts were made to assess the amount of siltation and erosion in the study area, but due to very unstable and rapidly changing morphological nature of this region as observed from the data, the assessment will not be realistic. However, from the analysis, a qualitative idea can be achieved about the siltation and erosion of the study area. The cross sectional data plotted in different years. The width, depth, cross sectional area, mean bed level were also analyzed. It is evident from the Fig 5 and 4 that the average depth of the river at bankfull stage has a decreasing trend and in general the width of the river has increasing trend. So it can be concluded here that the river bed has been silted up and the river becoming wider. From the Fig 6 it can also be stated that the mean bed level in the Jamuna has rising trend, on the other hand in the Padma, it is not so significant. That means, the siltation in the Jamuna riverbed is supported by the mean bed level analysis.

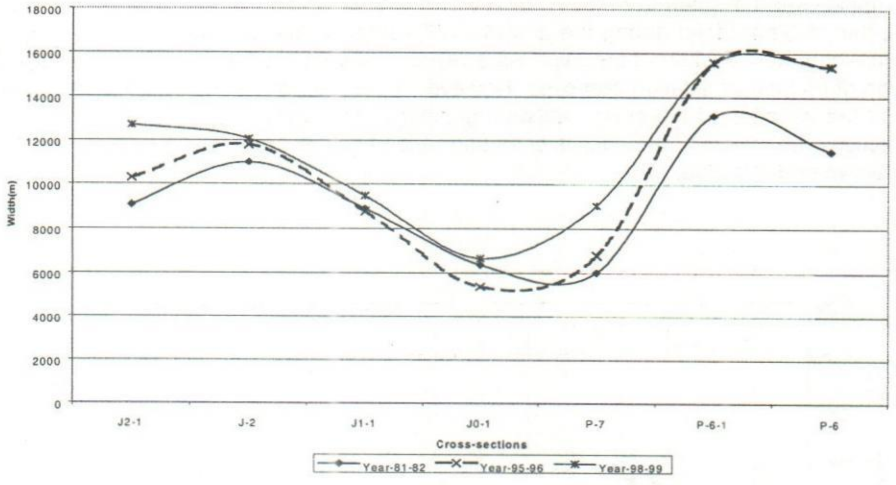

Figure 4 Variation of cross sectional width (m)

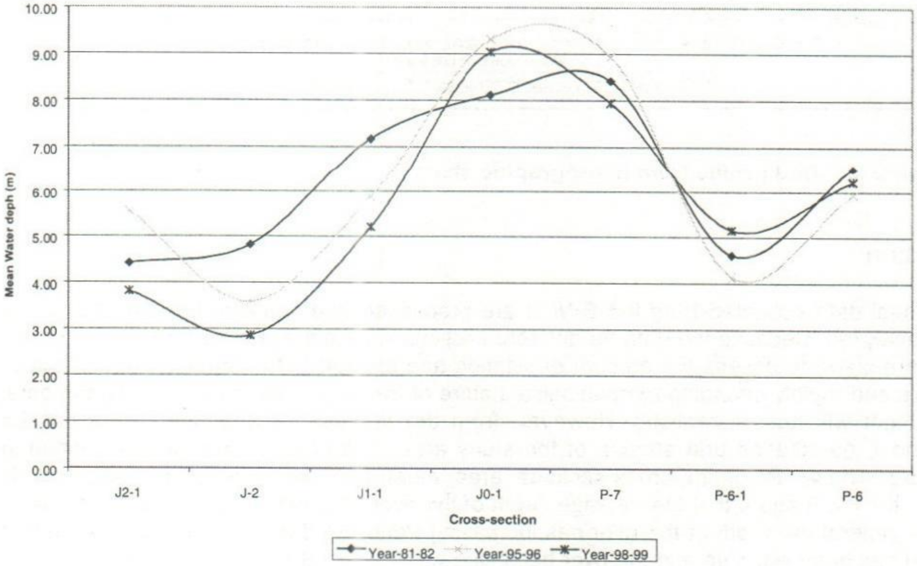

Figure 5 Variation of mean water depth (m)

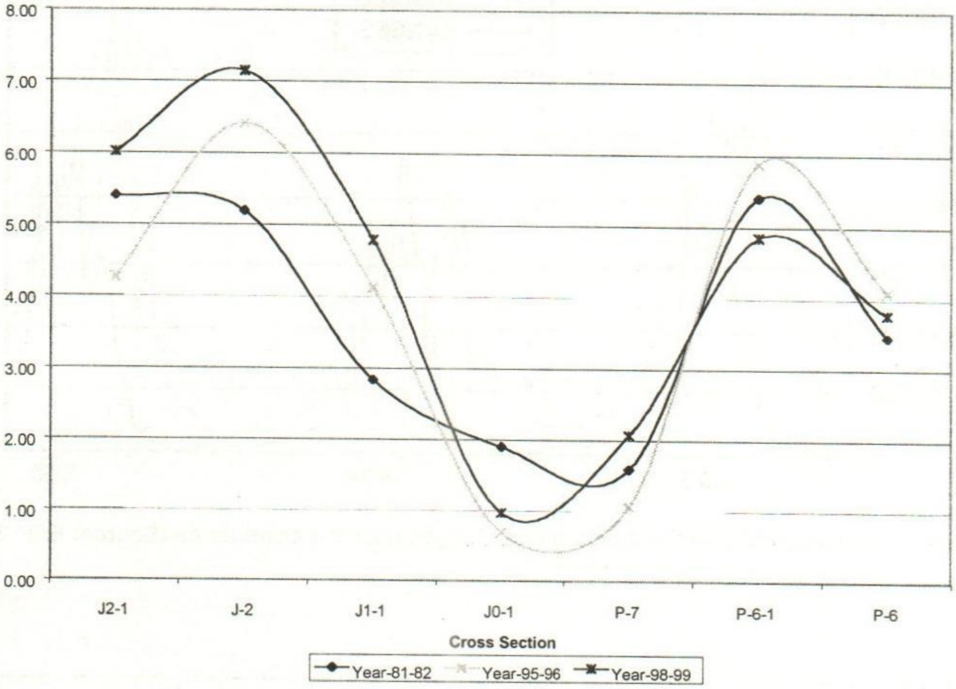

Figure 6 Variation of mean bed level (m)

Comparison of discharge

The discharge hydrgraph characteristics of the Ganges and Jamuna is not similar, which might have different impacts on the confluencing river, the Padma. A typical example for the discgahre hydrograph can be seen in Figure 7. The discharge ratio in the Ganges and Jamuna is also compared and shown in Figure 8.

The following observation is made if the discharges at Jamuna and Ganges is compared.

- The rise of the Jamuna river discharge is earlier than the Ganges river. But the fall of the Ganges discharge is usually earlier than the Jamuna
- The rise of the Jamuna river discharge is earlier than the Ganges river. But the fall of the Ganges discharge is usually earlier than the Jamuna
- The discharge ratio (Q_{Gan}/Q_{Jam}) of the Ganges is normally below 1, except in some cases during the flood and falling season. It means that the flow in the Ganges is much smaller than that of the Jamuna both for maximum, minimum and annual average flow.
- Deposition dominates during the recession of the flood in the Ganges, where as in the Jamuna the picture is more complex. Both deposition and scour occurs, and there is no real dominance of either of the two.

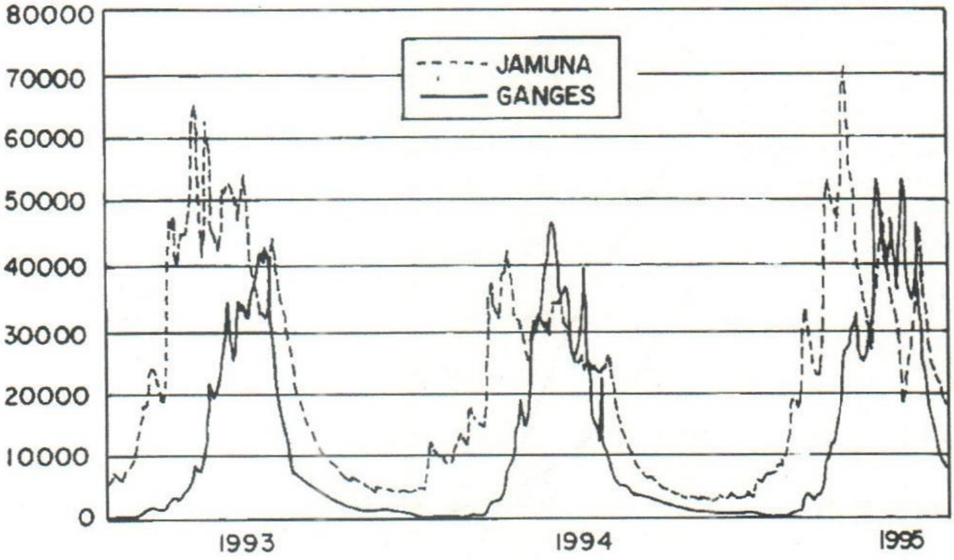

Figure 7 Hydrographs of the Jamuna and Ganges near the confluence (Source: FAP-24)

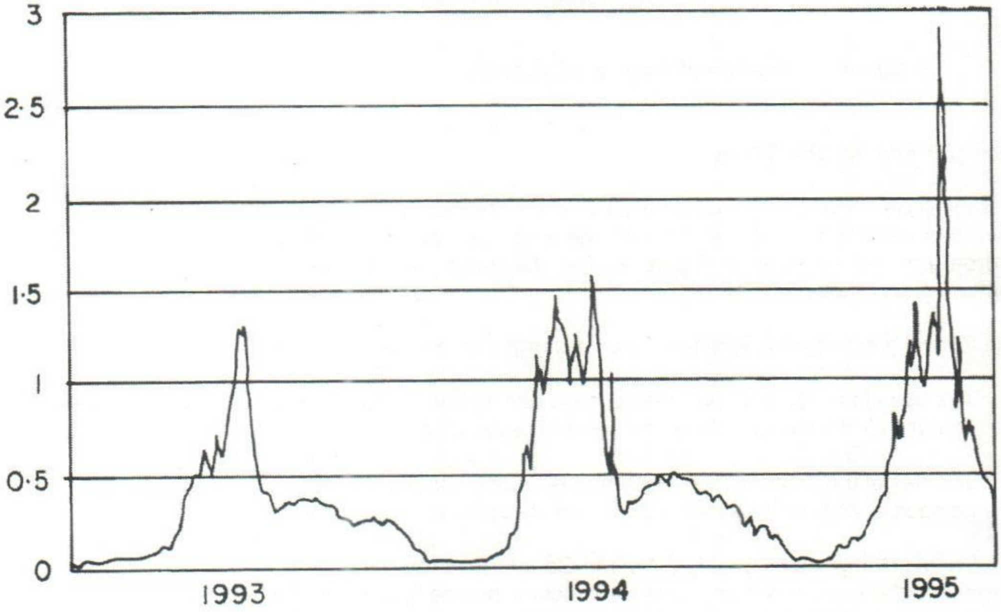

Figure 8 Hydrographs of the Jamuna and Ganges near the confluence (Source: FAP-24)

- So it can be mentioned here that the influence of the Jamuna on the Ganges is much larger than the influence of the Ganges on the Jamuna river. This is in line with the observations of the discharge hydrographs. The ratio Q_r is rarely larger than 1.

- Whatever is the discharge in Ganges and Jamuna, in general, the scour appears dominant in the Ganges, but in Jamuna both the erosion and deposition occurring. The dynamic behaviour upstream of the confluence is triggered by discharge differences between the two confluencing rivers.

Socio-economic impact due to dredging activities

It is mentioned in the earlier section that the Notakhola and Aricha are on the eroding bank and at Daulatdia mainly deposition is occured for last couple of years. A substantial amount of money is required each year to maintain the navigation route. Last nine years data shows that at Daulatdia the amount is maximum. The total volume of dredging for the last nine years is 49.58 Mm^3, 23.62 Mm^3 and 18.09 Mm^3 at Daulatdia, Notakhola and Aricha respectively (Source: BIWTA). On the other hand these dredging spoil can be and even being used in rebuilding the land adjacent to the river banks. This is helping also for the socio-economic improvement of the people near the dredging area. These land development activities are observed at the Aricha and Daulatdia area.

Conclusion and recommendation

Conclusion

Hydrological and morphological data have been analyzed to identify the probable causes of siltation problem of the present study. The siltation problem in the Notakhola-Aricha and Daulatdia navigation route made very complicated due to the location of these three Ferry Ghats on the bank of the active river as well as near the confluence. Moreover, this type of problem investigation needs very elaborate and in-depth study, which is beyond the scope of the study. To know the physical process responsible for the problem and its effective solution is not a easy task. However, within the scope of the present study and based on available information collected, the following conclusions are made:

The bank erosion problem at Notakhola is very erratic in nature and due to the planform and the main flow direction it is still at the stage of erosion prone zone. Geological factor /bank protection works some times can protect the bank from further erosion, which is not present at Notakhola. Another important point is that, the Jamuna has a tendency of shifting towards the West. This statement is supported by the historical planform changes, i.e. the bank erosion may continue as per demand of the natural process of the shifting of the river. Besides these the bank material at the Jamuna river composed of purely sand and it can't resist bank erosion during high flow velocity. On the other hand the riverbanks are collapsed due to seepage during falling stage of discharge.

- The Jamuna riverbed is being silted-up and the river is widening. The silting up of the Padma river is not so pronounced, but the river is widening.

- The Aricha Ferry Ghat is still on the eroding bank if it is analyzed and compared with the main flow. But the advantage is, the Ferry Ghat is to some extent protected from bank erosion due to the bank protection works at that area. As a result the bank erosion is not so dominant. Furthermore, the existence of a big char very close to the Aricha Ghat is noticeable.

- The Daulatdia Ferry Ghat didn't face significant erosion since last couple of years rather than deposition is found in this area. This can be explained that the main flow is along the left bank. But in course of time both the bank might face erosion unless it is restricted by the geological characteristics.

- The Ferry Ghat basin and most parts of the channel is situated perpendicularly to the general flow for which, there exists almost no flow in the basin and channel during the dry season.

- The siltation problem along the navigation route is a very acute problem, which is hardly possible to reduce at the present situation. Because these Ferry Ghat is located very close to the upstream and downstream of the largest river confluence. On the other hand, the Ganges and the Jamuna carries huge sediment load in addition to the local bank erosion. Therefore, it is a natural process that siltation will occur at the falling stage of the hydrograph each year. Moreover, the discharge has a wide range of variation through out the year, which can not adjust the wide cross section more than 10Km in the Jamuna. So the erosion and siltation is the outcome. In addition, this discharge variation from very low discharge to high discharge accumulates the other morphological problems, which makes the situation more complex. This can not be mitigated unless effective river training works are done.

Recommendations

The siltation problem of the Notakhola-Aricha- Daulatdia is very complicated and it is essentially requires detail study to identify real causes and the way of finding out the solution. In detail study and feasibility study could be carried out say for instance as Gorai River Restoration Project.

The river training is required to mitigate the siltation problem at the said area. The effectiveness of the required structure is very difficult to assess ahead for such a complicated problem. Therefore, the type of structure to be adopted here and its effectiveness should be studied in depth.

This type of morphological problem as well as the effectiveness of the required structure can be studied properly by physical modelling. RRI is the only authorized government organization to carry out the physical model study. It has vast experience in investigating the morphological problem as well as effectiveness of any hydraulic structure by physical model study.

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PHYSICAL MODEL STUDY OF DISTORTED MORPHOLOGICAL MODEL: A CASE STUDY OF GORAI RIVER RESTORATION PROJECT

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Abstract

This paper illustrates the features of possible hydrodynamic and morphological changes due to the construction of various engineering interventions at Ganges-Gorai channel especially at the Gorai offtake. An overall hydromorphological model of Ganges-Gorai river with recirculation of the sediment was constructed to study flow, sediment transport and 2-D bed topography of the Ganges-Gorai offtake, in particular to study the effect of any structural interventions in the system to improve the functioning of the offtake. In the modelling 24 km river reach along Ganges river (starting from Hardinge Bridge) and 14 km river reach along Gorai river (from offtake to 2 km d/s of Gorai Railway Bridge) were considered. Necessary topographic, hydrographic, bed and sediment data were collected and used for the design of overall distorted morphological model using a horizontal scale ratio of 1:300 and vertical scale ratio of 1:52. The model bed was filled up with a fine sand of D_{50} = 0.08 mm so that the morphological development could be occured in the model. Upstream and downstream boundary conditions were collected from ADCP survey by Surface Water Modelling Centre (SWMC). After necessary calibration, a number of test runs were conducted. Discharge and sediment passed through the Gorai channel were found from the re-circulating pipe system. Morphological development such as erosion, channel shifting, bar migration, formation of new channel and siltation in the vicinity of the Gorai offtake were studied. Predictions were made by analyzing the soundings. The overall results were qualitative in nature but the results obtained from the model study so far proved to be very useful for taking some important decisions. For quantitative predictions, sectional models were recommended.

Introduction

The Gorai river, off-taking from the Ganges river, is an important source of fresh water supply to the South West Region (SWR) of Bangladesh. It is the only remaining major spill channel of the Ganges river flowing through the SWR. For the last 10 years, or so, the dry season (January-May) discharges in the Gorai river have decreased resulting in an increased salt water intrusion with negative environmental impact on the coastal areas of the SWR and Khulna. The 'Sunderbans' area is also believed to be adversely effected. It is feared that the decreased dry season flows will lead to the siltation at the off-taking point of the Gorai channel to an extent that the river may be permanently disconnected from the Ganges river. This would deprive the region of an important source of freshwater supply. As a part of the project, an overall hydromorphological model of Ganges-Gorai river system was undertaken for finding engineering solution of river training works with a view to augment the water flow to the Gorai from the Ganges during the dry season. Seven test runs including calibration test were conducted in the model.

Model set-up and scale ratios

A distorted morphological model was set-up using the existing and developed facilities at RRI. An open-air model bed of 30m× 125m has been used for setting up the model. Area reproduced in

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the model is about 24km, which includes Hardinge Bridge in the upstream, 2km downstream of Gorai Railway Bridge in the Gorai and upto 10km downstream from the off-take in the Ganges downstream. The model layout can be seen in **Figure 1**.

The horizontal and vertical scales for the model have been selected primarily by RRI with the technical assistance of WL I Delft Hydraulics and BUET considering various aspects of the space, geometry, pumping capacity, measurements etc. The length scale have been selected as n_L=300 and the vertical scale has been primarily selected as n_h=60 by making comparison between different possibilities. Initially the model have been constructed with geometric scales of n_L=300 and n_h=60. But the vertical scale should automatically come out from the scale laws and conditions while operating the model. The vertical scale for this distorted morphological model have been found to be n_h=52 from the calibration of the model.

The bankfull discharge at Hardinge bridge is approximately 43000 m^3/s, which was used in the model design. Left channel in the Ganges(approximately 2000 m^3/s) was not reproduced in the model and accordingly 41000 m^3/s discharge was used for the model to be run for calibration and application tests.

Model construction

The river bed has been constructed in the model according to the bathymetric data before the dredging activities started. These are the data that have been collected by SWMC during 1998 pre-dredged survey (July to November 1998).

The model was constructed with a closed re-circulation system for water and sediment transport. Water and sediment were transported in the model and collected at the downstream sumps of the Ganges and Gorai. From these sumps the water sediment mixture was re-circulated through the pipes towards the upstream part of the model.

Test description

Test runs

The results of the calibration Test T0 as well as six application test runs (T1-T6) are presented in this paper. The calibration test was used to calibrate the model i.e., to match the model with the prototype condition. It is worth mentioning here that the interpretation made in this paper is indicative rather than quantitative. In each test run different scenario was studied which is briefly described here.

Test set-up and objective

The set-up of these tests and its objectives are described below and a summary of the test runs is shown in **Table 1.**

Calibration test

Test T0

Test T0 contributed to the calibration of the model. The 1998 predredged bathymetry surveyed by SWMC has been used in the model. The existing structures such as Kushtia groynes, Hardinge bridge, Gorai railway bridge, Talbaria scour hole with clay layer have been reproduced on scale. The model was run with a constant discharge of 400 l/s corresponding to the bankfull discharge of the Ganges active channel along the right bank (41,000 m^3/s).

Application tests

Test T1

This is the first application test carried out on the existing set-up of the calibrated model plus a series of nine groynes along the right bank of Ganges upstream of Talbaria. The objective of this test was to stabilize the right bank of the Ganges upstream of Talbaria. In the model some gravels were placed near the toe of the groyne head to protect the head of the groyne from exaggerated local scour.

Test T2

The set-up of this test was introduction of the flow divider at the Gorai off-take along with the final condition of Test T1. The objective of this test was to increase the flow through the Gorai and to observe the hydraulic and morphological change around the divider.

Test T3

In this test the length of the flow divider was increased. The other scenario was the final stage of Test T2, i.e., the final bathymetry of Test T2 along with the groynes. The objective of this test was to see the performance of extended flow divider on the discharge through the Gorai and to observe the hydraulic and morphological change around the off-take.

Test T4

This test was conducted with the end condition of Test T3 along with the inclusion of a Ganges-Gorai revetment at the right bank of the Gorai. The objective of this test was to see the performance of extended flow divider in combination with the Ganges-Gorai revetment on the discharge through the Gorai and to observe the hydraulic and morphological change around the off-take.

Test T5

The constructions tested in Test T5 consisted of the groynes along the Ganges Right Bank (same as in Test T1, T2, T3 and T4), the Ganges-Gorai revetment (same as in Test T4) and a new design for the divider. The model was remoulded so that the bathymetry at the start of Test T5 was equal to the bathymetry during the final stage of Test T1. The objective of this test was to see the performance of the flow divider in combination with the Ganges-Gorai revetment on the discharge through the Gorai and to observe the hydraulic and morphological change around the off-take.

Test T6

This test was same as Test T5 along with the advanced revetment at the right bank and a series of groynes at the left bank upstream of the Gorai Railway Bridge. Bathymetry used in this test was the final bathymetry of Test T1. The objective of this test was to see the performance of the flow divider and Ganges-Gorai revetment along with the training works in the Gorai and to observe the hydraulic and morphological changes around the off-take. **Table 1** shows the test objectives and scenerios of different tests.

Interpretation of test results

Six application tests have been done during which different constructions and combinations of constructions have been tested in the Distorted Morphological Ganges-Gorai Model. **Table 2** summarises the observations during the model tests. It is worth mentioning that the values indicated in this table are average values over the last three days of each model test for Test T0 through T6.

In order to make a conclusion on whether the constructions of interventions have resulted in a reduction of the blockage of the Gorai off-take some information should be kept in mind about the process of blockage. This blockage of the Gorai channel is caused by several factors. The first factor is that the off-taking channel of the Gorai splits with the Ganges under a certain angle. When this angle is bigger, more sediment will enter the Gorai channel. It is therefore recommended to design the constructions at the off-take in such a way to reduce this angle between the Ganges and Gorai.

This process of sediment transport into the Gorai is further increasing due to the fact that the Gorai off-take lies within an inner bend of the Ganges (downstream of Talbaria). Due to the helical flow in the Ganges bend the sediment transport will tend to flow towards the inner bend (= towards the Gorai). Due to the erosion upstream of the Talbaria hard point the radius of this bend has decreased. This has resulted in a situation where more sediment is directed into the off-take due to this process.

The blockage of the Gorai off-take during each monsoon is a natural phenomenon which has occurred for many decades. During the highest discharges during the monsoon season the combination of high flow velocities (resulting in high sediment transports) and high water levels the Gorai off-take result in a redistribution of sediments over the higher and lower parts of the off-take. The deeper channels will face entrapment of sediment. The area will be less undulated. During the falling limb of the hydrograph the Gorai channel tends to deepen due to retarded scour. It has been observed that the period over which the discharge reduces in the Ganges is reduced in the last decades. This results in the fact that the retarded scour can not develop a channel in the Gorai, which can remain open during the entire dry season. One of the major purposes of constructions in the off-take should therefore be to initiate the formation of a channel in the Gorai off-take during the monsoon season so that the retarded scour, which can only act during a shorter period, can still develop in a channel which can be maintained during the dry season.

A last point which is very much important for the sedimentation at the off-take is the large width of the off-take. During the high water levels at monsoon season the Gorai off-take becomes much wider at the off-take than the river is at further downstream. This results in a reduction of the flow velocities in the off-take which on its turn result in sedimentation. Planned constructions could be designed in such a way that the sediment is kept in motion so that less deposition takes place in the off-take.

The sediment transport into the Gorai would give a good view on potential amount of sediment which can be deposited in the off-take. The most suitable place for the measurement of this sediment transport would within the off-take. These type of sediment transport measurements are not carried out in the present set-up of the model. The distance between the off-take and the location where the Gorai sediment transport is measured is too long to find a direct relation. In fact, these sediment transport measurements were mainly used in order to determine whether the model was calibrated during the Test T0. Care should therefore be taken in making direct conclusions from the sediment transport in the Gorai.

During the Tests T1 to T6 a groyne field was tested along the Ganges right bank upstream of the Talbaria hard point. The model indicated that the Ganges channel along this groyne field is expected to shift away from the right bank. When the Ganges channel would shift over a long distance from the Ganges right bank this would result in a situation in which the Gorai off-take would not be located anymore in an inner bend. The model has indicated, however, that the shift was not large enough to change the location of the off-take in the inner bend. The morphological situation in the Gorai off-take was not improved by the placement of the groynes. Most probably it would not economically be feasible to make constructions which would shift the Ganges channel further away from the present bankline. In any case the groyne field can, by stopping further bank erosion in this reach, lead that the situation will not further deteriorate. During Test T2-T6 three alternatives of a divider was tested. The divider in Test T2, T5 &T6 was fully placed on top of the clay bank. In Test T3 and T4 the divider was extended so that the head of the divider would be placed outside the area where the presence of the clay bank is known. During all the three tests the divider showed to initiate the formation of a channel along the Gorai side of the divider. This is considered to be a very much positive development because this initiates the formation of a channel during the monsoon season which dimensions can later be enhanced by the retarded scour during the falling limb of the hydrograph. Although the formation of this channel would only really be effective during the falling limp of the hydrograph, it is also worth looking at the impact on the bankfull discharge in the Gorai. It can be concluded that both the initial and the extended divider resulted in an increase of the Gorai discharge. It is expected, however that the increase will be more during lower discharge values due to the formation of the distinct channel along the divider. During Test T4 to T6 a Ganges-Gorai revetment was constructed into the Gorai downstream of Talbaria. This Ganges-Gorai revetment has resulted in a situation in which the angle between the Ganges and the off-taking Gorai is reduced. Furthermore, the off-take is more gradual. The revetment also has narrowed the off-taking Gorai channel over a considerable length. These changes (off-take angle and width) have resulted in a situation in which the higher final discharge was recorded in the Gorai and which resulted in a distinct channel along the divider. Some more attention should be given to the sedimentation that occurred along the Ganges-Gorai revetment. This is most probably related to a combined effect of the formation of a pointbar along the Ganges-Gorai revetment and the flow around the divider head. It should be mentioned here that this sedimentation in the form of a point bar along the revetment is exaggerated in the morphological model. Also important is the impact of the presence of the clay bank. Test T3, T4 and T5 showed a very deep scour hole between the divider and the char. It is believed that the location of the (smooth) clay bank has had a major impact on the development of this scour hole. It is suggested to pay more attention to the hydraulic and morphological impact of the presence of this clay layer. The model has indicated that the divider would result in a redirection of the Ganges channel towards the char opposite of the divider. It is therefore expected that erosion will take place of the char bankline opposite (and downstream) of the divider. For the sustainability of the construction of the tested constructions it would be good to know the overall development of the Ganges channel. Due to the morphological development upstream of the Hardinge Bridge the Ganges might tend to shift away from the left bank. It is known that the location of channels of alluvial rivers are very much influenced by the presence of large scour holes. The channels have a tendency to remain at the location of this scour hole. The construction of a divider in the Ganges might result in the formation of another large scour hole downstream of the existing Talbaria scour hole. This would in fact be a positive development as the Ganges channel would tend to be located along these scour holes. It is worth mentioning that the clay bank might have a major impact on the actual formation of such scour holes as the clay bank seems to be quite resistible against erosion. In fact, the divider that was fully constructed on top of the clay bank in Test T2 did not show the development of a large scour hole. Test T5 & T6 indicated that the bar, which was clearly formed during Test T4, would be less pronounced when the divider tested in Test T5 & T6 would be constructed. Although a pointbar developed along the Ganges-Gorai revetment, this did not seem to block the Gorai channel too much. Test T5 showed a very deep scour hole between the divider and the char. It is believed that the location of the (smooth) clay bank has had a major impact on the development of this scour hole. The bathymetric surveys of SWMC indicated that such a scour hole could also be observed in the field, but at a different location. It is therefore strongly recommended to collect more information about the actual extend of the clay bank in the offtake, also into the Ganges channel. The location where this scour hole is formed seems to have a major impact on the flow field and the morphological development around the flow divider. In general, it can be stated that such a scour hole is positive to keep the Ganges channel flowing along this location. It is known that the location of channels of alluvial rivers is very much influenced by the presence of large scour holes. The channels have a tendency to remain at the location of this scour hole. The construction of a divider in the Ganges might result in the formation of another large scour hole downstream of the existing Talbaria scour hole. This would in fact be a positive development as the Ganges channel would tend to be located along these scour holes. The channel in between the divider and the char showed high flow velocities around the divider head and sedimentation along the char bankline. Although the model showed this sedimentation along the char, it is still believed that some erosion should be expected opposite of the divider. The construction of the advanced revetment and the groynes in the Gorai ,which was tested in test T6 would result in the lowering of the bed by 1.3 to 1.4 m due to constriction scour. Furthermore, these constructions would result in the increase of the slope between the offtake and the constricted reach. This is considered a positive effect to increase the retarded scour process by introducing an increase of the flow velocities in this reach.

Conclusions

From the test results it can be concluded that Test T6 seems to be the best option between all the options tested in this model. This is caused by several factors.

The first factor is that the Gorai discharge would be 10.4 % of the total Ganges discharge (at Hardinge Bridge). This is the highest discharge of all the earlier tests. The second factor is the formation of the channel along the flow divider. This channel will become bigger due to the retarded scour during the receding season. This will result in an increased dry season discharge.

The third factor is the reduced width of the Gorai off-take. During the Tests T4 -T6 a Ganges-Gorai revetment was tested along the Gorai right bank, downstream of Talbaria. This revetment has resulted in a situation in which the angle between the Ganges and the off-taking Gorai is reduced. Furthermore, the off-take is more gradual. The revetment also has narrowed the off-taking Gorai channel over a considerable length. This narrowing is good to keep the flow velocity large enough to keep the sediment into transportation. These two changes (off-take angle and width) have resulted during the Test T6 in a situation in which the highest final discharge was recorded in the Gorai and which resulted in a distinct channel along the divider.

Recommendations

The flow divider and Ganges-Gorai revetment at the off-take seems to be effective to increase the discharge through the Gorai as observed in overall distorted model running with the constant discharge. The length, slope and orientation of the flow divider tested in overall distorted model seems to be the best choice in Test T6. Though the model results were more indicative rather than quantitative, in particular the discharge and sediment distribution through the Gorai, but the results obtained from the distorted model will be very much helpful for taking important decisions. For quantitative results, sectional models were recommended.

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Table 1 Summary of the Test Objectives and Scenerios

Tests	Objective	Scenarios
T0	Calibration of the model	1998 predredged bathymetry with existing structures
T1	To test the groyne field along the right bank of the Ganges to stabilize the right bank of the Ganges	Equilibrium bathymetry obtained from T0, existing structure plus the groyne field (series of nine groynes along the right bank of the Ganges channel up to Talbaria hard point)
T2	To test the performance of the flow divider on the Gorai discharge and consequent hydraulic and morphologic changes.	Final bathymetry of the test T1 with existing structure, groyne field along the right bank of the Ganges and flow divider at the off-take
T3	To test the effectiveness of the extended flow divider on Gorai discharge	Final bathymetry of the test T2 with existing structure, groyne field plus extended flow divider
T4	To test the performance of the Ganges-Gorai revetment plus the extended flow divider at the off-take	Final bathymetry of test T3 with existing structure, groyne field at the upstream, extended flow divider of test T3 plus the Ganges-Gorai revetment.
T5	To test the performance of the Ganges-Gorai revetment plus short flow divider with hokey stick shape head at the off-take	Final bathymetry of test T1 with existing structure, groyne field at the upstream, short flow divider provided by the Main Consultant plus the Ganges-Gorai revetment.
T6	To test the effectiveness of the Ganges-Gorai revetment plus short flow divider with hokey stick shape head at the off-take plus an additional series of groynes along the Gorai left bank upstream of the Gorai Railway Bridge and a revetment along the Gorai right bank upstream of the Gorai Railway Bridge.	Final bathymetry of test T1 with existing structure, groyne field at the upstream, short flow divider provided by the Main Consultant plus the Ganges-Gorai revetment plus Gorai groynes & Gorai revetment.

Table 2 Summary of results of Distorted Morphological Ganges-Gorai Model Test T0 to T6

Effect / Test	Test T0	Test T1	Test T2	Test T3	Test T4	Test T5	Test T6
Description tested structures	calibration	groynes	groynes + divider	groynes + extended divider	groynes + extended divider + Ganges-Gorai revetment	groynes + changed divider + Ganges-Gorai revetment	groynes + changed divider + Ganges-Gorai revetment +Gorai groynes+ Revetment
Ganges discharge (m^3/s)	43,000	43,000	43,000	43,000	43,000	43,000	43,000
Discharge distribution final stage (%)	6.2	6.5	7.3	7.5	8.8	10.8	10.4
Water level GK (cm)	12.96	13.77	13.13	12.75	14.26	13.11	12.19
Water level Talbaria (cm)	8.61	8.61	8.34	8.20	9.48	8.41	7.67
Water level Ganges D/S (cm)	4.32	5.59	3.82	3.83	3.76	3.94	3.58
Water level Kushtia (cm)	4.60	4.75	4.87	4.68	6.21	5.80	4.99
Water level GRWB (cm)	1.27	1.53	1.78	1.97	3.12	2.94	2.99
Water slope GK - Talbaria (-)	0.000950	0.001130	0.001050	0.000997	0.001046	0.001030	0.000991
Water slope Talbaria - Ganges D/S (-)	0.001220	0.001420	0.001278	0.001237	0.001620	0.001265	0.001156
Water slope Talbaria - Kushtia (-)	0.001720	0.001660	0.001487	0.001507	0.001403	0.001119	0.001148
Water slope Kushtia - GRWB (-)	0.001430	0.001380	0.001323	0.001164	0.001324	0.001223	0.000855
Sediment transport Ganges (l/s)	0.0760	0.1351	0.1345	0.1064	0.1763	0.1696	0.1232
Sediment transport Gorai (l/s)	0.0012	0.0014	0.0014	0.0012	0.0021	0.0050	0.0050
Total sediment transport (l/s)	0.077	0.137	0.136	0.108	0.178	0.175	0.128
Shift Ganges channel away from bank in groyne field reach	0	+	+	+	+	+	+
Dimension Talbaria scour hole	0	+	+	+	+	+	+
Depth Talbaria scour hole	0	+	+	++	++	++	++
Scour between divider and char	0	0	+	++	+++	+++	++
Shift of Ganges channel due to divider	0	0	+	++	+++	++	0
Chance of erosion char	0	0	+	++	+++	++	+
Sedimentation in off-take area	0	0	+	++	+	+	+
Sedimentation downstream of divider	0	0	+	+++	+	+	+
Opening Gorai channel during constant bankfull discharge	0	0	+	++	+++	+++	+++
Expected effect on dry season discharge Gorai	0	0	+	+	++	+++	+++

Note: All values mentioned in this Table are the average values of the last three days of test.

0 = no change in comparison with T0
+ = increase in comparison with T0
++ = much increase in comparison with T0
+++ = highest increase in comparison with T0

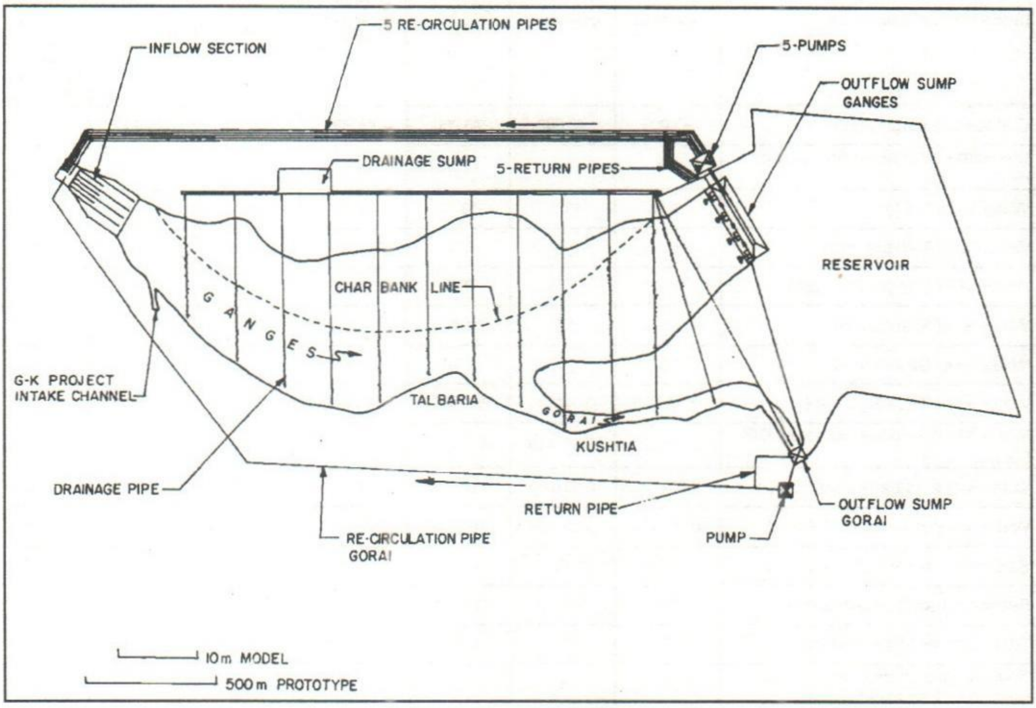

Figure 1 Layout of Ganges-Gorai Distorted Morphological Model

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THE CLASSIFICATION OF CATCHMENTS

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Abstract

Regionalisation is the process of generalising informati,.on from the sites where records are sufficient and transferring this information to the ungauged sites. All catchments belonging to a homogeneous region are assumed to behave in similar fashion. The first step in regional flood frequency analysis is the identification of homogeneous regions for which a modern informatic tool such as artificial neural network may be invoked. Application to this technique to the combined data set for Java & Sumatra in Indonesia has demonstrated that classes may be defined by Representative Regional Catchments (RRCs), whose characteristics are hydrologically more appealing than those imparted merely by geographical proximity. The employed technique, Kohonen neural networks is simple & straightforward in application, and was found to identify broadly similar RRCs.

Introduction

The graphical approach is the traditional way of identifying a homogeneous region. In this approach: i) an index flood is regressed upon catchment and rainfall characteristics for the whole data set; ii) the residuals *i.e.* the difference between observed and computed values of the index flood, are plotted geographically in order to identify groups of these differences that are similar in both magnitude and sign and therefore may be regarded as a sub-region; and iii) the regression analysis is repeated for the sub-regions identified and then generalised across the whole region (Hall & Minns, 1999). Clearly, the resulting flood regions will embrace catchments that are geographically contiguous. Here, the allocation of an ungauged catchment to a flood region can be achieved by plotting the geographical position of that catchment on a map and noting region within which it lies. The residual method has some drawbacks. Nathan & McMahon (1990) pointed out the large subjectivity involved in drawing the regional boundary means that different hydrologists would obtain different groupings. Wiltshire (1985), and Acreman & Sinclair (1986) also commented that the geographical proximity is no guarantee of homogeneity since neighbouring catchments can be physically different.

An alternative to geographical proximity as measure of affinity offered by some clustering algorithms is Euclidean distance in the *n*-dimensional feature space that is defined by the *n* characteristics that have been adopted for site description. This quantity is defined more formally below, but may be based on seadardized flow statistics (Mosley, 1981; Wiltshire, 1985), selected physical features of a catchment (Acreman & Sinclair, 1986), or a combination of both (Burn, 1990).

In the latter study, a threshold value of distance was employed to identify the group of catchments that define the region of influence of one particular site. This process of feature detection or pattern classification may also be carried out using modern informed tools, such as Artificial Neural Networks (ANNs). To date, ANNs have been applied successfully to rainfall-runoff modelling (e.g. Minns & Hall, 1996; Dawson & Wilby, 1998) by training the network to develop a relationship between a rainfall "input" and a discharge "output", a process known as *supervised learning*. However, neural networks can also be applied in a mode of unsupervised or competitive learning (see Beale & Jackson, 1990; Aleksander & Morton, 1990) using a particular type of ANN

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called a Kohone network for which there are no output data as such, but a feature line or map. A Kohone network therefore has the potential to define both the number of "classes" in a data set and the features that define each class. A possible disadvantage to methods of classification based upon Euclidean distance, including Kohone neural networks, is the absolute certainty of the allocation to a particular class (Hall & Minns, 1999).

In this paper each site may be defined by a finite number of features. As described in the following section, the Kohonen network uses these features as inputs, and identifies similar patterns by firing particular output units. The number of units that are fired defines the potential number of classes, and the input patterns that trigger each output unit serve to quantify that class.

Classificataion

The general problem of classification can be summarized in the following terms. Given a sample *X* of *K* data, i.e.

$$X = \{\bar{x}_1, \bar{x}_2, \bar{x}_3, \ldots, \bar{x}_k, \ldots, \bar{x}_K\}$$

Where each data point is defined by *N* features:

$$\bar{x}_k = \{\bar{x}_{k1}, \bar{x}_{k2}, \bar{x}_{k3}, \ldots, \bar{x}_k, \ldots, \bar{x}_{KN}\}$$

A procedure is required to identify the number of classes *c* into which *X* can be partitioned, where

$$2 \leq c \leq K$$

The upper limit to this range represents the trivial case in which each data point forms a separate cluster, whereas the use of 2 as the lower limit avoids the notion that there are no clusters at all in the data set. The process of classification is based upon the assumption that the members of a cluster are mathematically more similar to each other than to members of other clusters. A commonly-applied measure of similarity is the Euclidean distance, the use of which depends upon such distances being considerably less between points in the same cluster than between points in different clusters. Given that the features included are indeed sensitive to the purpose of the analysis, the objective should be identify the *c*-value that partitions the data set into the most plausible number of clusters. Hence, the dual objectives are (a) to minimize the Euclidean distance between each point in the feature space and the center of the cluster to which it belongs; and (b) to maximize the distance between the centres of the clusters (Hall & Minns, 1999).

Artificial neural networks

ANNs originated largely in the field of pattern recognition, and are notable for their ability to "learn" the relationship between a set of inputs and outputs without a priori knowledge of the underlying physical process that connects them. In general, the numbers of input and output nodes in the network correspond to the numbers of inputs and outputs of the deterministic relation being learned. However, sandwiched in between the layers of input and output nodes are one or more intermediate layers whose nodes are directly connected to all those in the input and output layers associated with each connection is a weight which can either inhibit or amplify the signal being transmitted. The nodes then act as summation devices for the (weighed) incoming signals, which are then transformed to an output signal using a threshold function, which restricts its range to the interval zero-to-one. Standard algorithms, such as the back-propagation method, are available for manipulating the weights so that the ANN reproduces the output from the input with minimum (Beale & Jackson),1990; Aleksander & Morton, 1990). The process of adjusting the weights is referred to as "training the network", and the desired input-output relationship is encapsulated in the weights.This is the process which is referred to as "supervised learning". In "unsupervised learning", the emphasis changes from "learning" input-output relationships to that of "recognizing" patterns in the input data. The Kohonen network is a typical tool for this purpose, consisting of a single layer of J output nodes, each of which is connected to all N input nodes. The training process begins by initializing the weighs, $w_{nj,}$ between the nth input and the jth output nodes. The network must then "decide' which output node is associated with each of the K input patterns, $\bar{x}_k$ as it is presented, and then to "fire" it. The node to be fired is decided by computing a similarity measure, such as the Euclidean distance for each output node, j:

$$D_{kj} = \sqrt{\sum_{n=1}^{N} \left(x_{kn} - w_{nj}\right)^2}$$

The "winning" node for a give input pattern is then selected as that with the smallest Euclidean distance measure. The affinity of the winning node to the input is then enhanced by adjusting the weights connected to the winning node by amount that is proportional to the difference between the input vector and the weight vector. Similar input patterns should therefore fire nodes that are close together. In order to maintain this neighbourhood feature, the weights of connections to nodes that are adjacent to the winner are also updated, but the number of nodes being changed decreases as training progresses. A visual impression of the final output can by counting the number of occasions each node is fired for the whole input data set. In effect, each frequently-fired node defines a class, and the input vectors that node are the members of that class (Hall & Minns, 1999).

Application of the kohonen network

The principle of training a Kohonen network is the same as that for any ANN, namely the repeated presentation of the input data sets (in this case, six catchment characteristics per gauging site) until the output response of each input vector has stabilized and the resultant weight changes are negligible. In this application, there were six input nodes and 92 patterns. For the design of a Kohonen network, Melssen et al. (1994) suggest that:

Number of patterns>> Number of output nodes > 2_ Number of classes

Since at least two, or possibly three, classes were expected, a set of fifteen output nodes was adopted.

The results from repeated presentations of the input patterns with different randomised initial weights are summarised in **Table 1**, which indicates a clustering around all 15 output nodes. The weights associated with the six connections to each of the input nodes, which are the standardised cluster centres in Euclidean space, define what may be termed RRCs. **Table 1** also represents the de-standardised catchment characteristics of these RRCs for 10 non-zero output nodes. This table demonstrate that the variations of each site characteristic are essentially monotonic, and that the classes identified move from relatively small, steep catchments with short main stream length, an average annual rainfall around 3454 mm and smaller *PLTN* & *LAKE* indices to larger, flat drainage areas with long main stream length, an average annual rainfall around 2523 mm and high *PLTN* & *LAKE* indices. For each of these 3 clusters, the average of the 6-catchment features was computed, giving rise to the RRCs summarised in **Table 2**. For convenience, the grouping of the smallest catchments is referred to as cluster A, and that of the largest catchments as cluster C. **Table 2** shows that Cluster B is an intermediate case between cluster A and C. Thus Kohonen neural network should produce clusters which are supportable from a hydrological point of view. The Euclidean distances between RRCs (cluster centres) and their corresponding member catchments were calculated and are presented in **Table 3**. The bold numbers indicate that they are at a closer distance from the corresponding RRC or cluster centre.

Conclusion

The reasonable agreement between the features of the RRCs defining the cluster centres on which the classes were based is encouraging, and demonstrates once again that, in hydrological terms, combinations of catchment characteristics are perhaps a more logical basis for a regionalization than geographical proximity. The results indicate the feasibility of employing this methodology on a country-wide basis.

Table 1 Classification of sites by Kohonen network, with numbers allocated and the characteristics of the Representative Regional Catchments for 15 potential classes.

Class	Number	Representative Regional Catchments					
(output node)	of sites	*AREA*	*AAR*	*MSL*	*S1085*	*1+PLTN*	*1+LAKE*
1	16	292.214	3454.433	36.545	41.470	1.007	1.000
2	7	425.113	3010.915	44.611	29.578	1.014	1.001
3	6	552.648	2989.439	50.791	27.026	1.018	1.002
4	1	557.840	2953.242	52.286	25.895	1.028	1.002
5	0						
6	0						
7	1	557.840	2953.242	52.287	25.895	1.028	1.002
8	27	704.226	2699.383	60.425	15.102	1.038	1.003
9	7	1870.988	2616.320	93.497	10.301	1.080	1.033
10	4	2001.011	2545.624	97.305	10.445	1.087	1.036
11	0						
12	0						
13	0						
14	3	2051.557	2523.342	98.433	10.293	1.088	1.037
15	20	3228.803	2534.734	133.984	5.704	1.140	1.064

Table 2 Average values of six catchment characteristics for 3 clusters

Characteristics	A	B	C
AREA	289.408	763.785	4187.843
AAR	3462.667	2567.718	2477.348
MSL	35.133	65.277	154.148
S1085	42.305	13.383	5.236
1+PLTN	1.006	1.044	1.158
1+LAKE	1.000	1.003	1.093

Table 3 Euclidean distances between RRCs and corresponding member catchments

Catchment no.	AREA	AAR	MSL	S1085	1+PLTN	1+LAKE	Euclidean distance
4	126.300	4950.000	12.500	22.400	1.000	1.000	1505.05
7	139.200	3631.000	56.600	22.400	1.000	1.000	235.28
25	79.300	4086.000	26.200	21.000	1.000	1.000	666.88
27	0.430	3650.000	0.400	87.000	1.000	1.000	356.04
28	3.050	3490.000	3.200	100.000	1.000	1.000	299.03
29	10.810	3483.000	5.500	111.000	1.000	1.000	292.92
30	4.720	3517.000	3.600	111.000	1.000	1.000	304.12
31	2.430	3480.000	1.300	123.000	1.000	1.000	304.17
32	212.400	4079.000	36.300	15.200	1.000	1.000	630.19
33	2642.400	4050.000	132.400	8.230	1.000	1.000	2426.60
43	56.400	3424.000	102.900	85.500	1.000	1.000	250.75
49	187.400	3250.000	32.100	55.000	1.000	1.000	230.18
313	209.300	3040.000	21.000	63.500	1.020	1.000	423.50
314	121.600	3860.000	20.200	45.000	1.000	1.000	440.31
316	110.000	3450.000	23.700	53.400	1.000	1.000	183.11
341	304.900	4050.000	31.400	31.200	1.019	1.000	595.81
8	49.200	2709.000	10.000	55.300	1.000	1.000	484.07
9	75.600	2679.000	11.500	43.700	1.000	1.000	483.34
15	179.900	3266.000	32.200	18.700	1.000	1.000	354.22
18	178.500	3389.000	30.800	17.800	1.000	1.000	451.77
23	34.600	3327.000	11.600	14.500	1.000	1.000	503.71
50	152.000	2469.000	27.900	64.200	1.000	1.000	608.06
343	304.000	3100.000	54.600	32.600	1.044	1.000	150.71
6	217.600	3482.000	52.200	1.250	1.000	1.000	596.27
17	634.700	3415.000	54.100	6.760	1.000	1.000	433.89
19	320.300	3279.000	48.600	8.560	1.000	1.000	371.72
20	300.000	3364.000	68.400	13.500	1.000	1.000	452.35
24	108.500	3261.000	25.000	9.740	1.000	1.000	521.51
342	1267.000	3440.000	67.400	12.500	1.023	1.000	844.86
701	649.700	3210.000	50.400	15.200	1.077	1.000	272.91
512	343.700	3220.000	77.000	14.800	1.022	1.000	343.15
10	757.400	2560.000	59.400	13.200	1.000	1.000	149.20
11	474.900	2715.000	35.500	19.900	1.000	1.000	231.25
16	622.100	2669.000	81.700	7.990	1.000	1.038	90.39
21	622.000	2970.000	91.100	7.060	1.000	1.000	284.61
26	495.100	2988.000	46.300	10.400	1.000	1.000	356.73
35	1749.400	2985.000	86.000	10.500	1.000	1.000	1083.81
36	417.200	2270.000	34.600	33.200	1.000	1.000	517.44
38	101.900	2295.000	16.100	30.200	1.000	1.000	726.99
39	141.500	2423.000	37.200	6.320	1.000	1.000	627.43
40	90.000	2034.000	18.600	40.200	1.000	1.000	906.86
44	1442.000	2122.000	54.100	1.600	1.000	1.031	936.97
52	772.200	1990.000	38.300	25.500	1.000	1.000	713.05
202	215.000	2600.000	37.700	16.200	1.000	1.000	499.74
205	979.000	2650.000	76.300	19.200	1.107	1.000	279.66
216	836.900	2120.000	60.800	19.500	1.000	1.000	594.40
219	629.700	2970.000	60.000	8.400	1.041	1.000	280.77
243	180.800	1950.000	45.000	24.600	1.000	1.000	914.26

Table 3 (continued)

Catchment no.	AREA	AAR	MSL	S1085	1+PLTN	1+LAKE	Euclidean distance
246	727.700	2040.000	53.500	8.550	1.001	1.000	659.87
331	436.900	2850.000	45.300	15.700	1.053	1.000	307.21
422	906.100	2790.000	61.500	14.600	1.012	1.000	221.28
431	346.400	2340.000	44.000	10.700	1.006	1.000	507.43
515	923.000	3140.000	97.600	11.500	1.056	1.000	493.36
801	432.100	2450.000	53.400	15.700	1.101	1.000	369.18
817	416.000	2460.000	49.200	2.940	1.125	1.000	375.04
823	526.700	2490.000	92.300	12.800	1.028	1.000	276.37
825	111.300	2420.000	44.000	20.100	1.040	1.000	655.68
839	205.200	2450.000	30.800	27.600	1.024	1.000	558.80
1	1832.600	2305.000	65.400	4.810	1.000	1.039	314.98
12	1996.000	2631.000	130.400	6.820	1.000	1.000	131.22
13	1514.800	2559.000	114.600	7.620	1.000	1.000	361.40
22	1858.000	3120.000	111.300	1.830	1.000	1.000	504.23
522	1505.300	3220.000	106.600	11.300	1.175	1.000	705.93
709	2046.000	2920.000	105.200	7.530	1.056	1.000	350.71
712	567.000	2900.000	81.400	0.800	1.134	1.000	1334.58
218	820.000	2290.000	68.400	9.870	1.139	1.000	1208.70
818	661.600	2430.000	99.200	10.300	1.159	1.000	1344.39
824	555.600	2430.000	77.000	11.800	1.238	1.000	1450.17
827	528.500	2375.000	59.000	0.310	1.185	1.000	1482.89
2	2367.000	2256.000	90.600	2.260	1.000	1.030	413.65
41	1968.100	2034.000	128.000	0.400	1.000	1.032	497.39
834	903.000	2420.000	71.200	7.800	1.248	1.000	1153.52
3	4232.000	2479.000	132.200	5.730	1.000	1.017	1004.75
42	9578.000	2245.000	213.500	0.460	1.000	1.008	6356.30
45	5900.000	2342.000	201.400	0.460	1.000	1.009	2678.99
46	12429.000	2189.000	331.900	0.330	1.000	1.006	9208.82
47	8750.100	2167.000	228.000	2.370	1.000	1.357	5534.33
48	9972.900	2176.000	255.200	1.840	1.000	1.313	6754.72
51	6902.000	2231.000	202.400	2.570	1.000	1.453	3686.37
103	4494.300	2700.000	173.000	4.170	1.053	1.000	1276.84
118	4402.700	2450.000	231.200	2.880	1.072	1.000	1180.96
201	3788.900	2770.000	178.100	8.430	1.054	1.003	609.11
206	917.600	2750.000	78.900	10.600	1.563	1.000	2321.87
208	679.500	2770.000	93.400	13.500	1.622	1.000	2560.47
209	1022.500	2710.000	105.600	9.980	1.255	1.000	2213.44
413	3128.700	2580.000	159.100	2.350	1.039	1.000	112.75
511	4578.60	3290.00	150.10	7.20	1.006	1.009	1546.82
521	1256.000	2400.000	89.600	10.500	1.137	1.788	1977.90
707	4463.600	2730.000	166.600	3.630	1.102	1.112	1250.57
803	1697.900	2440.000	90.300	8.990	1.480	1.000	1534.46
807	786.000	2450.000	52.400	8.360	1.519	1.000	2445.64
812	2102.000	2400.000	122.700	5.620	1.483	1.000	1134.89

NB: The bold number indicates catchments closest to their corresponding RRCs.

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ASSESSMENT OF THE POSSIBILITY OF EROSION OF TANGAIL TOWN AND ITS ADJACENT AREA BY THE RIVER JAMUNA AND ITS PROBABLE REMEDIAL MEASURE

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Abstract

The analysis of the present study mostly concentrates on the pattern of the bank erosion along the left bank of the Jamuna river at downstream of the Bangabandhu bridge. Historical maps of he Jamuna river were collected and converted into 1:100,000 scale. Land sat and digital images were collected for the period 1973-2001. Average rate of bank erosion along the curved bank was taken into account instead of maximum bank erosion rate. The average bank erosion rate most probably will make the prediction method more realistic. Observing the superimposed historical maps and recently available satellite images of SPARRSO & EGIS-II it can be inferred that downstream part of the Jamuna river had been gradually shifting towards the west before 1973 but after that the shifting trend reversed i.e., the river has been gradually shifting towards the east.

Introduction

The main source of the Jamuna is Manas Lake of Tibet. It originates as the Tsangpo from the lake and runs several hundred km towards East and through north-east corner of Arunachal state, it enters into Assam. It passes through Assam valley as the Brahmaputra towards west and enters into Bangladesh. In Bangladesh the river flows from north to south as Jamuna and divides the country into two sectors, apparently. The Jamuna then joins the Padma at Aricha-Daulatdia (Gualando) and the combined flow then meets the Meghna at Mohanpur-Eklaspur near Chandpur and has reached the Bay of Bengal. The total distance covered by the river from its source to the Bay of Bengal is about 2900 km. In Bangladesh originally the Brahmaputra was flowing towards south-east across Mymensingh district where it received the Surma river and joined the Meghna. This original course of the Brahmaputra is known as " Old Brahmaputra" and is still flowing across the Mymensingh district as an insignificant river.

River bank erosion is a complex phenomenon which is influenced by many factors. The rate of bank erosion is determined by flow characteristics, sediment transport mechanism, composition of bank materials and properties and human activities. The bank of Jamuna river are fairly steep and consists of material with apparently no or little cohesive characteristics (80% fine sand and 20% silt/Clay). Cohesive bank erodes by mass failure when a critical stability condition is exceeded. Non-cohesive bank erodes mainly due to wave action and undercutting due to existence of secondary currents. Investigations reveal that bank erosion has a cyclic behavior. The river bed erosion results in steeper slope of the river and it increases the bank height.

The river Jamuna causes extensive bank erosion due to its unstable nature. Moreover, due to the interventions created by the construction of all river training works and bridge, the total flow concentration exerts adverse impact along both banks at the upstream & downstream of the bridge, which leads to simultaneous bank and char erosion. The adverse impact due to

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construction of Bangabandhu bridge is very significant to the left bank of the river at downstream of the bridge (RRI, Downstream Model, 1998). Tangail district has been facing tremendous erosion of the Jamuna river.

Literature Review

The river Jamuna causes extensive bank erosion due to its unstable nature. It originates in Tibet on the northern slope of the Himalayas and drains snowmelt and rainfall from China, Bhutan, India and Bangladesh. Before its confluence with the Ganges at Aricha, the river travels a length of 2,740 km. Its total catchment area is 570,000 km^2, of which only 7% are within Bangladesh. This river flowing from north to south and dividing the country approximately into two halves forms the lower part of the Brahmaputra-Jamuna drainage system. In the beginning of the 19 th century, the Brahmaputra, which at that time followed the course of the old Brahmaputra, started to flow through a new course named as the Jamuna but the upper reach still retained the old name. It is believed that an abnormal flood in the late 18 th century led to the change in the course of the Teesta. This may have caused a diversion of the Brahmaputra into its present north-south channel i.e., the Jamuna though tectonic movements in the trough between the Barind and the Madhupur Tracts may have been partly responsible. Already before entering Bangladesh, the river assumes braided patterns consisting of several channels separated by small sandbars called chars within the course. During the last 200 years or so, the channels have been swinging between the main valley limitations. As a result, during monsoon extensive over bank spill, bank erosion, bankline shifts and charland shifts have become typical for the Jamuna.

The river Jamuna is the part of the largest river systems in the world and its dimensions alone make it difficult to understand its behavior and morphological changes. As the river is highly mobile due to its fine sediments and the large floods, it is experiencing changing of its plan form in every year. Its plan form is changing completely within few years only.

Rivers of this magnitude and with these characteristics have hardly been studied in the past and therefore our theoretical understanding is still limited. The first comprehensive description about the Jamuna river was given by Coleman in 1969.

Hydrology

The mean annual rainfall on some selected stations varies from 2,372 mm to 1,440 mm with a well-defined seasonal variation. The mean estimates represent the drainage characteristics of the Brahmaputra basin in Bangladesh; the monsoon season rainfall is significant and it is about 75% of the annual rainfall whereas the dry season rainfall is a small fraction of the annual rainfall.

Maximum discharge of the Jamuna River at Bahadurabad is 100,244 m^3/s whereas minimum and average flows are 2,427 m^3/s and 20,177 m^3/s respectively. Average water surface slope is approximately 7.6 cm per km for the upper reach of the Jamuna river and 6.5 cm per km for the lower reach.

The water level during the months of July, August and September are generally high. The lowest water level generally occurs in February. The discharge starts increasing in April and the first peak flood generally occurs in June - July and is characterized by a rapid rise, the major peak occurs in August. The maximum flood of the Jamuna river is generally earlier than the one in the Ganges river. The flows in these two rivers are not in phase.

River Characteristics

The valley slope of the river decreases in downstream direction. Near Bahadurabad it is about 8 cm per km, while near the confluence with the Ganges river it is about 6 cm per km, hence varying between 0.000085 and 0.00006. The bed material of the river is fine sand with D_{50} varying between 0.22 mm at Chilmari and 0.165 mm near Aricha. The gradation is about 1.3, hence fairly uniform sediments. There is some vertical sorting also, the finer particles on the average being deposited at the higher char levels. According to an extensive sampling campaign carried out by FAP-1, 1993 bank material seems to be quite uniform also and consists of fine sand too, the highest chars being covered by a layer of 1 to 2 m thickness of deposition with more clayey particles. The little variation in bank material composition in downstream direction is different from what was suggested by Coleman, notable that the existence of nodal points is due to old clayey deposits.

The Jamuna river is a braided system, with several parallel channels in each cross-section. The dimensions of these individual channels were studied in the Jamuna Bridge Study, Phase 2 (Klaassen and Vermeer, 1988), and it was found that in first approximation regime equations could be derived for these channels as well (FAP-24, 1993). The bankfull discharge of the Jamuna river near Bahadurabad is about 44,000 m^3/s and can be slightly smaller for downstream from the offtake of the Dhaleswari River.

Shifting Characteristics

The Jamuna river is an extremely dynamic. These dynamics can be divided into the dynamics of the 2 nd and 3 rd order channels and related bars and the changes in the location and the width of the 1-st order channel.

The dynamics of the lower order channels can best be illustrated by stating that the channel pattern usually has changed completely in some 3 years. In this period bends have eroded often more than 300 m/year, channel have widened and others have narrowed or even completely disappeared, while many cutoffs are taking place every year. Figure-1 shows the historical bank line positions of the Jamuna river from the year 1830 to 2001 and the differences are amazingly large. From an inspection of these figures it can be noted that:

- There are some places in the middle of river where never a major channel has been. These are the so-called stable chars or megachars.
- Only at a few places there has always been a major channel. Notable places are near Sirajganj, already for a long time definitely because of its pronounced protrusion.
- In most cross-sections the location of the channels tends to exhibit an almost normal distribution pattern.

Shifting and widening of the river system

In addition to the dynamic behavior of the 2 nd and 3 rd order channels also the 1st order channel is subject to substantial changes, even over the limited period over which detailed information on the river system is available.

- some reaches of the river are moving in a western direction and some reaches are moving in a eastern direction.
- the upper reaches and lower reaches of the Jamuna river are widening over the last decades.

Although in the report on the Jamuna Bridge Study, Phase 2 (1989) it is still stated that no significant changes can be observed based on an analysis of the BWDB cross-sections which are surveyed every year, in the mean time the evidence is piling up that suggests that the 1 st order channel is subject to major changes.

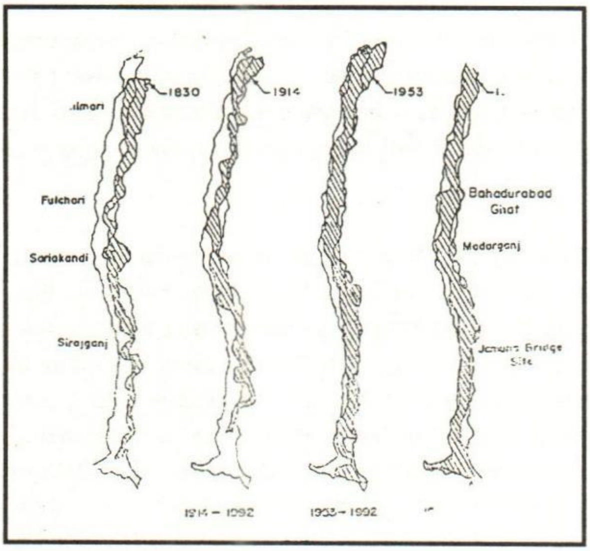

Figure-1: Historical bank line position of Jamuna river.

The evidence quoted comes from the comparison of older maps with newer ones and from studies based on the satellite images covering the period 1973-2001. Although there is some doubt as to whether the coordinate system of the Wilcox map can be used for comparison with other maps, this comparison seems to support the movement in western direction. Also the satellite images appear to suggest that in the past most of the erosion was along the western bank. For other reaches of the river this tendency is less pronounced. Figure-1 provides an overview of the downstream part of the Jamuna river where the river courses are overlaid for the period 1988-2001. It is shown in Figure-1 that in the more downstream reaches the trend is even in eastern direction.

The cause for the supposed trend in either direction or the widening is not known. The overall movement could possibly be related to tectonic activities. The Brahmaputra-Jamuna river has a record of avulsive behavior, and it may well be that this overall movement has a similar background. The widening can be attributed to an advancing alluvial fan or to the fact that the river has not fully adapted itself after the year shift to its new course around 1800. In this respect it is interesting to remark here that in 1830 the river showed, according to the Wilcox map, a clear meandering behavior also in the upstream reach.

Finally, it is good to underline that the trends described here have not been established beyond doubt: the available information is too scarce and there is doubt as to reference levels and coordinate system. Yet, putting all the evidence available now together, the described behavior of average movement in either direction or the widening seems likely.

Bends, bank erosion, cutoffs and widenings

Over the last years the understanding of bend evolution, bank erosion etc. phenomena is increasing due to the use of satellite images. Especially in the present study much effort has been put into understanding the changes of the river system over the years. The results presented here are derived from an analysis of satellite images whereby images of subsequent years were compared.

It was found from the study of FAP that major bank erosion is related to the presence of large bends that have a life cycle of up to 7 years. In fact these bends are the most stable phenomena in the Jamuna river. Bank erosion along these bends was studied on the basis of satellite images as suggested by Hickin and Nanson (1984). First analysis was made by Klaassen & Masselink (1992) for the Jamuna river and they observed erosion rates along outer banks of major bends that vary between 200 to 700 m (and exceptionally even to 1 km) in one year. Furthermore they plotted the erosion (E) versus the relative local radius of curvature (R/W), where E= erosion rate in m/y, R = radius of curvature and W = Width of the channel. In a further attempt they scaled the erosion E with W, plotting E/W versus R/W. The resulting graph showed a substantial scatter.

The balancing mechanism for increased bend formation is the occurrence of cutoffs. Klaassen & Masselink (1992) also reported upon results of a study into the occurrence of cutoffs and they suggest that the relative length of the two reaches downstream of the potential bifurcation is an important parameter. It was found, however, that the angle a channel makes with the upstream (un-bifurcated) channel is by far the most important parameter does not occur. Increasing the angle leads to an increased probability of the bend being cut off. (FAP-21, 1993)

In the present study it was furthermore found that:

- bifurcation disappear in three years or less
- asymmetry of the bifurcation increases the probability of abandonment, and
- abandoned channels downstream of a bifurcation are most often situated in an inner bend.

Also widening were studied in the present study.

Methodology

Analysis of the present study mostly concentrates on the pattern of the bank erosion along the left bank of the Jamuna river and downstream of the Bangabandhu bridge. Historical maps of he Jamuna river were collected and converted into 1:100,000 scale. Land sat and digital images were collected for the period 1973-2001.

Bank line maps of the year 1830(Wilcox), 1951 & 1953 were also collected. All the maps were converted into the same scale and superimposed. As the land sat & digital maps were for the dry season it seems difficult to identify exactly the location of bank lines. There may be some errors or debate in identifying the location of bank lines. There were some inconsistency and distortion in both the land sat & digital images. In the land sat co-ordinates were not shown correctly and on the other hand in digital maps though co-ordinates were shown nicely yet there were some inconsistency in the position of co-ordinates. However, adjustments were made applying own judgement and maps were corrected as consistently as possible.

Dry season digital images for the period 1996-2001 were used to develop a prediction tool to predict the possible bank erosion along these curved channels of the Jamuna river at the downstream of the Bangabandhu bridge. In developing the predicting tool mainly Hickin & Nanson (1984) and Klaassen & Masselink (1992) approaches were used with some modifications.

In the Hickin & Nanson's approach centre line of the curved channels were used. But in drawing center line of the complex curved channel subjective bias was unavoidable which of course would influence the relative curvature (R/W) significantly and the result of the analysis. To avoid this inconsistency outer bank of the curved channels were used to measure the radius of curvature. Hickin & Nanson (1984) relationship had been derived for estimating the future erosion rate of the curved channels.

Average rate of bank erosion along the curved bank was taken into account instead of maximum bank erosion rate. The average bank erosion rate most probably will make the prediction method more realistic. Observing the superimposed historical maps and recently available satellite images of SPARRSO & EGIS-II it can be inferred that downstream part of the Jamuna river had been gradually shifting towards the west before 1973 but after that the shifting trend reversed i.e., the river has been gradually shifting towards the east.

Line maps of different years average bank erosion rates along the both banks were computed and presented in tabular form and in graphical form. Along the left bank, downstream of the Bangabandhu bridge, most vulnerable zones were identified and special attention were made to analyze the bank erosion rate and flow pattern in those areas.

Usually bank erosion along the Jamuna river occurs through the reach in monsoon i.e. in both straight reach and curved reach. Though bank erosion rate along the curved reach (concave) is more then that of straight reach. Widening of the river channel were analyzed in the present for the study reach comparing the bank line positions in different years.

Data analysis

Previous trend of river course shifting

Proper understanding of the historical channel pattern changes of alluvial river is very important for all river engineering projects. Investigations into the river channel changes of the Jamuna river downstream of Bangabandhu Bridge and western side of Tangail town have been extended. The practical aim of the research work was to collect the historical data and to draw conclusion for required river training works.

In Figure-2 bank lines of the Jamuna river in different years (1830,1951,1953,1989 & 2001) for the reach Bhuapur to near Aricha have been shown. Figure-2 shows that in 1830 the Jamuna river was almost a meandering river and its position was far Eastward than the present course. A large bend upstream of Tangail was extended towards the East and if a tangent was drawn at the peak of the bend, extension of that tangent might touch the Tangail town. That is, there is a historical record that in the past the Jamuna river was flowing near Tangail town. From superimposed bank line maps in Figure-2 it was seen that the river course is gradually shifting towards the West. Shifting of the river course from 1830 to 1951 is not that much especially for the reach downstream of Bhuapur. But overall river course shifting from 1951 to 1989 was significant. Immediately downstream of Bhuapur this shifting was almost 3.8 km in 38 years. On the other hand river course shifting from 1830 to 1951 i.e., in 121 years was maximum 1.4 km at downstream of Tangail town and at immediately downstream of Bhuapur this shifting was only 200 m towards the west. Historical river course shifting trend also can be seen in **Figure-1**. From Figure-1 it is seen that the river course had been shifting towards west from 1830 to 1953. But after 1973 shifting trend of the river course especially of the reach downstream of Bhuapur had been reversed. The river started to shift towards the East.

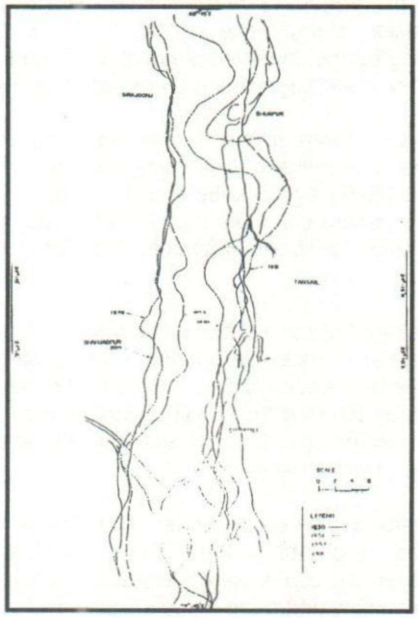

Figure-2: Historical bank line position of Jamuna rive

Recent trend of the river course shifting

From the superimposed bank line maps of the Jamuna river for the reach Bhuapur to near Aricha in Figure-3 it was seen that after 1973 the river bank (left bank) gradually shifted towards the East from 1973 to 1988. This shifting was about 900 m at some location. From Figure-3 shifting trend of the left bank of the Jamuna river can be seen. Maximum shifting of the bank lines from 1988 to 1995 was 1100 m and from 1995 to 2001 it was about 700m towards the East. Overall shifting from 1973 to 2001 was 2150m towards the East. In Figure-4 bank line maps of the Jamuna river for the year 2000 and 2001 can be seen. From this it was seen that left bank of the river course this year shifted towards the East by 450m at same locations. That is, the river course is still shifting towards the East. River course is shifting towards the East due to bank erosion and the average bank erosion rate on the basis of data from 1973 to 2001 is 77 m/year. On the other hand bank erosion from 2000 to 2001 was 450 m i.e. 450 m/year.

Long term bank erosion rate

Using the satellite images for the period 1973-1995 analysis was done to find out the bank erosion rates along the both the left and right bank of the Jamuna river for the reach Bhuapur to about 45 km down stream of the Bangabandhu bridge

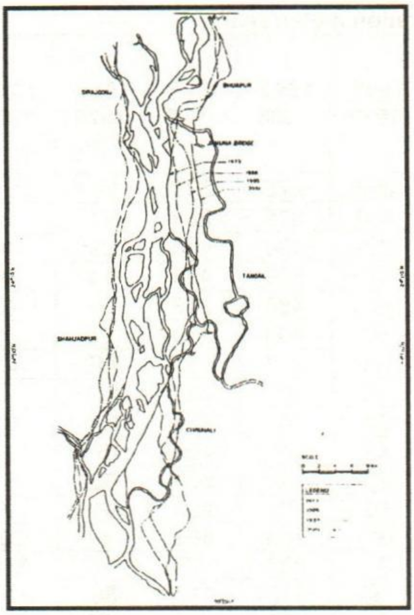

Figure-3: Shifting of river course for the reach Bhuapur to near Aricha

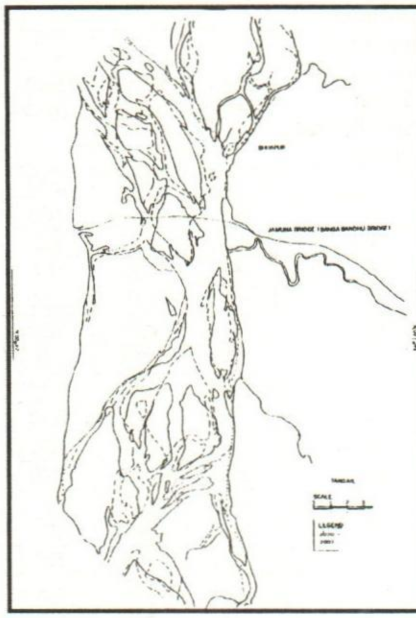

Figure-4: Shows the recent change in bankline of Jamuna river

The analysis shows that Table-1 maximum bank erosion rate along the left bank in 1973-78 was 340 m/year at 35 km downstream from the bridge axis and 330 m/year at 5 km downstream from the bridge axis. Average bank erosion rate within 1973 to 1978 was about 230 m/year. Maximum bank erosion rates along the left bank in 1978-85, 1985-88, 1988-92, & 1992-95 were 450 m/year, 767 m/year, 500 m/year and 317 m/year respectively. The locations of maximum bank erosion rate were not the same. It varies widely. Locations of maximum bank erosion rates along the left bank in 1978-85, 1985-88, 1988-92 & 1992-95 were 23 km, 45 km, 10 km, and 6 km downstream from the bridge axis respectively (Table-1).

Table-1 Bank erosion rate along the left bank (downstream of Bangabandhu bridge)

Distance Measured from axis of Banga Bandhu Bridge in km	Bank migration meter/Year								
	2001-2000	2000-1998	1998-1997	1997-1996	1995-1992	1992-1988	1988-1985	1985-1978	1978-1973
1	0	750	0	-400	-817	458	157	114	0
2	50	500	300	-1050	-267	88	217	0	60
3	0	750	-300	-1100	-150	188	183	-114	160
4	0	600	-1050	-50	133	275	0	-157	260
5	0	100	50	50	283	263	200	-307	330
6	0	150	50	150	317	288	267	-286	300

Table-1 (continued)

Distance Measured from axis of Banga Bandhu Bridge in km	Bank migration meter/Year								
	2001-2000	2000-1998	1998-1997	1997-1996	1995-1992	1992-1988	1988-1985	1985-1978	1978-1973
7	100	200	200	100	267	275	333	-243	290
8	300	200	100	200	150	375	283	21	0
9	400	175	50	300	17	438	400	29	-40
10	50	125	100	350	0	500	433	14	-60
11	0	175	100	350	42	488	317	29	-40
12	0	225	300	100	50	400	250	57	0
13	100	275	150	100	100	213	150	143	0
14	200	250	200	0	133	63	267	121	0
15	100	50	200	-200	50	0	350	164	0
16	200	-100	200	0	83	-25	400	164	100
17	200	-85	270	50	25	38	500	93	-30
18	450	-25	0	0	50	75	750	-29	-40
19	200	50	50	-50	100	163	583	-14	20
20	0	150	50	50	33	238	-17	171	60
21	250	25	200	300	150	113	117	86	200
23	100	50	300	0	0	250	-17	450	20
25	0	500	100	-100	-100	150	267	429	-200
27	0	-50	100	0	-100	288	350	357	-420
29	150	175	200	-100	-67	400	33	343	-380
31	0	0	0	25	-100	88	-117	129	-180
33	100	25	50	50	100	188	-117	0	0
35	0	175	150	-100	50	450	33	-243	340
37	50	300	50	-100	0	375	-83	157	80
39	200	175	100	0	250	250	-400	314	80
41	0	700	300	300	267	-163	17	386	20
43					-100	0	583	236	280
45					-67	275	767	257	300

NB- +ve sign stands for bank erosion and -ve sign stands for new bank build up

Average bank erosion rates in 1978-85, 1985-88, 1988-92 & 1992-95 were 306 m/year, 406 m/year, 344 m/y & 207 m/year respectively. That is, average bank erosion rate as well as maximum bank erosion rate in 1985-88 were significantly higher in comparison to other years. From analysis it is found that at the upper part of the Bangabandhu bridge along left bank rates of the bank erosion also significant (Table-2). From table-2 it appeared that in 1973-75,1978-85,1985-88,1988-92 & 1992-95 the maximum bank erosion rates along the left were 300 m/year, 200 m/year, 383 m/year, 500 m/year, and almost zero m/year respectively. Average bank erosion rates in the previous sequences were 212 m/year, 131 m/year, 237 m/year, 194 m/year & 0 m/year respectively. That is, at the upstream reach of the Bangabandhu bridge the bank erosion rates were also significant but almost stopped after 1992.

Table-2 Bank erosion rate along the left bank (upstream of Banga Bandhu bridge)

Distance Measured from axis of Banga Bandhu Bridge in km	Bank migration meter/Year								
	2001-2000	2000-1998	1998-1997	1997-1996	1995-1992	1992-1988	1988-1985	1985-1978	1978-1973
2	100	400	550	250	0	500	67	114	200
4	0	300	100	0	-33	250	333	186	200
6	0	0	0	400	-50	38	233	200	-20
8	100	275	350	200	0	0	-17	129	240
10	0	275	300	350	-200	13	150	29	300
12	0	50	200	200	0	0	367	-71	120
14	-100	0	100	0	0	-288	383	-71	100
16	0	37.5	125	-100					

NB- +ve sign stands for bank erosion and -ve sign stands for new bank build up

From the results of analysis Table-1 it is observed that most vulnerable zones for bank erosion along the left bank were 9 km to 19km downstream from the bridge axis in 1985-88 and 6 km to 13 km downstream from the bridge axis in 1988-92. The vulnerable zone for bank erosion in 1992-95 was 4 km to 7 km downstream from the bridge axis along the left bank.

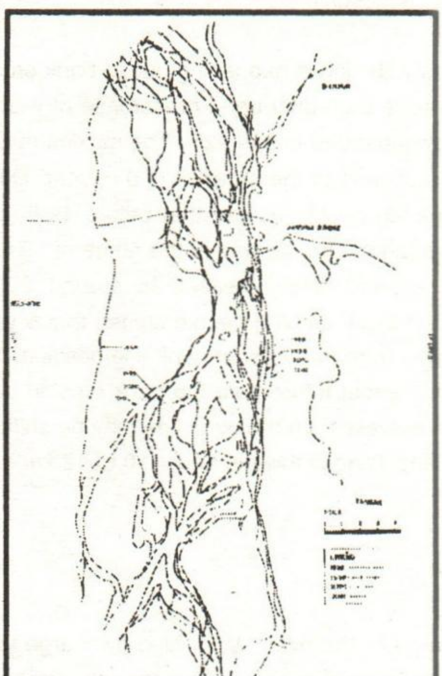

Figure-5: River course of Jamuna in 1998 to2001

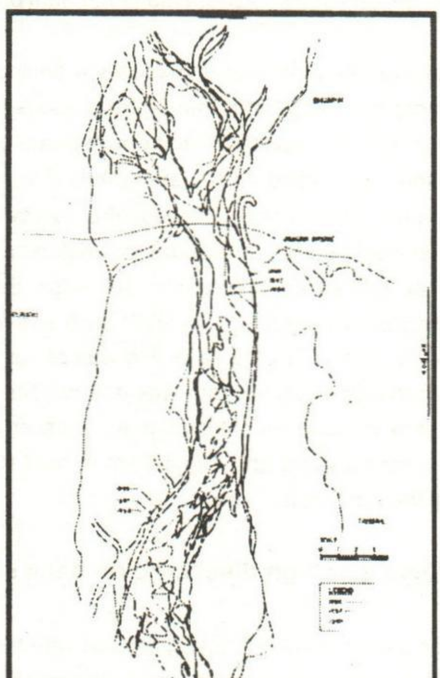

Figure-6: River course 1996 ,1997 &1998 for the study area

That is, the vulnerable zone for bank erosion along the left bank gradually shifted towards upstream from 1978 to 1995. But in 1973-78 this vulnerable zone was in 3 km to 7 km downstream of the bridge axis. That is, there is a cyclic process (Table-1).

From the analysis it was found that total shifting of the river in 1973 to 1995 was about 1550 m and in 1995 to 2001 total shifting was about 1100 m Figure-3. Total shifting (maximum) of the left bank to Eastward direction in 1973 to 2001 was in the order of 2000 m and that of right bank in 1973 to 1995 was 1600 m to Westward direction (Figure-3). After 1995 shifting of right bank is insignificant. The maximum shifting of the river bank occurred at two locations at immediately downstream of the Bangabandhu bridge and at the upstream of Aricha for the left bank.

Short terms bank erosion rate

From the analysis of bank erosion using the recent satellite images from EGIS-II for the period 1996-2001 it was found that along the left bank downstream of the Bangabandhu bridge the maximum bank erosion was 450 m in 2000-2001 (Figure-5 & Table-1).The maximum bank erosion point was 18km downstream from the bridge axis. Average bank erosion rate in 2000-2001 was in the order of 200 m/y. The analysis also shows that along the left bank the maximum bank erosion rates immediately upstream of Tangail town were about 400m, 100m, 225m, and 500m, in 1996-97, 1997-98, 1998-99 & 1999-2000 respectively Figure-5 & Figure-6, whereas bank erosion in these years along the right bank found almost nil.

It indicates that the river is gradually widening and this widening is happening due to bank erosion towards the East. From that figure it is observed there is a gradual trend of increase of width of channel both at upstream and downstream of the Bangabandhu bridge axis. The maximum bank erosion i.e., shifting of the left bank to East ward direction is in the order of 500 m/year. During field investigation and questionnaire survey local riparian people opined that before 1995 bank erosion rate along the left bank downstream of Bangabandhu bridge was in the range of 50 to 75 m/year but after construction of bridge the bank erosion rate increases to around 250 to 300m/year. Regarding position of bank line most of the local affected people opined that 5 years ago that is, in 1996 the bank line was about 2 km away from the present bank line position. That is, on average erosion rate was 400 m/year. Moreover about future possible bank erosion along left bank riparian people think that it present situation prevails then the bank line may be shifted 2 km in next 5 years and 4 to 4.5 km in next 10 years and Tangail town is about 10 to 12 km away from the present ban line.

Influence of high discharge on bank erosion

River bank erosion is closely related with the discharge of the river. With high discharge usual bank erosion rate may be higher in comparison to bank erosion rate during the low discharge. This hypothesis is investigated in the present study. Superimposing the bank line maps of the preceding and following years of the two major floods (1988 and 1998) in Bangladesh this was investigated. Figure-7 shows the superimposed bank line maps for the year of 1988,1989,1998 &

1999. Comparing the bank line positions, maximum bank erosion at three different locations along the left bank were measured and found to be 925 m, 1500 m & 1800 m in 1988 to 1989. The locations of these maximum erosion points were approximately 8.5 km. 15 km & 19.5 km downstream from the bridge axis.

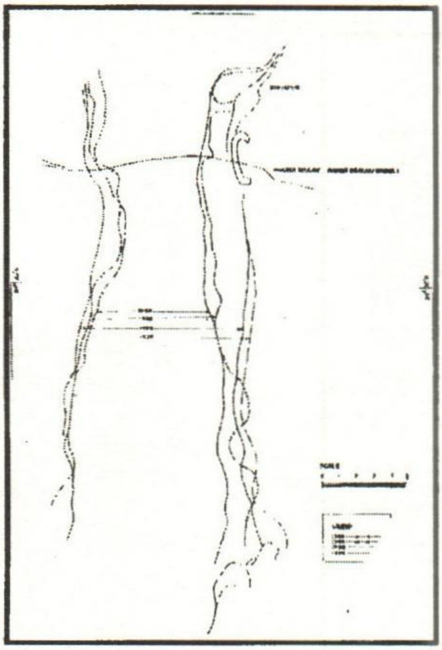

Figure-7: Banklines before and after Major flood in Bangladesh

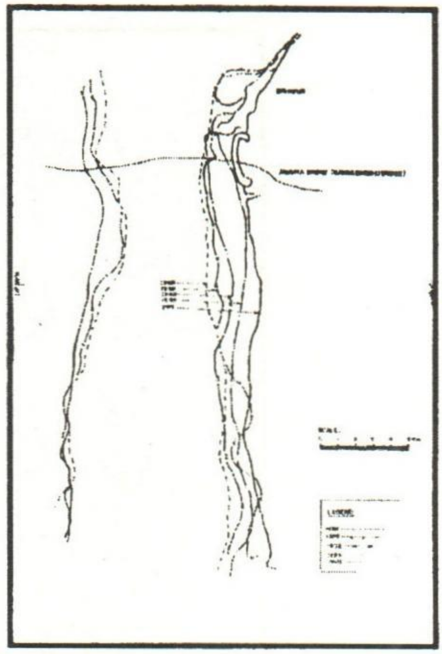

Figure-8: Bankline position of Jamuna river for different year near the study reach

Maximum bank erosion in 1998 to 1999 along the left bank at three locations were about 550 m, 950 m and 1500 m. The locations of these three points were approximately 11.5 km, 18 km & 22.2 km downstream from the bridge axis. On the other hand maximum bank erosion along the right bank were in the order of 650 m to 900 m in 1988-89 and 200 m in 1998-99.

Maximum bank erosion rate along the left bank in other years was found in the order of 400-550 m/year for the same river reach (Figure-8). Comparing the bank erosion rates in normal flood year with that of high food year it can be concluded that bank erosion with high discharge is much higher and erosion rate is strongly related with the river discharge in the Jamuna river. From Figure-7 & 4.6 it is observed that high bank erosion may occur even in convex bank and straight bank. Usually it is believed that high bank erosion occurs in concave bank. But in the Jamuna, a highly braided river severe bank erosion can be occurred in straight bank also. It is clear from the bank line maps of different years as shown in Figure-7 & Figure-8.

Bend evolution and migration

Typical bend evolution immediately at the upstream of Tangail town are shown in Figure-9. In the first figure gradual development of the bend from 1996 to 1998 is shown and in second figure development from 1999 to 2001 is shown. Combination of the above figures can be seen in third figure.

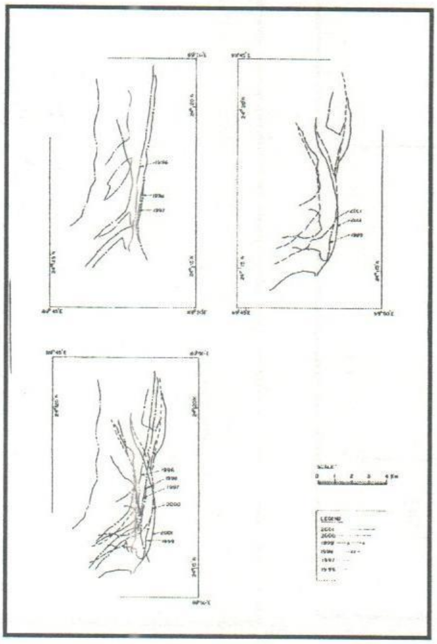

Figure-9: Typical bend evolution in the Jamuna river at the d/s of Bangabandhu bridge(along left bank)

As it was found from FAP-1 studies that major bank erosion is related to the presence of large bends that have a life cycle of between 3 and 7 years. Bank erosion along this bend was studied on the basis of satellite images for the period of 1996 to 2001.

Attempts were made to find out the relative radius of curvature and bend migration rate for consecutive years. But the numbers of data were very small and insignificant to plot on a graph. The radius of bend in 1999, 2000, and 2001 were found to be 2000 m, 2325 and 3125 m respectively. Relative radius of curvature R/W were found to be 2.22, 2.58 and 4.16 for the years 1999, 2000 and 2001 respectively. Average bend migration from 1996-97, 1997-98,1998-99,1999-2000 and 2000-2001 were found to be 196 m, 100 m, 500 m, 100 m and 870 m respectively.

We know from Hickin and Nanson (1984) study that maximum bank erosion rates occur for R/W values of about 2.5. For this bend the relative radius of curvature, R/W value was 2.58 in the year 2000. Coincidentally it is observed that average bank erosion rate from 2000-2001 was 870 m/year. That is, when relative radius of curvature was low (2.2) the erosion rate was also low and when relative radius of curvature value approaches to 2.5 the bank erosion rate becomes high. But after 2000, i.e., in 2001 the relative radius of curvature found to be 4.16 for the same bend. For this relative radius of curvature (4.16) it can be expected that the bank erosion rate will be reduced in consecutive years at this bend.

Possible future channel changes within the study reach

The Jamuna river in Bangladesh is a highly braided system with multiple parallel channels in each cross-section. The bankfull discharge of this river near Bahadurabad is about 44,000 cumec Braiding characteristics of the river varies along the reach. At the upstream part i.e., above Bangabandhu bridge axis the river is highly braided i.e., number of channels are more than 3 even 4. But at the lower part downstream of Bhuapur the river is relatively less braided, number of major channels are often 2 which tend to behave as meandering channels.

From satellite images of the year 1973 to 2001 (Figure-6 & Figure-8) for the study reach it is appeared that in 1973 the main channel of the river at the downstream of Bangabandhu bridge was near the East bank but in 1980 the main channel shifted towards the West bank. Again in 1986 the main channel changed its position and moved to the East bank and from then the main channel remains close to the East bank up to 1998. After 1998 the main channel showed a tendency to gradual movement towards the inside of the river. From Figure-8 it can be seen that in 1999 the main channel at the downstream of Bangabandhu bridge bifurcated and this situation existed up to 2000. But in 2001 the main channel divided into three channels. Though from Figure-8 it is observed that the channel close to the East bank is still prominent. Yet from the standpoint of regular channel geometry it can be expected that in near future this channel close to the East bank will be abandoned and river may follow the mid channel as main channel.

That is, bank erosion rate along the East bank, West side of Tangail town may not continue with such high rate like the present situation. After one or two year intensity of erosion will most probably be reduced at this site but erosion rate of the upstream of this area i.e., immediately downstream of Bangabandhu Bridge may be increased significantly as the main channel approaches the bank with sharp angle and from that point the main channel deflected towards the opposite bank.

Result discussion

From the study it is found that there is a history that once the Jamuna river was flowing close to the Tangail town (Wilcox 1830). After that river had a tendency to shift towards the west upto 1973. But after 1973 the river changed its shifting direction especially in the study reach. That is the river is gradually shifting towards the east i.e., towards Tangail town. The present average erosion rate is in the order of 400 to 550 m/year. If this erosion rate exist for long time then within 20 to 22 years the river may reach near Tangail town. But the present erosion rate may not continue for the long time. As bank erosion is a cycle process. For some time there may be severe bank erosion but after a few years vulnerable zone for bank erosion may change. A large bend is developed at the immediately upstream of Tangail town along the left bank. Flow from the upstream is attacking directly with a sharp angle. Bend was migrating towards the east rapidly. In the year 2000 relative radius of curvature R/W for this bend was around 2.58 and with this relative radius of curvature the migration was 870 m/year, which is quite high. But in the year 2001 the relative radius of curvature R/W for the same bend was about 4.16, which is far more than 2.5. As per Hickin and Nanson's (1984) concept the bend migration rates in the following years for this bend should be reduced. It is likely as from flow condition it is found that main channel has been divided into three channels immediately upstream of this bend. In near future, may be in the next year the channel close to the east bank may be abandoned.

Though possibility of erosion of Tangail town is not significant yet surrounding areas of Tangail town is eroding significantly by the river Jamuna. It is expected that in near future more area of Tangail district will be lost due to severe bank erosion of the Jamuna. And also as there is a history, the Jamuna river may shift more towards east i.e., towards Tangail town in future. So it is necessary to stabilize the left bank downstream of Bangabandhu bridge upto at least 20 km from the bridge axis. To stabilize the bank and to stop further bank erosion, revetment type of structures may be useful instead of groyne like structures.

Revetment can deflect the flow relatively more smoothly and thus less adverse effect to the opposite bank and other areas. Suitable structure for bank protection and design parameters can be selected from detail scale model investigation with present bathymetry and flow conditions for the site.

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RIVER MODEL AS A TOOL FOR SOLUTION OF THE BRIDGE PROBLEM: A CASE STUDY OF DHALESWARI BRIDGE

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Abstract

This paper presents a solution to the Problem of Dhaleswari Bridge-1caused due to the differential settlement of Pier-4 of the bridge. This solution comes up through physical model studies in two different phases: at first an Overall distorted model and later a Detailed Undistorted Model. The ultimate objective of the study was to way out a means to make the Pier-4 safe and thus the bridge-1. Attempts were made in the overall model by adopting dredging at bifurcation point of the Dhaleswari River at the upstream of the Dhaleswari Bridge-1 & 2 with a view to augmenting water flow through Bridge-2 opening and thus saving the Bridge-1. However, volume of dredging at the outset and maintenance dredging thereafter unfeasible. In the Detailed model, attempts with the adopting of a triangular shaped cutting at the Bridge-1 section at the right bank along with the adoption of a bally spur at upstream of Bridge-01 across the left bank appeared a pragmatic solution giving more flow concentration towards the right part of the Bridge and thus reducing the stress at left part of the Bridge where Pier-4 lies.

Introduction

The first Dhaleswari and second Dhaleswari Bridge are on the first and second Dhaleswari River respectively on the Dhaka-Mawa-Khulna Highway. The first Dhaleswari Bridge was commissioned for traffic in 1997 and the second bridge in 1998. The first Dhaleswari Bridge is 260 m long, 10 m wide RC Prestressed Deck Girder Bridge. Substructure of Bridge-1 comprises of 5 numbers of RC piers founded on 33 m long 760 mm dia bored cast in situ piles and abutments are founded on 1000 mm dia bored cast in situ piles of 30 m length. The total length of the Second Dhaleswari Bridge is 383.04 m. There are 7 numbers of RC piers founded on cast-in-situ piles.

After one year of commissioning, it was observed in December 1998 by Roads and Highways Department (RHD) that the Pier-4 of first Dhaleswari Bridge had shown a sign of differential settlement to the extent of some 80 mm (sloping towards downstream). Immediately after this occurrence, the RHD appointe0d Bangladesh Consultants Ltd. (BCL) for the consultancy services for strengthening of Pier-4 of first Dhaleswari Bridge. And later on the RHD felt necessity of a physical model study and accordingly they proposed River Research Institute (RRI) to conduct a physical model study to investigate the hydromorphological impact in the vicinity of the Dhaleswari Bridge 1 and 2.

As per Terms of Reference the study was carried out in two separate models in two different phases. In the first phase, a study was done constructing an Overall Distorted Model covering a river reach of 7.0 km of which around 5.5 km at upstream and around 1.5 km downstream of the bridges proper. This model was built to investigate the flow field, flow distributions through each bridge, to find out the way how to make bridge-1 safe by diverting more water flow through the opening of bridge-2, flow velocity, and importantly, to have boundary conditions for the detailed model.

In the second phase, an Undistorted Detailed Model covering 3 km area around bridges (2 km u/s

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and 1 km d/s of bridges) was constructed and tested. This model was to investigate mainly to get information about local scour around piles qualitatively and quantitatively. Moreover, as the Pier-4 of the Bridge-1 is under distress, an attempt was made to distribute more flow towards the right side of the Bridge–1 in order to reduce flow concentration at the left side around Pier-4 and Pier-5.

The objectives of the model study were :

- To investigate the hydraulic and morphological consequences in the vicinity of the existing bridge.
- To investigate the protection/river training works in the study area.
- To find out design parameters such as velocity, scour depth, flow pattern etc.
- Optimization of the location, orientation and alignment of the river training/protection works.

The Dhaleswari river

Dhaleswari River at the upstream of Dhaleswari Bridge-1 & 2 shows complex behaviour. The two channels-Isamati and Dhaleswari at the upstream of the bridges meet at a point, then bifurcates, again they meet at the downstream of the bridges and then again bifurcates, thus forming a closed loops at the vicinity of the bridges. In addition to these, there is a canal, which interconnects the channel-1 and channel-2 as shown in **Figure-1**. In the past the right channel was relatively more active than the left one. In course of time situation has been changed. Now the left channel has become dominant in carrying water discharge. The length of the Dhaleswari Bridge-1 is 260 m and that of Dhaleswari Bridge-2 is 383 m. To reduce the pressure on Bridge-1, it is planned to divert the more water flow through the channel-2 so that the channel-2 becomes more active.

Data acquisition

Models were constructed with the bathymetric data surveyed in 1999. Bed and Bank material information and water discharge, velocity to some extent were obtained from the said survey. Water discharge and other necessary information were obtained from reports supplied by RHD.

Methods and materials

Collected data was analysed by PC using Microsoft Excel software. Overall model was run for observing flow line, velocity, near bank velocity & detailed model was run to get maximum equilibrium scour around bridge piers. Model discharge was calculated using Froudian model law. This discharge was measured by sharp-crested weir using Rebock formula.

The following equipment were used to carry out the tests in the model :

a) Pumps having capacity of 400 lps.
b) Point gauges.
c) Floats of different types.
d) Current meter – A-OTT type
e) Sounding rod
f) Sieve analyzer.
g) Still camera
h) Video camera.

Selection of scale

For overall model

Considering available physical facilities of RRI a distorted model of horizontal scale of 1:150 and vertical scale of 1:60 were selected for first phase. All the verifications and similitude were done applying Froude's model law. Depending on these geometric scales, the velocity scale and discharge scale were 1: 7.746 and 1: 69713.7 respectively.

For detailed model

Considering the available physical facilities of RRI, an undistorted model having length scale of 1:70 was selected. Applying the Froude's law did all verification and similitude. Depending on this length scale the velocity and discharge scale were 1:8.87 and 1:40996.34 respectively. Schematic view of detailed model can be seen in Figure no-2.

Calibration test and test scenarios

For overall model

To reproduce the similar behavior of the prototype in the model it is essential to calibrate the model using prototype data. And in this study May, 1999 bathymetric data were used. As boundary condition the measured discharge (bankful condition) distribution and water level were used and the model was calibrated satisfactorily. The test scenarios of the overall model can be seen in **Table-1**.

For detailed model

In this test, the model was calibrated with the condition (dredging as well as % distribution of discharge through the bridge openings 1 & 2) prevailed in the Test 10 of overall model. Water level near Bridge-1 at C/S # 51 was 4.71 mPWD and near Bridge-2 at C/S # 49 was 4.7 mPWD. The main objective of this test was the simulation of prototype behavior (Test-10 of overall model). A brief test scenarios of all the tests can be seen in **Table 2**.

Result and discussion

For overall model

From test results, summarized in **Table-3** it is observed that with the surveyed bathymetry (Test-2) discharge distribution in Dhaleswari Channel-1 and Channel-2 are 61.81% and 38.19% respectively. It is also seen in the **Table-3** that due to dredging the flow through the Channel-2 was increased in Test-3 to Test-7. However, this increase can not be considered as a significant improvement, because only about 6% flow was increased. But in Test-8 it was observed a considerable increase in flow through Channel-2.

Test-9 and Test-10 were done with greater dredging through the right channel up to the link canal. In this case, in Test-10 flow through Channel-2 increased up to 49.37%. However, in Test-11 with a T-head groyne at the confluence and dredging as was done in Test-10 through the right channel to the link canal, the flow through channel-2 increased up to 54.75% in bankfull condition and 50.24% in flood condition. From overall consideration, the Test-11 gave a best result so far with respect to the diversion of flow through Channel-2. Flow line of Test-10 and Test-11 can be seen in **Figure-3** and **Figure -4** respectively.

For detailed model

From the **Table-4** it is observed that in Test-3 and Test-4 flow concentration was more around Pier-4 and Pier-5. After test run of Test-5 it is also observed from **Table-5** that bed levels around Pier-4 and Pier-5 were –10.35 mPWD and –5.8 mPWD respectively and in Test-4 those were –12.38 mPWD and –10.7 mPWD respectively. From the test results, it is also observed that in Test–5 velocity distribution toward right bank in channel–1 near upstream of the bridge axis were found more than those of the Test-4. It may be due to the triangular shaped dredging **(Figure-5)** along the right bank of the channel–1. The intensity of velocity was not reduced around Pier-4 but the net scour level around Pier-4 was observed less than that of Test–4. The flow velocity around Pier-4 and Pier-5 of Bridge-1 reduced in Test–6, which might be due to the incorporation of a permeable bally spur at the upstream across the left bank of the Bridge-1. In Test-8 the flow was attracted towards the right side of the Bridge-1. This was perhaps due to extended triangular shaped cutting **(Figure-6)**. In the previous tests (Test-5, Test- 6,Test-7) the maximum velocity occurred at the bay between Pier-5 and Pier–4. However, in this Test (T-8) that was shifted right wards and occurred in the bay between Pier-4 and Pier-3. In Test-9, maximum velocity observed around Pier-3 but in Test-7 it was around Pier-4 that is maximum velocity point shifted towards right bank of Bridge-1. From **Table-5** it is also observed that in Test-9 scour around the piers increased towards the right bank and decreased towards the left bank. In these tests, relatively much flow concentrations also observed towards the right bank of Bridge-1.

Conclusion

From the test results of overall model, it is revealed that the Test-11 can be considered as effective measures to divert the significant amount of flow through the Channel-2. But in that case regular maintenance dredging is required. From the test results of detailed model, it is revealed that the Test-9 seems effective to distribute the flow towards right bank of Bridge-1. As a result of this distribution, the intensity of flow concentration around Pier-4 and Pier-5 has been reduced.

So having considered the findings of overall model and detailed model it is understood that the Test-9 of detailed model with extended triangular shaped dredging along with permeable bally spur shows pragmatic result to divert the flow concentration towards the right bank of the Bridge-1. But in that case, regular maintenance dredging is to be required. And in this case due care should be taken to Abutment-1 of Bridge-1 so that it can not be endangered.

From the findings of this model study it is obvious that there is a great scope of further research to way out a permanent solution so that two bridges can be saved for longer period.

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Table-1 Brief test scenarios of Dhaleswari Bridge-1& 2 model (Overall Model)

Test No	Type of test	Test Condition	Given discharge (m^3/s) / WL(mPWD) into		Measurements/ Adjustments (in model)
			Channel-1	Channel-2	
T1	Calibration Test	**a)Discharge :** Bankful discharge (60% of flood discharge) **b) Water Level :** WL at C/S # 13 at both banks **c) Bed condition :** As per surveyed bathymetry	1935.6 / 5.2 at C/S # 13	990 / 5.19 at C/S # 13	Water level, Velocity distribution, still photograph, VIDEO, etc.
T2	Application Test	**a)Discharge :** Corresponding to about 1 m/s average velocity at C/S # 13 (flood condition) **b) Water Level :** Considering observed WL of 1998 flood **c) Bed condition :** As per surveyed bathymetry	3226 / 7.5 at C/S #51	1650 / 7.5 at C/S #49	Water level, C/S velocity, Flow line, Flow field observation, velocity near abutment and pier, still photograph, VIDEO, etc.
T3	"	**a)Discharge :** Corresponding to about 1 m/s average velocity at C/S # 13 (flood condition) **b) Water Level :** Considering observed WL of 1998 flood **c) Dredging** : done on river bed at right side of confluence between C/S #18 and C/S #21	3226 / 7.5 at C/S #51	1650 / 7.5 at C/S #49	Water level, C/S velocity, Flow line, Flow field observation, velocity near abutment and pier, still photograph, VIDEO, etc.
T4	"	**a)Discharge :** Corresponding to about 1 m/s average velocity at C/S # 13 (flood condition) **b) Water Level :** Considering observed WL of 1998 flood **c) Dredging** : done on river bed at right side of confluence as in T3 but deeper.	3226 / 7.5 at C/S #51	1650 / 7.5 at C/S #49	Water level, C/S velocity, Flow line, Flow field observation, velocity near abutment and pier, still photograph, VIDEO, etc.
T5	"	a)Bankful discharge (60% of flood discharge) b)WL at C/S # 13 at both banks c)Dredging : same as in T-4	1935.6 / 5.2 at C/S # 13	990 / 5.13 at C/S # 13	Water level, C/S velocity, Flow line, Flow field observation, velocity near abutment and pier, still photograph, VIDEO, etc.
T6	"	**a)Discharge :** Same as in T-5 **b)Water level :** Same as in T-5 **c) Dredging:** Dredging done both on river bed and flood plain between C/S # 17 and C/S # 20 at right side of confluence to have a direct flow path towards the channel-2.	1935.6 / 5.2 at C/S # 13	990 / 5.13 at C/S # 13	Water level, C/S velocity, Flow line, Flow field observation, velocity near abutment and pier, still photograph, VIDEO, etc.

Table-1 (Continued)

Test No	Type of test	Test Condition	Given discharge (m^3/s) / WL(mPWD) into		Measurements/ Adjustments (in model)
			Channel-1	Channel-2	
T7	Application Test	**a)Discharge :** bankful, Same as in T-6 **b)Water level :** at CS# 13, Same as in T-6 **c) Dredging :** Dredging done on river bed from the mid section between CS#16 and CS#17 to CS#20. In this test more area was dredged towards left side of confluence than that of T-6.	1935.6 / 5.2 at C/S # 13	990 / 5.13 at C/S # 13	Water level, C/S velocity, Flow line, Flow field observation, velocity near abutment and pier, still photograph, VIDEO, etc.
T8	Application Test with Structures	**a)Discharge :** bankful, same as in T-7 **b)Water level :** Same as in T-7 **c) Dredging :** Dredging dine both on river bed and flood plain from the mid section between CS#16 and CS#17 to CS#20 at right side of confluence to have a direct flow path towards the channel-2. **d)Structure :** 2 repelling groynes. One at CS#17 having length of 112.5 m from L/B with angle of 30^0(against bank).The other one is at 135 m d/s of CS#19 having length of 142.5 m with angle of 30^0 (against bank).	1935.6 / 5.2 at C/S # 13	990 / 5.13 at C/S # 13	Water level, C/S velocity, Flow line, Flow field observation, velocity near abutment and pier, still photograph, VIDEO, etc.
	"	**a)Discharge :** flood condition **b)Water level :** Same as in T-4 **c)Dredging :** Dredging dine both on river bed and flood plain from the mid section between CS#16 and CS#17 to CS#20 at right side of confluence to have a direct flow path towards the channel-2. **d)Structure:** 2 repelling groynes. One at CS#17 having length of 112.5 m from L/B with angle of 30^0 (against bank) The other one is at 135 m d/s of CS#19 having length of 142.5 m with angle of 30^0(against bank).	3226 / 7.5 at C/S #51	1650 / 7.5 at C/S #49	Water level, C/S velocity, Flow line, Flow field observation, velocity near abutment and pier, still photograph, VIDEO, etc.

Table-1 (Continued)

Test No	Type of test	Test Condition	Given discharge (m^3/s) / WL(mPWD) into		Measurements/ Adjustments (in model)
			Channel-1	Channel-2	
T9		**a)Discharge :** bankful, same as in T-8 **b)Water level :** Same as in T-8 **c) Dredging :** From C/S #17 to C/S#20, same as in T-6 and C/S#20 to C/S#34, of the right channel was also dredged.	1935.6 / 5.2 at C/S # 13	990 / 5.13 at C/S # 13	Water level, C/S velocity, Flow line, Flow field observation, velocity near abutment and pier, still photograph, VIDEO, etc.
	"	**a)Discharge :** flood condition **b)Water level :** Same as in T-8 **c) Dredging :** From C/S #17 to C/S#20, same as in T-6 and C/S#20 to C/S#34, of the right channel was also dredged.	3226 / 7.5 at C/S #51	1650 / 7.5 at C/S #49	Water level, C/S velocity, Flow line, Flow field observation, velocity near abutment and pier, still photograph, VIDEO, etc.
T10	Application test	**a)Discharge :** bankful, same as in T-8 **b)Water level :** Same as in T-8 **c) Dredging :** From C/S #17 to C/S#20, same as in T-6 and C/S#20 to C/S#35, the whole right channel was dredged. In this case more dredging were done to increase the conveyance capacity of the right channel. **d) Structures :** one T-head repelling groyne at 37.5 m d/s of CS#18 having length of 90 m with angle of 30^0 (against bank) of which T length is 90^0.	1935.6 / 5.2 at C/S # 13	990 / 5.13 at C/S # 13	Water level, C/S velocity, Flow line, Flow field observation, velocity near abutment and pier, still photograph, VIDEO, etc.
	"	**a)Discharge :** flood condition **b)Water level :** Same as in T-8 **c) Dredging :** From C/S #17 to C/S#20, same as in T-6 and C/S#21 to C/S#36, the whole right channel was dredged. In this case more dredging were done to increase the conveyance capacity of the right channel. **d) Structures :** one T-head repelling groyne at 37.5 m d/s of CS#18 having length of 90 m with angle of 30^0 (against bank) of which T length is 90^0.	3226 / 7.5 at C/S #51	1650 / 7.5 at C/S #49	Water level, C/S velocity, Flow line, Flow field observation, velocity near abutment and pier still photograph, VIDEO, etc.

Table-1 (Continued)

Test No	Type of test	Test Condition	Given discharge (m^3/s) / WL(mPWD) into		Measurements/ Adjustments (in model)
			Channel-1	Channel-2	
T11	Application Test with Structures	**a)Discharge :** bankful, same as in T-8 **b)Water level :** Same as in T-8 **c) Dredging :** From C/S #17 to C/S#20, same as in T-6 and C/S#20 to C/S#35, the whole right channel was dredged. In this case more dredging were done to increase the conveyance capacity of the right channel. **d)Structure:** One T-head repelling groyne at 150 m d/s of C/S18 having length of 127.5 m with angle of 30^0 (against bank) of which T length is 120 m.	1935.6 / 5.2 at C/S # 13	990 / 5.13 at C/S # 13	Water level, C/S velocity, Flow line, Flow field observation, velocity near abutment and pier still photograph, VIDEO, etc.
	"	**a)Discharge :** flood condition **b)Water level :** Same as in T-8 **c) Dredging :** From C/S #17 to C/S#20, same as in T-6 and C/S#20 to C/S#35, the whole right channel was dredged. In this case more dredging were done to increase the conveyance capacity of the right channel. **d)Structure:** One T-head repelling groyne at 150 m d/s of C/S#18 having length of 127.5 m with angle of 30^0 (against bank) of which T length is 120 m.	3226 / 7.5 at C/S #51	1650 / 7.5 at C/S #49	Water level, C/S velocity, Flow line, Flow field observation, velocity near abutment and pier, still photograph, VIDEO, etc.

Table-2 Brief test scenarios of Dhaleswari bridge-1 & 2 model (detailed model)

Test No	Type of test	Test condition	Discharge (m^3/s) / WL(mPWD)		Measurements/ Adjustments (in model)
			Channel-1	Channel-2	
T1	Calibration Test	**a)Discharge :** Bankful discharge **b)Water level :** Same as in T-11 of overall model **c) Dredging :** From C/S # 32 to C/S# 35 same as in T-11 of overall model	1328.28 / 4.71 at C/S #51	1607.06 / 4.7 at C/S #49	Water level, Velocity distribution, still photograph, VIDEO, etc.

Table-2 (Continued)

Test No	Type of test	Test condition	Discharge (m^3/s) / WL(mPWD)		Measurements/ Adjustments (in model)
			Channel-1	Channel-2	
T2	Application Test	**a)Discharge :** Froude discharge **b)Water level :** Considering observed WL of 1998 flood **c) Dredging :** From C/S # 32 to C/S# 35, same as in T-11 of overall model	2206.42 / 7.5 at C/S #51	2669.68 / 7.5 at C/S #49	Water level, C/S velocity, velocity distributions at bridge opennings, Flow line, Flow field observation, velocity near abutment and pier, Instantaneous bed level at 14 m u/s, 14 m d/s and 28 m d/s from bridge axis, still photograph, VIDEO, etc.
T3	"	**a)Discharge :** Scour discharge (Using V_s= $1.65V_{crm}$) **b)Water level :** Considering observed WL of 1998 flood **c) Dredging :** Same as in T2.	4202.94 / 7.5 at C/S #51	4928.99 / 7.5 at C/S #49	velocity distributions at bridge opennings, Instantaneous bed levels at 14 m u/s, 14 m d/s and 28 m d/s from bridge axis, max. scour and its position, still photograph, VIDEO, etc.
T4	"	**a) Discharge :** Scour discharge (Using V_s= $2.25V_{crm}$) **b) Water level :** Considering observed WL of 1998 flood **c) Dredging :** Same as in T3.	5731.29 / 7.5 at C/S #51	6721.35 / 7.5 at C/S #49	velocity distributions at bridge opennings, Instantaneous bed levels at 14 m u/s, 14 m d/s and 28 m d/s from bridge axis, Contour for max. scour and its position, still photograph, VIDEO, etc.
T5	"	**a) Discharge :** Scour discharge (Using V_s= $2.25V_{crm}$) **b) Water level :** Considering observed WL of 1998 flood **c) Bed condition :** As per surveyed bathymetry except some area near bridge-1. d) **Dredging :** From C/S # 49 to C/S# 53, a triangular shape dredging was done of which one arm is parallel and 5m apart from pier P1 towards left bank.	8238.76 / 7.5 at C/S #51	4213.88 / 7.5 at C/S #49	velocity distributions at bridge opennings, Instantaneous bed levels at 14 m u/s, 14 m d/s and 14 m d/s from bridge axis, max. scour and its position, still photograph, VIDEO, etc.
T6	"	**a) Discharge :** Scour discharge (Using V_s= $2.25V_{crm}$) **b) Water level :** Considering observed WL of 1998 flood **c) Bed condition :** As per surveyed bathymetry. d) **Structures:** 61m long permeable bally spur with 33% opening; 220 m u/s of bridge-1 at left bank.	8238.76 / 7.5 at C/S #51	4213.88 / 7.5 at C/S #49	Velocity distributions at bridge openings, Instantaneous bed level at 14 cm u/s, 14 m d/s and 28 m d/s from bridge axis, max. Scour and its position, still photograph, VIDEO, etc.

Table-2 (Continued)

Test No	Type of test	Test condition	Discharge (m^3/s) / WL(mPWD)		Measurements/ Adjustments (in model)
			Channel-1	Channel-2	
T7	"	**a)Discharge :** Scour discharge (Using V_s= $2.25V_{crm}$) **b)Water level :** Considering observed WL of 1998 flood **c) Bed condition :** Same as in T5 **d) Dredging :** Same as in T5 **e) Structures:** 61m long permeable bally spur with 67% opening; 220 m u/s of bridge-1at left bank.	8238.76 / 7.5 at C/S #51	4213.88 / 7.5 at C/S #49	Velocity distributions at bridge openings, Instantaneous bed levels at 14 m u/s, 14 m d/s and 28 cm d/s from bridge axis, max. Scour and its position, still photograph, VIDEO, etc.
T8	"	**a)Discharge :** Froude discharge **b)Water level :** Considering observed WL of 1998 flood **c) Bed condition :** Same as in T7 d) **Dredging :** Same as in T5 but deeper. Also more area was dredged towards up stream. **e) Structures:** Same as in T7.	3226/ 7.5 at C/S #51	1650 / 7.5 at C/S #49	Water level, C/S velocity, velocity distributions at bridge opening, Flow field observation, velocity near abutment and pier, Instantaneous bed level at 14 m u/s, 14 m d/s and 28 m d/s from bridge axis, still photograph, VIDEO, etc.
T9	"	**a)Discharge :** Scour discharge (Using V_s= $2.25V_{crm}$) **b)Water level :** Same as in T8 **c) Bed condition :** Same as in T8 d) **Dredging :** Same as in T8 **e) Structures:** Same as in T8	8238.76 / 7.5 at C/S #51	4213.88 / 7.5 at C/S #49	Velocity distributions at bridge openings, Instantaneous bed level at 14 m u/s, 14 m d/s and 28 m d/s from bridge axis, max. Scour and its position, still photograph, VIDEO, etc.

Table 3 Brief summary of test results of Dhaleswari Bridge 1 & 2 model (overall model)

Test No. (Date)	Given Discharge (Cumecs)		Water Level Adjustment (mPWD)		% of discharge into channel		Maximum Velocity attained near bridge (m/s)	
	Through Dhaleswari	Through Ichamati	Channel-1	Channel-2	1	2	1	2
T-1	3226	1650	7.5 at C/S # 51	7.5 at C/S # 49	-	-	-	-
T-2	3226	1650	7.5 at C/S # 51	7.5 at C/S # 49	61.81	38.19	2.01	1.7
T-3	3226	1650	7.5 at C/S # 51	7.5 at C/S # 49	59.2	40.8	2.25	1.78
T-4	3226	1650	7.5 at C/S # 51	7.5 at C/S # 49	58.51	41.49	2.09	1.78

Table-3 (Continued)

Test No. (Date)	Given Discharge (Cumecs)		Water Level Adjustment (mPWD)		% of discharge into channel		Maximum Velocity attained near bridge (m/s)	
	Through Dhaleswari	Through Ichamati	Channel-1	Channel-2	1	2	1	2
T-5	1935.6	990	5.2 at C/S # 13	5.13 at C/S # 13	56.9	43.1	2.17	2.09
T-6	1935.6	990	5.2 at C/S # 13	5.13 at C/S # 13	55.15	44.85	2.17	2.17
T-7	1935.6	990	5.2 at C/S # 13	5.13 at C/S # 13	57.4	42.6	2.09	1.70
T-8	1935.6	990	5.2 at C/S # 13	5.13 at C/S # 13	58.22	41.78	2.09	1.63
	3226	1650	7.5 at C/S # 51	7.5 at C/S # 49	52.49	47.51	2.09	1.63
T-9	1935.6	990	5.2 at C/S # 13	5.13 at C/S # 13	57.83	42.17	2.01	1.55
	3226	1650	7.5 at C/S # 51	7.5 at C/S # 49	51.86	48.14	1.94	1.94
T-10	1935.6	990	5.2 at C/S # 13	5.13 at C/S # 13	53.12	46.88	2.09	1.94
	3226	1650	7.5 at C/S # 51	7.5 at C/S # 49	50.63	49.37	2.01	1.78
T-11	1935.6	990	5.2 at C/S # 13	5.13 at C/S # 13	45.25	54.75	2.01	1.78
	3226	1650	7.5 at C/S # 51	7.5 at C/S # 49	49.76	50.24	2.17	2.32

Table-4: Velocity distribution at bridge opening at 25.0 m up from bridge axes of Dhaleswari Bridge-1 & 2 model (detail model)

Sl. No.	Dist.from R/B (m)	Average Velocity (m/s)							
		T2	T3	T4	T5	T6	T7	T8	T9
				Bridge -1					
1	0.7 (*)	1.15	1.27	2.31	1.57	1.49	2.11	0.98	2.51
2	23.2	1.12	0.89	1.02	1.57	0.77	1.77	1.12	2.86
3	45.7	1.13	1.43	1.33	2.48	1.18	2.53	1.58	3.4
4	68.2	1.21	1.85	2.48	3.46	1.95	3.11	1.66	3.85
5	90.7	1.56	2.27	3.05	3.71	3.10	3.36	1.57	4.03
6	113.2	1.58	2.86	3.30	3.79	3.72	3.53	1.65	4.30
7	135.7	1.61	2.78	3.38	3.63	3.18	3.78	1.73	4.43
8	158.2	1.65	2.86	3.05	3.71	3.33	4.04	1.66	4.13
9	180.7	1.80	2.86	3.55	4.28	3.41	3.87	1.58	3.75
10	203.2	1.91	3.53	3.63	3.79	3.10	4.37	1.66	3.6
11	225.7	1.60	3.28	4.20	2.31	3.18	3.36	0.98	2.51
12	248.2	0.76	2.02	2.97	0.00	-0.84	2.02	0.00	0.00
13	262	0.00	0.00	0.00	0.00	-1.11	0.00	0.00	0.00
				Bridge -2					
1	0.7 (**)	0.45	0.67	1.57	1.30	0.91	1.12	0.31	0.75
2	23.2	0.91	1.18	1.41	1.25	1.11	1.45	0.57	1.46
3	45.7	0.91	1.77	1.24	1.56	1.79	1.53	0.78	1.75
4	68.2	1.21	1.27	1.74	1.6	2.10	1.96	1.05	2.36

Table-4 (Continued)

Sl. No.	Dist.from R/B (m)	Average Velocity (m/s)							
		T2	T3	T4	T5	T6	T7	T8	T9
5	90.7	1.56	1.94	2.56	2.15	2.56	2.38	1.10	2.36
6	113.2	1.39	2.27	2.72	2.72	2.64	2.30	1.11	2.52
7	135.7	1.47	2.36	3.30	3.13	2.87	2.55	1.18	2.67
8	158.2	1.47	2.53	3.05	2.72	2.64	2.89	1.19	3.03
9	180.7	1.56	2.19	3.13	2.89	2.64	3.06	1.05	2.68
10	203.2	1.30	2.27	3.22	2.64	2.49	2.47	0.98	2.51
11	225.7	1.47	2.19	2.64	2.10	1.95	2.13	0.99	2.40
12	248.2	1.56	2.27	1.98	1.70	1.79	2.63	0.91	2.33
13	270.7	1.06	2.11	1.82	1.70	1.56	2.30	0.85	2.16
14	293.2	1.47	1.85	1.33	1.30	1.49	2.04	0.71	1.81
15	315.7	0.60	0.65	0.55	0.45	1.41	1.28	0.70	1.75
16	338.2	1.47	1.03	1.41	1.25	1.18	1.53	0.84	1.90
17	360.7	1.35	1.25	1.25	1.10	1.11	1.53	0.98	2.20
18	383.2	0.00	0.00	0.00	0.00	1.41	1.28	0.85	1.50

Table-5 Maximum scour level around piers and abutments during test run of Dhaleswari Bridge-1 & 2 Model (Detail Model)

Abutment/ Pier Identification	Abutment top/Pile cap bottom level in m PWD	Maximum scour level in mPWD & position during test run					
		T3	T4	T5	T6	T7	T9
		Bridge-1					
A1	16.41	-3.21 (21m apart from abutment along bridge axis)	-7.76 (18.2m apart from abutment along bridge axis)	-4.75 (17.5m apart from abutment along bridge axis)	-5.45 (17.0m apart from abutment along bridge axis)	-3.84 (18.5m apart from abutment along bridge axis)	-4.75 (16.8m apart from abutment along bridge axis)
P1	1.15	-1.6 (towards right bank)	+1.9 (towards right bank)	-1.25 (towards Left bank)	-0.95 (towards Left bank)	-1.50 (towards Left bank)	-4.40 (towards Left bank)
P2	1.15	-4.05 (towards Left bank)	-6.92 (towards Left bank)	-7.2 (towards Left bank)	-6.15 (towards Left bank)	-6.95 (towards Left bank)	-7.76 (towards Left bank)
P3	1.49	-5.1 (towards Left bank)	-10.7 (towards Left bank)	-10.35 (towards Left bank)	-9.86 (towards Left bank)	-10.30 (towards Left bank)	-10.5 (towards Left bank)
P4	1.15	-10.35 (towards Left bank)	-12.38 (towards Left bank)	-9.3 (towards Left bank)	-9.15 (towards Left bank)	-11.68 (towards Left bank)	-11.05 (towards Left bank)
P5	1.22	-5.8 (towards right bank)	-10.7 (towards Left bank)	-4.40 (towards right bank)	-6.12 (towards right bank)	-9.44 (towards Right bank)	-7.41 (towards Right bank)

Table-4 (Continued)

Abutment/ Pier Identification	Abutment top/Pile cap bottom level in m PWD	Maximum scour level in mPWD & position during test run					
		T3	T4	T5	T6	T7	T9
A2	15.36	-2.3 (11.9m apart from abutment along bridge axis)	-9.86 (12.5m apart from abutment along bridge axis)	+4.56 (15.6m apart from abutment along bridge axis)	+5.4 (13.0m apart from abutment along bridge axis)	+3.72 (11.75m apart from abutment along bridge axis)	+2.6 (22.33m apart from abutment along bridge axis)
Bridge-2							
A1	19.21	No scour	-1.6 (10m apart from abutment)	No scour	-0.9 (9.8m apart from abutment)	+0.85 (9.9m apart from abutment)	-1.81 (25.55m apart from abutment)
P1	3.46	-3.35, (towards right bank)	-2.3 (towards Left bank)	-0.83 (towards right bank)	-1.6 (towards Right bank)	-1.81 (towards Right bank)	-1.25 (towards left bank)
P2	1.92	+0.78 (towards Left bank)	-0.69, (towards right bank)	+1.55 (down streamside)	+2.25 (towards Left bank)	+0.64 (towards Right bank)	+0.5 (towards Right bank)
P3	1.92	-3.0 (towards Left bank)	-4.75 (towards right bank)	-2.65 (towards right bank)	-2.65 (towards Left bank)	-2.65 (towards Left bank)	-2.65 (towards right bank)
P4	1.57	-5.8 (towards Left bank)	-7.06 (towards right bank)	-4.68 (towards Left bank)	-7.2 (towards Right bank)	-5.1 (towards Left bank)	-4.4 (towards right bank)
P5	1.92	-3.0 (towards right bank)	-3.35 (towards Left bank)	-1.53 (towards right bank)	-4.4 (towards Right bank)	-2.65 (towards Left bank)	-2.3 (towards Left bank)
P6	3.46	+1.2 (towards right bank)	+4.0 (towards Left bank)	+3.02 (down streamside)	-1.18 (towards Left bank)	+0.08 (towards Left bank)	+0.5 (towards Left bank)
P7	5.29	+2.95 (towards Left bank)	+2.25 (towards Left bank)	+3.44 (towards Left bank)	+2.6 (towards Left bank)	+1.55 (towards Left bank)	+2.11 (towards left bank)
A2	18.86	No scour	No scour	No scour	+4.0 (9.5m apart from abutment)	+3.3 (10 m apart from abutment)	+3.3 (15.4m apart from abutment)

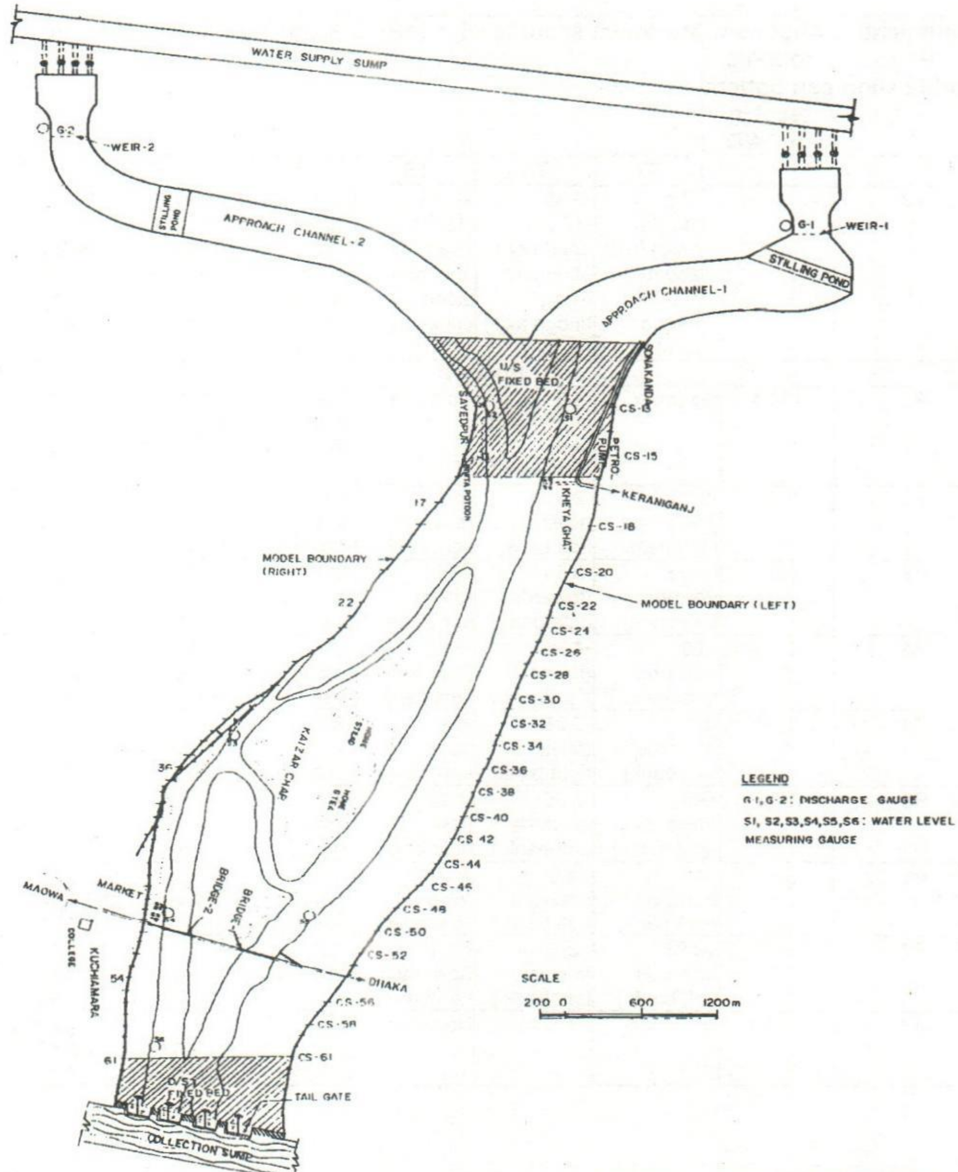


FIG. NO. 1 : LAYOUT PLAN OF DHALESWARY BRIDGE 1 & 2 MODEL (OVERALL MODEL)

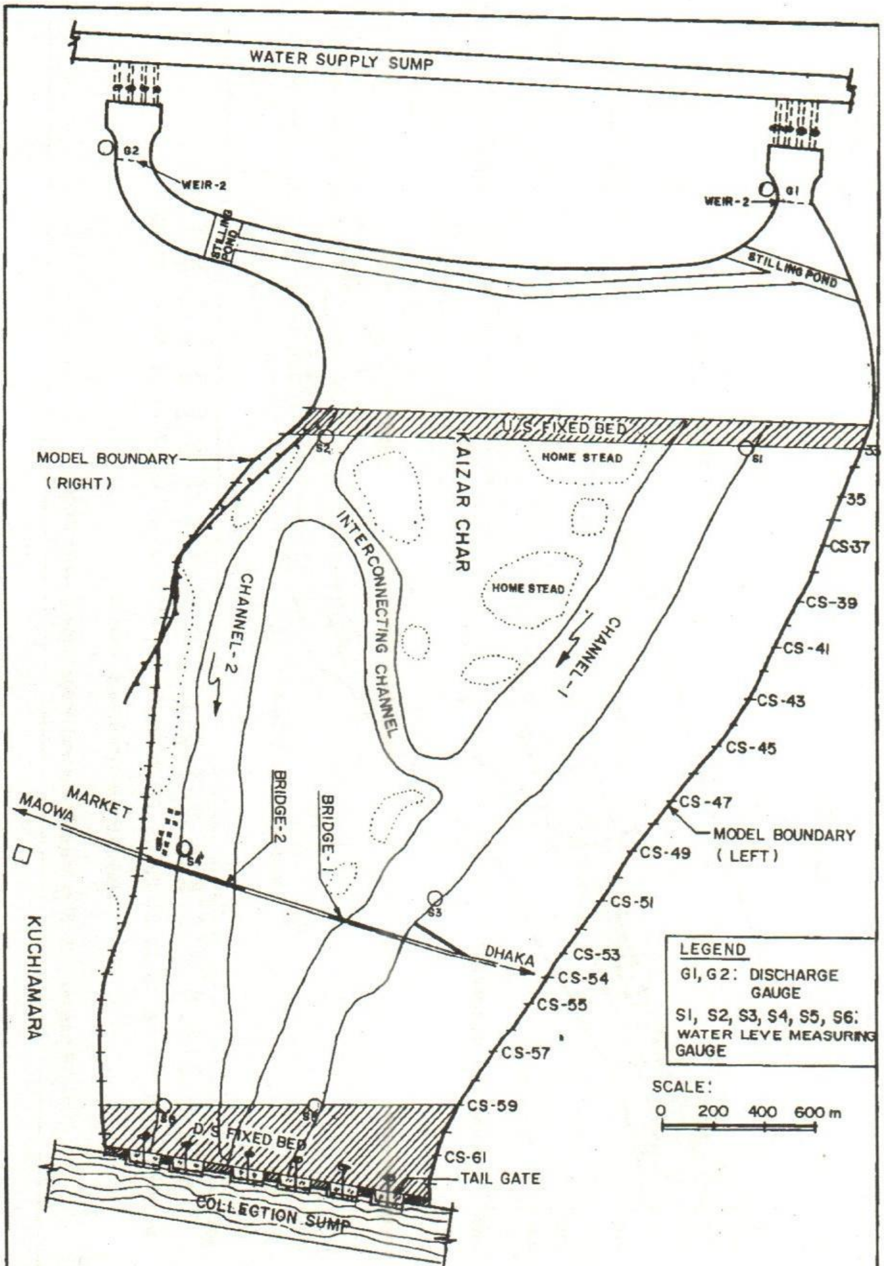


FIG. NO. 2 : LAYOUT PLAN OF DHALESWARI BRIDGE I & 2 MODEL (DETAIL MODEL)

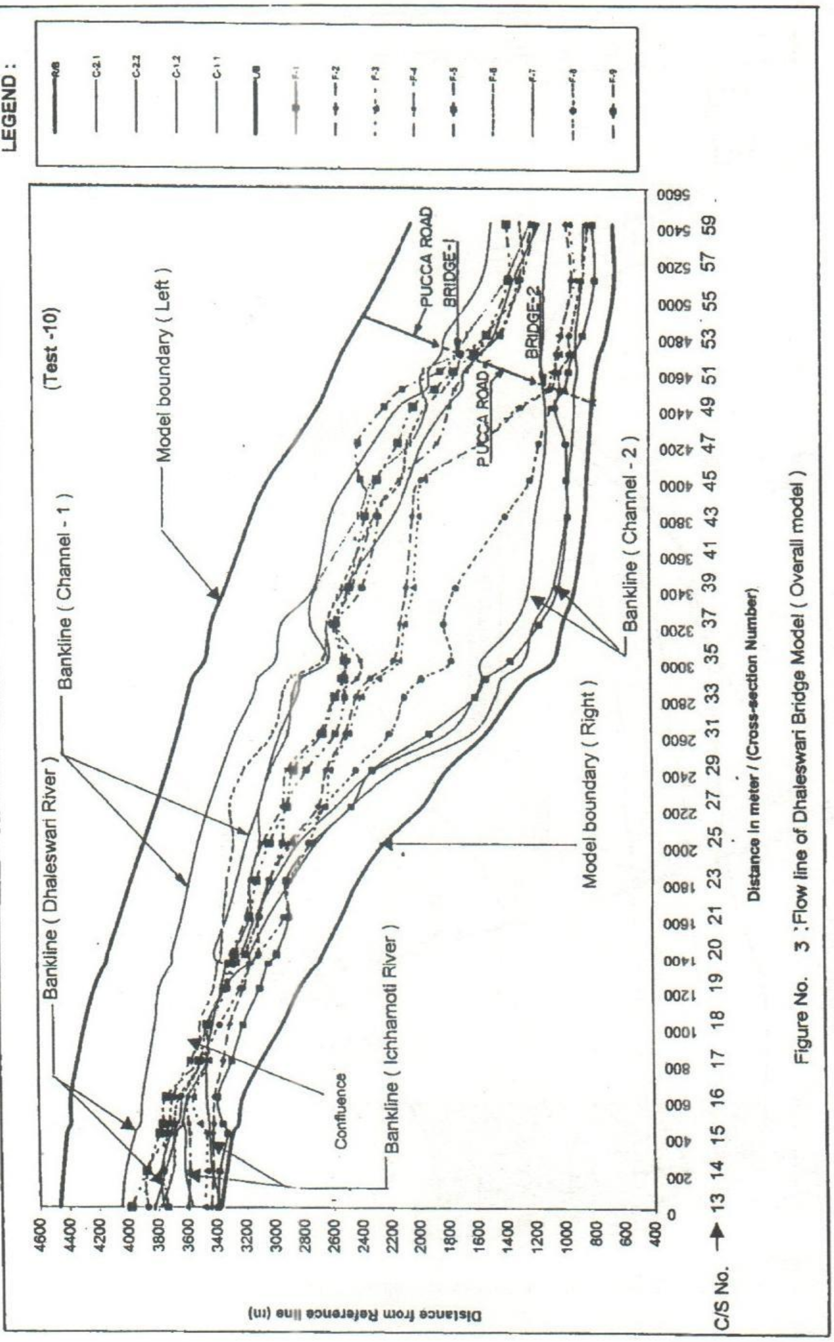


Figure No. 3 :Flow line of Dhaleswari Bridge Model (Overall model)

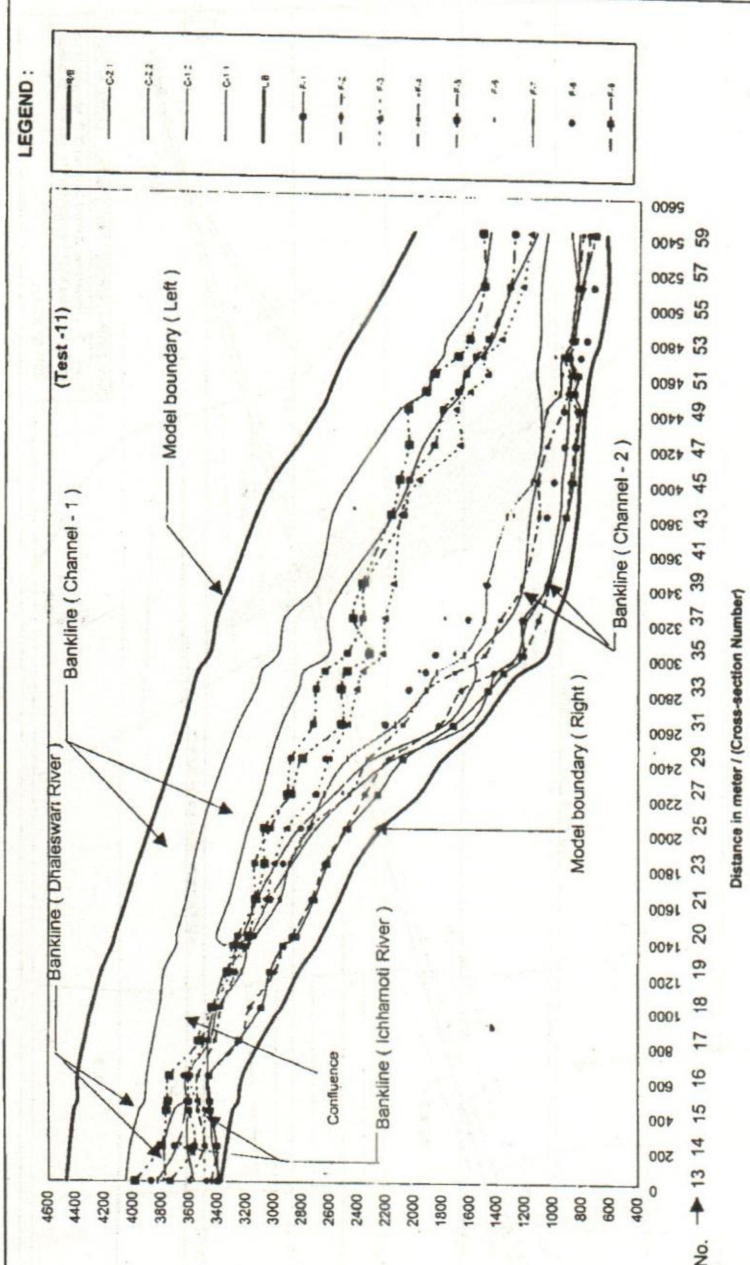
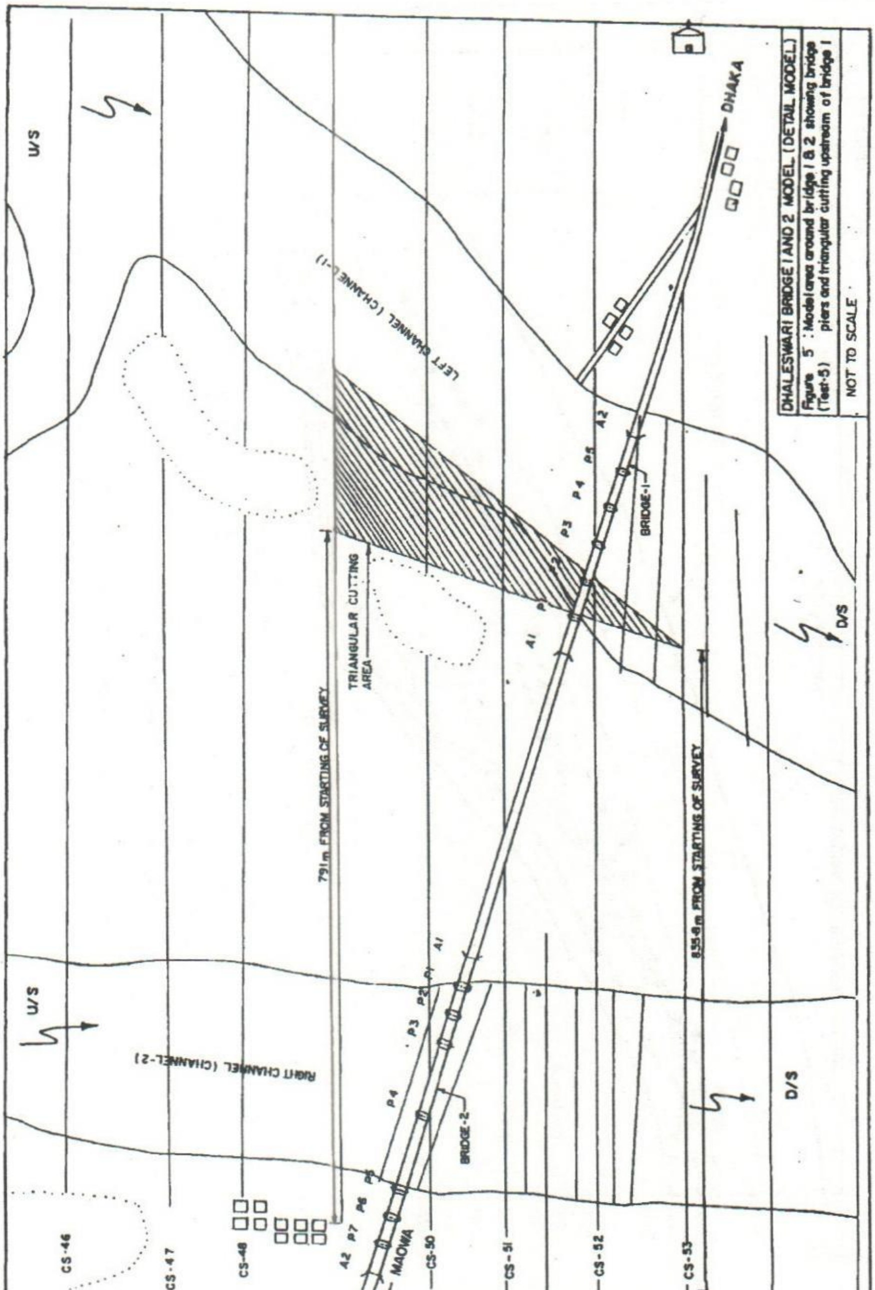


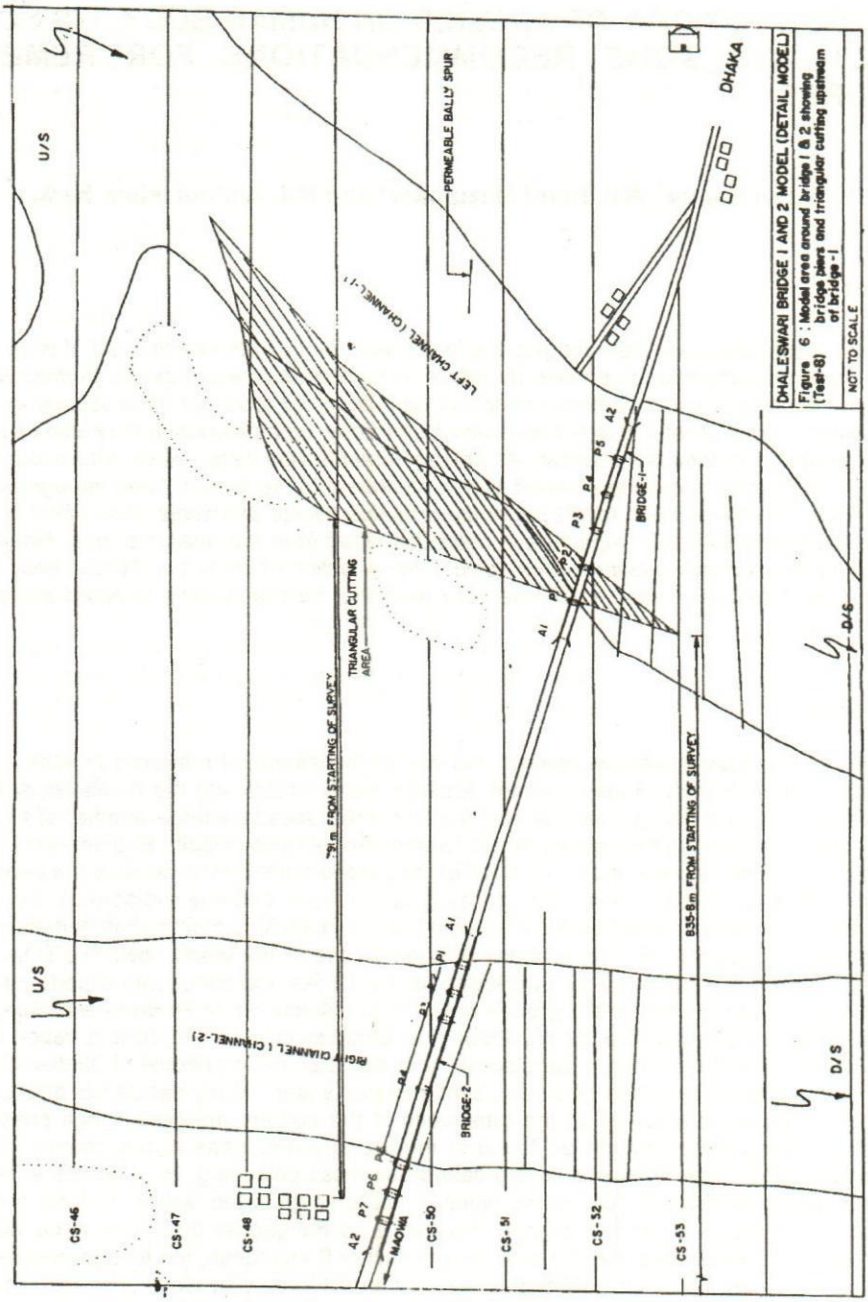
Figure No. 4 : Flow line of Dhaleswari Bridge Model (Overall model)



DHALESWARI BRIDGE I AND 2 MODEL (DETAIL MODEL)

Figure 5 : Model area around bridge I & 2 showing bridge piers and triangular cutting upstream of bridge I (Test-5)

NOT TO SCALE



DHALESWARI BRIDGE 1 AND 2 MODEL (DETAIL MODEL)

Figure 6 : Model area around bridge 1 & 2 showing bridge piers and triangular cutting upstream of bridge-1 (Test-8)

NOT TO SCALE

leaching and seepage. But some one also opine that the contamination of arsenic in ground water is due to the change of geo-chemical environment for withdrawal of large quantity of ground water for Irrigation. But it is difficult to say whether the hydrological imbalance due to heavy ground water withdrawal or seasonal water level fluctuation has any relation with the process of arsenic contamination in ground water. (Guha Mazumder, 1997). But for detection of the source of arsenic contamination in ground water no comprehensive study has yet been under taken with multidisciplinary approach to understand the geology, geo-hydrology and geo-chemistry of the arsenic affected area.

Toxic effect of arsenic on human body

Arsenic is a dangerous environment pollution element. In recent years it has been appeared as a serious health risk in Bangladesh as well as many countries. Arsenic is an unseen killer. Its poising action occurs when its accumulation in human body exceeds the permissible level. The maximum permissible value of arsenic in drinking water according to WHO is 0.01mg/l. In Bangladesh the maximum permissible value of arsenic in drinking water is taken as 0.05mg/l (WHO guideline 1997). Arsenic enters into the human body through air, food and drinking water. When the amount of ingestion is greater than excretion with urine, the arsenic accumulates in hair, nails, skins, liver and bones. Generally arsenic poisoning is found in two forms such as acute poisoning and chronic poisoning. Acute poisoning occurs in the body from the ingestion of large amount of arsenic within short time where as chronic poisoning occurs when a small amount of arsenic enters in to the body through food and water over prolonged period (khaleque, 1996).

Table-2 Health problem created due to the drinking of arsenic polluted water (WHO 1996, WADUD Khan, 1977)

Reactions	Symptoms	Remarks
Black-foot disease	Melanism, Keratosis, paleness,	
Arsenic polluted skin	Malignant dermatitis	
Indefinite	Vomiting tendency pain in stomach, Diarrhoea, troubles in eyes etc.	When a large amount of arsenic enters into body within short time or a small amount for a long period.
Pregnancy complexity	Abortion	
Heart disease	Heart problem	Among the children
Cancer	Urine bladder, skin, kidney, lungs, liver	
Death		For cancer.

Generally the sysmtomps of arsenic appears in three stages. In first stage there are raindrop pigmentation on the body dermatitis, keratosis, conjuntivitis bronchitis. In second stage it is keratosis through out the body, peripheral Neuropathy, Hepatopathy, Melanosis, Depigmentation. In third stage, there are problems of kidney, liver, Gangrene in the limbs or skin cancer (Guideline given by WHO for drinking water, second edition, Vol.-1, 1993).

Social impact

Arsenocosis does not only create adverse effect on health but it is also creating problem in social life. An instance of West Bengal incident may be cited. There in villages it becomes a problem for parents to marry off their affected daughter. Even husbands are giving divorcing their arsenic affected wives and vice-versa. Sometimes wives are sent back to their parents together with their children. Even competent candidates called for interview are not offered jobs after noticing the skin manifestation . In some cases the ignorant villagers often confused skin manifestation with leprosy and therefore avoid the person socially (Durjog Nivaron, 1996).

Remedial measures for arsenic toxicity

The arsenic toxicity in Bangladesh and West Bengal, India is the most serious threat to some 100 million people of this subcontinent. A lot of efforts are being made by the Department of Public Health Engineering to find out the real cause of contamination of arsenic in ground water. But the hazards of the arsenicosis are urgent. The damage caused by arsenic is mainly due to the fact that inorganic arsenic present in drinking water enters body fluid (blood) and then binds the sulphydryl group of the tissue proteins, notably vital enzymes. The trivalent arsenic (sodium arsenite) is the most toxic form. Prof. Kamal Uddin Ahmad (1999) opines that if methyl($-CH_3-$) is in short supply in the body for any reason, methylation of inorganic arsenic is impaired. Inorganic arsenic will continue to bind sulphydryl enzymes disrupting normal metaboilism resulting in the toxic consequence. He also believes that inadequacy in methionine i.e. rich protein in diet is the cause of toxicity of arsenic. So the improvement of diet with rich protein such as hen egg, milk etc. may redress the situation of the people of the arsenic affected area, (Prof. k. Ahmad, 1999). It is observed that arsenic diseases are more in the areas, where the people suffer much from malnutrition. For this, the experts suggest that the food in rich protein increases the arsenic metabolism and thereby lessening arsenic deposition in the tissue by flushing it out with urine. Researchers on arsenic toxicity comment that it is a disease of poor people. The diet of those people is poor in protein, they are affected by the toxicity of arsenic. As arsenicosis is a consequence of deficiency in the diet that is protein, hence dietary care can solve somewhat arsenic toxicity effect on human health. So the researchers must concentrate their research to find cheap sources of plant protein, which the poor people of Bangladesh will be able to afford.

Another remedial measure is that those who are drinking arsenic contaminated tube well water must change to drinking surface water from ponds which will be protected from contamination and reserved for drinking water only. Cultivation of aquatic shell species like lobster, crabs, shrimps, Oyster and turtle will remove any inorganic toxic arsenic from water. It may be mentioned here that the toxicity takes a long time to show up and the disappearance of toxicity will also be taking time.

Conclusion and recommendations

Contamination of arsenic in drinking water is our national problem. Intake of arsenic in human body beyond permissible limit is dangerous. It acts in the body as an unseen killer. So immediate necessary step should be taken to find out the real cause of arsenic contamination in drinking water. Now it is very urgent to test water of all the shallow and deep tube wells of the country for detection of arsenic and in tube wells in which arsenic is found beyond permissible limit should be sealed up and advice should be given to the people to take drinking water from alternative sources. After all, measures must be taken so that excess of arsenic beyond permissible limit does not enter into the body of any people as disease due to arsenicosis is very difficult to cure. The following recommendation can be kept so that excess of arsenic beyond permissible limit does not enter into human body through drinking water.

- Alternative source of drinking water should be found out where tube well water contains arsenic beyond permissible limit so that further ingestion of arsenic does not take place.
- Necessary steps should be taken for treatment of surface water to make it suitable for drinking.
- Drinking water should store over night and then filter through layer of fine sand which may reduce arsenic concentration since the oxidation of arsenic due to storage convert arsenite to arsenate which is less toxic.

- During construction of tube well proper sealing should be done so that arsenic from higher aquifer does not enter into lower aquifer.
- During the time of installation of tube wells arsenic rich aquifer should be avoided in the arsenic affected area.
- Project should be taken up for removal of arsenic.
- Low cost arsenic removal filter should be found out and supplied to the arsenic affected areas.
- Necessary arrangement should be taken for treatment of the people attacked by arsenicosis by trained doctors. Required amount of medicine and necessary apparatus should be supplied to the hospital for treatment of the disease due to arsenicosis.
- In the arsenic affected areas if possible pipe water supply scheme may be taken up to supply treated water from surface water sources.
- In order to identify the sources of arsenic in affected areas, drilling is necessary to investigate the geochemistry and hydrology of the affected aquifer.
- In the area where arsenic level is beyond the permissible limit, arsenic removal plant based on iron removal plant using horizontal flow roughing filter may be constructed.
- Manufacturing of domestic filter for removal of arsenic by co-precipitation method should be encouraged.
- The level of arsenic content in the arsenic affected area needs to be studied intensively in order to determine seasonal variations and their trend over a period.
- A system of periodic monitoring of arsenic content around the known arsenic affected areas should be developed in order to check weather arsenic incidence is spreading in new areas.
- Arsenic along with other parameters and sampling or aquifer provenance of ground water should be determined in order to investigate source and mobility of arsenic.
- Immediate step should be take up to set up more laboratories for determination or detection of arsenic.
- Awareness among the people and facilities for detection of disease due to arsenocosis should be increased.
- Proper training for health workers, Doctors, Engineers should be arranged to make them efficient in this regard.
- A National data base center should be developed for collection of information, preservation, exchange and distribution about arsenic.
- It is necessary to set up modern National Laboratory for detection of level of arsenic along with other harmfull materials in drinking water and in this regard international co-operation may be wanted.
- Last of all, multi mass media should take active part in this regard. They should take necessary action to aware the people about the adverse effect of arsenic through T.V., Radio and Newspapers.

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THE ARIAL KHAN RIVER AND ITS GEOMETRIC ASPECTS

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Abstract

A study was conducted to investigate the geometric characteristics of Arial Khan river which is one of the important tributaries of the Padma (lower Ganges)and covers a reach length of about 200 km from its offtake. This study comprises analysis of cross-sectional geometry, development of non-dimensional correlation, thalweg and bankline shifting, mean bed level variation, specific gauge analysis and determination of meander parameters. The study showed that the planform geometry as well as hydraulic geometry of the river have undergone considerable change over a period of about twenty years. The study further revealed that flood discharge showed an increasing trend and mean bed level suffered considerably.

Introduction

Bangladesh is a land of rivers having an agrobased economy. From ancient time to the present days, rivers have been playing a dominant role in human activities. Rivers provide waterways to transport the agricultural and other commodities from one place to another, water for drinking, irrigation and act as reservoir for fish culture. They also help in the generation of electric power. But occasional heavy flood discharge causes flooding of lands and caving of the banks, thereby causing destruction to the cities and other important engineering constructions. The countries, which have succeeded in controlling and harnessing the rivers, have progressed very quickly. Examples of such success are found in many countries of the world starting from the USA, through Europe to Asia.

During monsoon, rivers of Bangladesh carry huge amount of sediment along with water. They altogether cause significant change to geomorphic and other hydraulic characteristics of the rivers. Again during lean flows, there is heavy deposition of silts. Thus, throughout the year, changes in cross-section, slope, thalweg etc. of the river take place. Again these parameters undergo great changes from year to year due to change in discharge and sediment discharge. The Arial Khan is no exception to these changes. Keeping these facts in mind a study on the geometric characteristics of the river is extremely important in connection with the river bank stabilization, navigation, flood control and also for the development of water resources projects. It may be worthwhile to mention that the Arial Khan flows through a region where the population density is one of the highest in Bangladesh. Moreover, the region is undergoing through significant development works with a view to bring prosperity and economic solvency to the poor inhabitants. Hence the present attempt to investigate the geometric aspects of the Arial Khan is very important.

The Arial khan river

The Arial Khan is a meandering river. It has two parts, one is called as the Arial Khan Upper (AKU) and the other is the Arial Khan Lower (AKL), both of them are distributaries of the Padma. Both the parts of the river are originated from the Padma near Chowdhury Char and Dubaldia respectively. The Arial Khan river is shown in **Figure 1.** The length of the AKU and the AKL is about 70 km & 125 km respectively. The AKU meets the AKL at Shalmaback, downstream of

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cross-section no. 6, in the district of Madaripur. The distance between the AKU and the AKL at their junctions with the Padma is about 30 km and the distance between offtake of AKU and Aricha confluence is about 70 km.

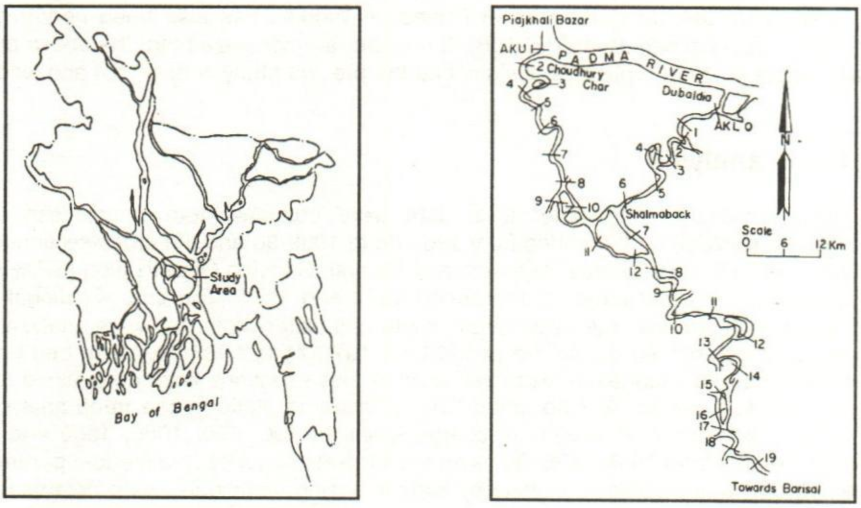

Figure 1 The Arial Khan river

Both the AKU and AKL are meander rivers with sharp curves and bends. After combining with the AKU, the AKL extends towards the downstream direction to meet various rivers such as Naya Banga, Babuganj, Kirtonkhola etc. and finally meets Biskhali river which discharges into the Bay of Bengal through the Sundarban forest. The Arial Khan is navigable year round and almost throughout the whole river course. It is used moderately by the surrounding inhabitants for their day to day travel to nearby market place and transporting of commercial commodities to other trade centers of the country. The study reach covers the AKU as well as the AKL which is about 200 km and extends from cross-section no. 1 to 12 for the Arial Khan Upper and cross-section no. 0 to 19 for the Arial Khan Lower.

Literature review

Proper utilization of water resources of the country for the overall benefit and progress was understood many decades ago. There were several development projects such as Sureswar Project, Faridpur Project, Sutla-Bagda Project, Barisal Irrigation Project-1 etc. with the object of providing irrigation, flood control and drainage facilities by utilizing the Arial Khan, Dubaldia, Joyanti, Palong-Nari, Little Padma etc. and their connecting channels. No significant hydrauligic, morphologic or sediment transport study has so far been undertaken on the Arial Khan. But similar studies have been undertaken on the major rivers of Bangladesh.

It is worth mentioning that severe bank erosion and shifting of the Arial Khan endanger the Bhanga-Mawa road and agricultural lands. In 1989, Bureau of Research Testing and Consultation (BRTC), Bangladesh University of Engineering and Technology (BUET), studied the Arial Khan river and presented a report on the, 'Design of Bank Protection Works of the Arial Khan near Bhanga-Mawa Road'. In March 1990, Snowy Mountains Engineering Corporation (SMEC), Australia, in associated with Bangladesh Consultants Limited (BCL) prepared a report on the, 'Protection of Bhanga-Mawa Highway', after studying the Arial Khan on behalf of the Roads and Highway Department, Government of the People's Republic of Bangladesh. These reports did not consider any detail analysis of the geometric or morphological behavior of the river. These studies only concentrated on the river bank protection of the Arial Khan at a site. Moreover, a report on model study for the protection of Bhanga-Mawa Highway from erosion of Arial Khan has been published by River Research Institute (RRI), Faridpur (1990), which shows design finalization and effectiveness of the proposed protective works. In order to protect the town from possession of the Arial Khan, a study on the, 'Madaripur Town Protection Works', has also been performed by Bangladesh Water Development Board (BWDB). It may be re-emphasized that the above studies were basically object oriented. Thus it is obvious that the present study is essential and would be fruitful.

Method of data analysis

The rating curve, discharge and water level data were obtained from Bangladesh Water Development Board (BWDB) for the period from 1965-66 to 1989-90 and the cross-sectional data for 1970-71 and 1987-88. From Space Research and Remote Sensing Organization (SPARRSO) the landsat imageries were collected for the period 1972 and 1991. The cross-sectional data, water areas, average depth, average water depth, width and water width etc. were analyzed and their variations were determined during the period from 1970-71 to 1987-88. Mean bed level at various cross-sections and changes in mean bed level at these sections were determined for the years from 1970-71 to 1987-88. At Chowdhuri Char (Discharge station) the trend analysis on specific gauge was conducted at various discharge levels of 100, 500, 1000, 1500 and 2000 cumecs utilizing the data from 1965-1986. By using the landsat imageries, the mender parameters at some selected bends and bankline shifting by superimposing techniques were determined for the years 1972 and 1991.

Results and discussions

Variation of cross-section and thalweg shifting

The selected cross-sections of AKU were plotted on the same scale for the years 1970-71 and 1987-88 and these were then superimposed to observe the variation of geometric characteristics. A typical plot is shown in **Figure 2** for the AKU-3. The changes of cross-sectional area, water area, top width, top water width, average depth and average water depth for various cross-sections are summarized in **Table 1**. It was evident from **Table 1** that the average cross-sectional area and water area were increased by 21.5% and 79.3% respectively. The average depth was decreased by 8.3% and average water depth was increased by 23.4%. Again the average width and the average water width were increased by 17.1% and 23% respectively. The thalweg in different cross-section of the AKU was observed to shift very widely and randomly. It was observed that the thalweg in 1987-88 at sections AKU-1, 5 to 8, 11 and 12 moved leftward and at sections AKU-2 to 4, 9 and 10 moved rightward with respect to thalweg in 1970-71.

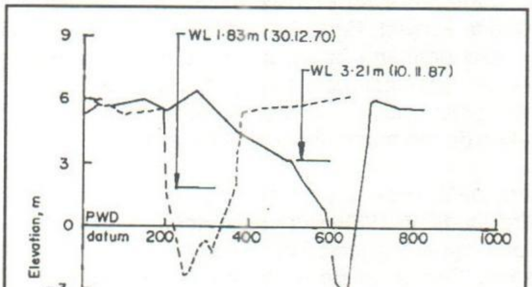

Figure 2 Cross-section for the Arial Khan Upper (AKU-3)

Table 1 Summary of cross-sectional area, water area, top width, top water width, average depth, average water depth and thalweg shifting for the AKU

Section No.	Year	Cross-Sectional Area (m2)	Water Area (m2)	Top Width (m)	Top Water Width (m)	Average Depth (m)	Average Water Depth (m)	Thalweg Shifting (m)
AKU-1	1970-71	1419.4	823.1	384.2	353.1	3.7	2.3	
	1987-88	2627.7	1345.3	419.1	386.1	6.3	3.5	120
AKU-2	1970-71	979.5	546.5	223.5	200.5	4.4	2.7	
	1987-88	2309.0	1355.2	406.4	265.8	5.7	3.7	20
AKU-3	1970-71	4330.6	1056.2	957.6	407.7	4.5	2.6	
	1987-88	2030.2	771.9	486.2	167.6	4.2	4.6	500
AKU-4	1970-71	2785.3	553.8	624.8	384.8	4.5	1.4	
	1987-88	3043.2	1755.4	596.9	445.8	5.1	3.9	90
AKU-5	1970-71	1429.6	297.1	304.8	282.6	4.7	1.1	
	1987-88	2820.4	1257.0	553.7	411.8	5.1	3.1	520
AKU-6	1970-71	1071.6	405.0	190.5	171.5	5.6	2.1	
	1987-88	1594.5	569.5	436.9	196.2	3.7	2.9	395
AKU-7	1970-71	1948.4	735.5	590.6	301.0	3.3	2.1	
	1987-88	5823.1	3385.7	584.3	970.6	5.9	3.5	115
AKU-8	1970-71	2546.5	743.8	481.3	428.6	5.3	1.7	
	1987-88	1866.2	827.9	593.7	309.6	3.1	2.7	730
AKU-9	1970-71	1298.4	565.3	240.0	212.1	5.4	2.7	
	1987-88	779.8	325.2	255.3	221.0	3.1	1.5	75
AKU-10	1970-71	1261.9	424.9	327.4	190.5	3.9	2.2	
	1987-88	1656.0	846.8	335.6	292.1	4.9	2.9	110
AKU-11	1970-71	1142.9	764.6	129.5	129.5	8.8	5.9	
	1987-88	382.6	163.6	114.3	99.1	3.3	1.7	205
AKU-12	1970-71	1119.2	415.2	303.5	262.9	3.7	1.6	
	1987-88	983.4	363.4	388.6	223.5	2.5	1.6	95

Variation of mean bed level

Mean bed level (MBL) at various sections of AKU was computed and plotted for the years 1970-71 and 1987-88 as shown in **Figure 3.** It was observed that MBL in 1987-88 rises at AKU-3, 5, 6, 8, 9, 11 and 12 and falls at AKU-1, 2, 4, 7 and 10 compared to 1970-71. The maximum rise and fall of MBL occurred at sections AKU-11 and 7 respectively with respect to MBL of 1970-71. Variation in MBL profile was also determined to observe the erosion-deposition at various sections in the AKU. It was revealed that the amount of material deposited within the study reach is much higher than the amount of material eroded away and carried out of the reach. Assuming linear variation of change in MBL, the calculated sediment deposition and erosion were found 27.27 million cubic meter and 7.25 million cubic meter respectively during 1970-71 to 1987-88. The net deposition was calculated as 20 million cubic meter which corresponds to 3.96 cm sediment deposition each year throughout the study reach of the Arial Khan Upper. This aggradation-deposition was cross-checked by developing area-elevation relationship, showing the variation of cross-sectional area with elevation at various sections. It was found that the area-elevation relationship was in agreement with the trend obtained for MBL. A typical area-elevation relationship was shown in **Figure 4.**

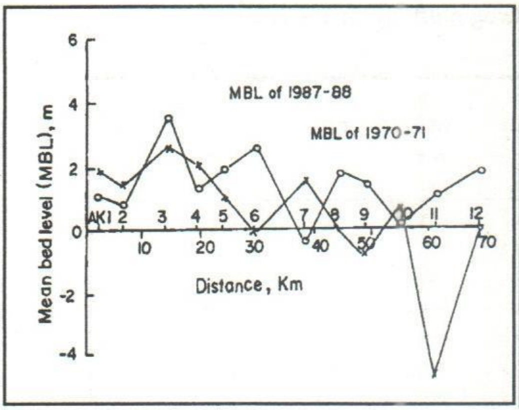

Fig. 3 Variation of mean bed level (MBL) for the Arial Khan Upper

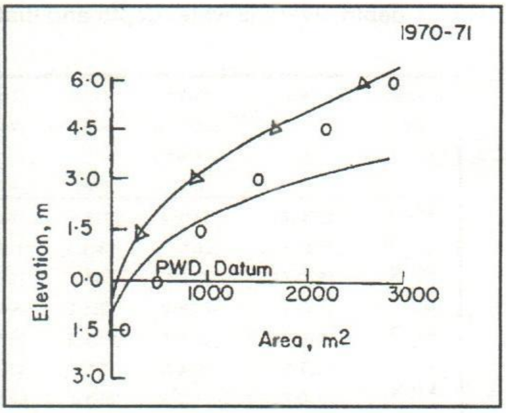

Fig. 4 Area-elevation relationship (AKU-4)

Specific gauge analysis

At a station specific gauge analysis was done to determine if there are any trends with time in the elevation of water level corresponds to a given discharge. This analysis was based on discharge levels of 100, 500, 1000, 1500 and 2000 cumecs and the **Figure 5** Variation of stage of the Arial Khan Upper at Chowdhury Char at different discharge level corresponding stages from the rating curve for the period from 1965-66 to 1985-86 as shown in **Figure 5.** The trend of the curve indicates that the stage is decreasing in a sinuous pattern which indicates the general dynamic behavior in alluvial river. This figure also explains that the scouring at Chowdhury Char might have been occurred.

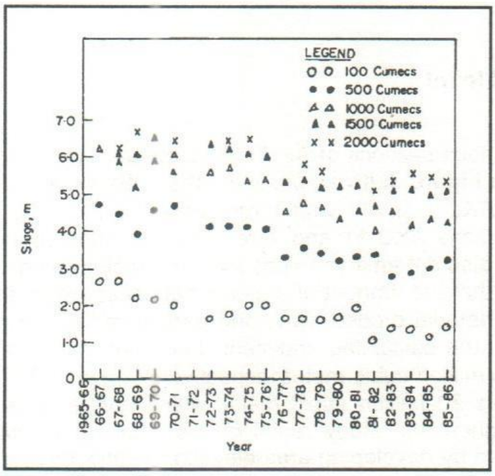

Figure 5 Variation of stage of the Arial Khan Upper at Chowdhury Char at different discharge level

Bend movement

Based on landsat imageries the shifting of various bends was occurred both laterally and longitudinally during the period 1972 to 1991. There were many new bends formed and old bends abandoned. The confluence of the AKU and AKL was shifted both laterally by about 5 km to right and longitudinally by about 3 km upstream. The lateral shifting near the Bhanga-Mawa highway was found about 0.5 km. The maximum lateral shifting was taken place by about 3.5 km left and the maximum longitudinal shifting was taken place by about 2.5 km downstream.

A study on sinuosity and meander parameters was conducted considering the selected bends of Arial Khan river for 1972 and 1991. The meander length was found to increase with the increase of meander belt. The average sinuosity values obtained from the selected bends were 1.66 and 2.037 in 1972 and 1991 respectively. On the other hand, the average sinuosity of the whole river reach was found to be 2.164 and 1.876 in 1972 and 1991 respectively. This indicates that the river has become less sinuous in 1991 compared to 1972. A typical relationship between meander length and mander belt is shown in **Figure 6.**

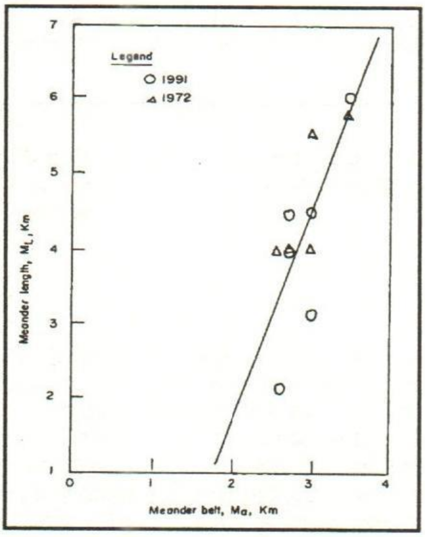

Figure 6 Relation between meander length (M_L) and meander belt (M_B)

Non dimensional correlations

Use of non-dimensional correlations in the study of alluvial geometry are becoming gradually popular for many reasons. One potential application of such correlataion is the study of scale models. Keeping this in mind, correlations between shape (W/D), flow

Froude number [$V/\sqrt{(gD)}$] and non-dimensional discharge [$Q/\sqrt{(\nu D)}$] were established. The correlations show a general trend of decrease of flow Froude number with the increase of width-depth ratio as shown in Figure 7. Relationships were also established for $V/\sqrt{(gD)}$ and $Q/\sqrt{(\nu D)}$ and good correlations were found. This correlations, however, showed a general increasing trend of flow Froude number with increase of $Q/\sqrt{(\nu D)}$. This relationship is shown in Figure 8. The regression equations developed for the two figures as shown in Figures 7 & 8 may respectively be written as follows:

$$V\surd(gD) = 98.753\ (W/D)^{-1.606} \quad 1$$
$$V\surd(gD) = 6.4\times10\text{-}8\ [Q/(\nu D)\times10^{6}]^{0.747} \quad 2$$

The coefficient of correlations for Equations (1) and (2) were determined statistically and found to be 0.941 and 0.989 respectively. The basis of selecting these non-dimensional parameters stems from the findings of previous studies (Hossain, 1987). Similar type of correlations were established by Hossain (1989) and Hossain & Das (1995) for some major rivers of Banglsdesh.

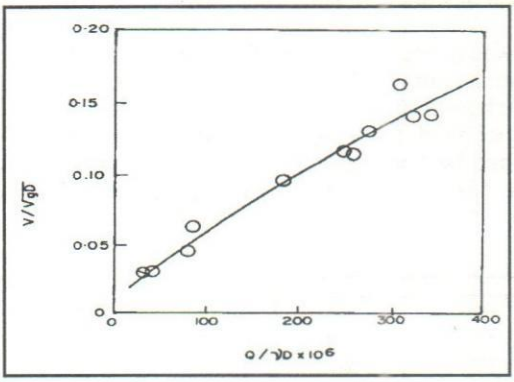

Fig. 7 Relation between V/√(gD) and W/D at Choudhury Char (1993)

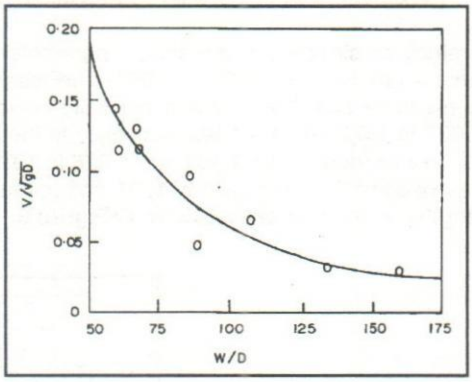

Fig. 8 Non-dimensional plot of Q/√(νD) vs. V/√(gD) for the Arial Khan Upper at Choudhury Char (1993)

Hydrological aspects

The morphological changes in an alluvial river are dependent on the variation of discharge, sediment flow and flood plain characteristics. The flow characteristics of the Padma highly influences the Arial Khan river. Thus the duration and magnitude of discharge as well as concomitant sediment activity in the Padma and Arial Khan is of vital importance. The prediction of morphological parameters are still not fully understood due to this complexity and highly dependent on empirical treatments supported by statistical analysis. The distributary entrance to the Arial Khan has changed over years, at time through a deep pool and at other time behind a bar. Accordingly the discharge into the Arial Khan varied considerably as shown in **Table 2.** The table shows the percent entry of discharge has a slight increasing trend.

Conclusions

The cross-sectional area of the AKU varies widely and randomly. An increasing trend in the cross-sectional area at some sections indicating degradation while a decreasing trend at other sections indicating aggradation. The thalweg of the river shifted from one bank to another in a random fashion. In most of the sections, the thalweg in 1987-88 was deeper than those of 1970-71 indicating channel bed degradation. The study showed MBL at some sections rises and falls at other sections in 1987-88 compared to that of 1970-71. A net deposition was found to occur which corresponds to about 4 cm sediment deposition each year throughout the study reach of the AKU. All the bends are shifted laterally to a certain extent ranging from 0.25 km to 3.5 km over the study period. The average sinuosity of the river was found to decrease from 2.16 to 1.88. At a station specific gauge analysis indicated that stage has a decreasing trend due to bed degradation at that section. In the present study the cross-sectional geometry and specific gauge were analyzed in the upper part of the river. Similar type of study should be carried out in the other part of the river to have an insight in to the overall morphological behavior of this river.

Table 2 Comparison of Aial Khan river flows with that of the Padma

Year	Arial Khan Maximum m3/s	Padma Maximum m3/s	Arial Khan % of Padma
1965-66	1520	85000	1.8
1966-67	1130	85200	1.3
1967-68	2280	69200	3.3
1968-69	2230	91000	2.5
1969-70	1910	98200	1.9
1970-71	3540	85200	4.2
1971-72	-	-	-
1972-73	1540	78600	2.0
1973-74	3960	100000	4.0
1974-75	3200	111000	2.9
1975-76	1950	-	-
1976-77	1760	84400	2.1
1977-78	2150	99900	2.2
1978-79	2310	88500	2.6
1979-80	1790	77300	2.3
1980-81	2260	109000	2.1
1981-82	3040	77300	3.9
1982-83	3240	65400	5.0
1983-84	2100	84600	2.5
1984-85	2640	110000	2.4
1985-86	2600	73300	3.5
1986-87	3230	85400	3.8
1987-88	3370	118000	2.9
1988-89	4880	87300	5.6
Average	2549	89264	2.9

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