

RECENT FLOODS IN BANGLADESH: POSSIBLE CAUSES AND SOLUTIONS

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Md. Khalequzzaman

Department of Geology
University of Delaware
Newark, DE 19716, USA

Present address: Present address: Dept. of Geology & Physics,

Lock Haven University, Lock haven, PA 17745

ABSTRACT

In recent years the frequency of abnormal floods in Bangladesh has increased substantially, causing serious damage to lives and property. The most crucial questions that need to be addressed are: what really causes the havoc-creating floods and is there any solution to the problem?

The heavy monsoon downpour and synchronization of flood-peaks of the major rivers are generally considered to be the main causes of the floods. Some underlying factors also deserve serious consideration as possible contributors to the recent floods: change in the base level of the rivers due to local sea level rise and subsidence, inadequate sediment accumulation on flood plains, a possible increase in the watershed area due to seismic and neotectonic activities in the region, river bed aggradation due to siltation and damming of rivers, soil erosion due to unwise tilling practices, deforestation in the upstream region, and excessive development and population growth.

Without regional cooperation among the co-riparian nations any major interbasin flood control activity is considered to be almost impossible. However, among other proposals in this paper, extensive annual dredging of the rivers, channels and creeks, and reoccupation of the abandoned channels in Bangladesh through re-excavations could still increase the water carrying capacity of the rivers. Land elevations could be increased if the dredged or excavated materials are dispersed on the flood plains, which would in turn reduce the severity of floods.

INTRODUCTION

Unusual or above normal surface-water flow that inundates otherwise high ground is called a flood. Riverine floods occur when the amount of water flowing in a drainage basin or watershed (the area that collects and directs the surface water into the streams that drain it) exceeds the carrying capacity of rivers which drain the area. Flooding can occur due to river overflow or surface runoff. There are two types of floods which occur in Bangladesh: annual floods (barsha) and low frequency floods of high magnitude (bonna). While the annual floods are essential and desirable for overall growth of the Bangladesh delta

and the economy, the low frequency floods such as those that occurred in 1974, 1984, 1987 1988, and 1991 are destructive and cause serious danger to lives (Chowdhury, 1988; Brammer 1990).

Flooding propensity in an area can vary greatly with a change in the water carrying capacity of a drainage basin and/or with a change in land elevation with respect to the base level (the depth to which a river can cause erosion) of rivers - the ocean. For example, an increase in the water carrying capacity of a drainage system and/or an increase in the elevation of adjacent land on either side of a drainage system will reduce flooding propensity in an area. Therefore, the flood problem and the solution can be analyzed in the context of two fundamental parameters: water carrying capacity of rivers and land elevation.

Bangladesh is but a small part of a large geologic setting which does not acknowledge political boundaries and occupies a much larger territory consisting of many countries in the region. Bangladesh is drained by 300 major rivers and channels most of which originate outside the country (Er-Rashid, 1978). Only 7% of the watershed area of these rivers falls within the territory of Bangladesh (Shahjahan, 1983; Siddiqui, 1983; Alexander, 1989a; Brammer, 1990). Therefore, formulating solutions to the flooding problem requires an understanding of the regional geologic setting and the underlying cause of floods. Flooding in Bangladesh is but a part of the overall hydrodynamic process active in the entire region. Only solutions that are in harmony with the natural processes can prevail. Confrontation with natural processes leads to disequilibrium within the natural hydrodynamic system in the region and will create more problems.

This paper makes an attempt to explain the genetic causes of the flood problem in the context of changes in water carrying capacity and land elevation in Bangladesh. Future research directions are outlined and suggestions are made as to ways to regulate these two parameters and thus mitigate the flood problem.

POSSIBLE CAUSES OF FLOODS

The factors responsible for the recent low frequency floods in Bangladesh can be analyzed in terms of short-term (immediate causes) and long-term processes. Evident phenomena that take place prior to and during floods, which can easily be related as plausible causes for floods, are termed short-term processes. On the other hand, the slowly occurring phenomena which can not be tied to the flood problem directly are termed long-term processes.

Short-term Causes

(A) Monsoon downpour: An increased amount of precipitation can cause flooding. An above normal monsoon downpour in the Ganges-Brahmaputra-Meghna drainage system is thought to be the primary cause of the 1988 flood in Bangladesh (GOB and UNDP, 1989; Brammer, 1990). It is not known, however, if the heavy precipitation is actually an effect of other processes such as the greenhouse effect or destruction of forests in the upstream region.

(B) Synchronization of Flood Peaks: The synchronization of flood peaks for the major three rivers took place within a two week time period, causing a sudden increase in water level in virtually all areas of the country (GOB and UNDP, 1989; Brammer, 1990). While the synchronization of flood peaks can explain the cause of the 1988 flood, it fails to explain the reason for an overall increased propensity for low frequency floods in recent years such as occurred in 1974,

1984, 1987, and 1991. The answer might lie in other long-term processes that reduce the water carrying capacity of the drainage system and decrease land elevation with respect to the base level of the rivers in Bangladesh.

Long-term Causes

(A) Local Relative Sea Level Rise: The ultimate destination of all rivers is the ocean. The land elevation is measured with respect to sea level in an area. Therefore, any change in sea level causes land elevation to change. At the present time sea level is rising globally (Pilkey et al., 1989). If sea level rises in an area at a rate faster than the rate of land aggradation due to sedimentation, then land elevation decreases. Any decrease in land elevation can cause increased inundation by rivers overflowing at bankfull stage. The rate of local relative sea level rise is 7 mm/year around the coastal areas of Bangladesh (Emery and Aubrey, 1990). An increase in sea level raises the base level of rivers, which in turn reduces the gradient of river flow. As a result, the discharge of rivers decreases as the water flow becomes sluggish, creating a backwater effect further inland. The backwater effect caused by sea level rise can result in more flooding of land from "piled up" river water inland (Warner, 1987). This certainly seems to be one of the reasons for the increase in flood intensity in recent years in Bangladesh.

(B) Inadequate Sediment Accumulation: The only way for land to counter the effects of a rising sea is for sediment to accumulate at a rate that is sufficient to keep pace with the rate of sea level rise. Limited data show that the average sediment accumulation rate for the last few hundred years in the coastal areas of Bangladesh is 5-6 mm/year, which is not enough to keep pace with the rising sea level (Khalequzzaman, 1989). As a result, net land elevations must have been decreasing over time, resulting in more flood inundations.

(C) Subsidence and Compaction of Sediments: Sediments on a delta plain are rich in decomposed organic matter, and are subject to compaction due to dewatering and the weight of the overburden. Most deltas subside due to the weight of the thick sediment layer. Subsidence along with compaction reduces land elevation with respect to the rising sea level (Pilkey et al., 1989). Even though the rate of subsidence and compaction are not yet well documented, based upon our knowledge about processes active in other deltas it can be assumed that Bangladesh's delta is also undergoing subsidence and compaction.

(D) Riverbed Aggradation: Due to relatively higher settling velocity, the large-grained sediments are deposited near the source area on the riverbeds, forming sand bars. The river gradient decreases rapidly if sedimentation continues on the riverbeds. Because of low gradients and high sediment loads, the riverbeds of most of the rivers in Bangladesh aggrade very quickly. Riverbed aggradation is most pronounced for the Ganges and its distributaries. From the border with India to the point where the Ganges meets the Brahmaputra, the riverbed has aggraded as much as 5-7 meters in recent years (Alexander, 1989b). Riverbed aggradation is so pronounced in Bangladesh that changes in riverbed level can be observed during one's lifetime. For example, the Old Brahmaputra was navigable for steamers only about 30 years ago, and is presently an abandoned channel. This situation is true for many other distributaries of the Ganges and Meghna such as the Madhumati, the Bhairab, the Chitra, the Ghorautra, etc. Riverbed aggradation reduces the water carrying capacity of rivers, causing them to overflow their banks. This recent increase in riverbed levels must have contributed to the increased flooding propensity in Bangladesh.

(E) Deforestation in the Upstream Region: A rapid increase in population in the Indian Subcontinent over the course of the present century has resulted in an acceleration of deforestation in the hills of Nepal to meet the increasing demand for food and fuel wood (Bajracharya, 1983; Ives, 1989; Sharma, 1991). Deforestation of steep slopes is assumed to lead to accelerated soil erosion and landslides during monsoon precipitations. This in turn is believed to contribute to devastating floods in the downstream regions such as in Bangladesh (Hamilton, 1987; The New York Times, 1988; Alexander, 1989a).

(F) Damming of Rivers: Damming of a river reduces the velocity of water flow downstream from the dam. As a result of reduced velocity, the sediments carried by the river start to settle down faster on the riverbed, causing riverbed aggradation and in turn reducing the water carrying capacity of the river (Shalash, 1982). The Farakka Barrage on the Ganges has already caused tremendous damage to the agriculture, navigation, environment, and hydrodynamic equilibrium in Bangladesh (Shahjahan, 1983; Siddiqui, 1983; Broadus et al., 1986; Khalequzzaman, 1989).

(G) Soil Erosion due to Tilling: Ploughing makes the land surface more susceptible to soil erosion. Surface run-off can easily wash away the topsoil from cultivated land. This surface erosion reduces land elevation, which in turn increases flood intensity in an area. The land elevations in Bangladesh must have been reduced over time due cultivation. Aside from this, the tilling on the mountain slopes of the Himalayas is thought to be responsible for massive soil erosion in Nepal (Dregne, 1987; Thapa and Weber, 1991; Sharma, 1991) that eventually causes rapid riverbed aggradation in Bangladesh (Alexander, 1989a).

(H) Excessive Development: Rapid population growth creates extra pressure on the land of already overcrowded Bangladesh. Agricultural lands give way to housing developments and roads. This rapid development and urbanization must have aggravated the flooding problem in Bangladesh.

Prior to urbanization there is a greater lag time between intense rainfall and peak stream flow. After urbanization the lag time is shortened, peak flow is greatly increased, and total run-off is compressed into a shorter time interval - favorable conditions for intense flooding. For example, in a city that is totally served by storm drains and where 60% of the land surface is covered by roads and buildings, floods are almost six times more numerous than before urbanization (Pipkin and Cunnings, 1983).

(I) Seismic (Earthquake) and Neotectonic Activities: Bangladesh lies on the Indian lithospheric plate, which is pushing against the Asian plate, causing growth of the Himalayas and occasional earthquakes in the region. Earthquakes cause movement of the land, and this can change the topography of the region and alter river courses. A sudden change in a river course can cause substantial flooding. For example, the Old Brahmaputra changed its course to its present location following an earthquake in the mid eighteenth century (Er-Rashid, 1978). The northern regions of Bangladesh are earthquake-prone (Morgan and McIntyre, 1958). Neotectonic activities (recent movements in the Earth's crust) are affecting river courses in the area. The Madhupur tract and the Barind tract are undergoing such neotectonic activities (Morgan and McIntyre, 1958). Most of the recent floods have been approximately simultaneous with earthquake activities. For example, the 1950 earthquake in Assam caused "swallowing" of the Brahmaputra, by causing to breach its banks and flood in the region (The Times of India, 1988). The floods of 1988 and 1991 also are coincident with

earthquake activities in northern parts of Bangladesh (The Times of India, 1988; The New York Times, 1991). Recently, a powerful earthquake occurred on October 20 of 1991 in northern India, which was preceded by a flood in Bangladesh and was followed by another flood in the Ganges valley in India (The Philadelphia Inquirer, 1991).

Floods can be both a cause of or an effect of an earthquake. Flood water places an extra hydrostatic pressure on unstable and mobile crustal blocks. If this extra pressure reaches the threshold strain limit along a fault zone or plate boundary within the Earth's crust, it can cause an earthquake to occur due to a sudden release of the strain energy accumulated over time. Similarly, an earthquake can change the surface drainage pattern and consequently the course of a river, causing sudden flooding in an area. Even though the cause and effect relationship between floods and earthquakes is not very clear, historic records suggest a relationship between these two phenomena.

(J) Greenhouse Effect: The world is about to enter a period of rapid warming. Should the greenhouse effect become a reality, the low lying coastal areas will be affected by a rising sea level of even greater magnitude (Milliman et al. 1989; Gable and Aubery, 1990). Bangladesh will be severely impacted by such an increase in sea level (Broadus et al., 1986; Khalequzzaman, 1989; Ali and Huq, 1989; Brammer 1989; Hossain 1989). Besides many other adverse environmental, economic, and climatic consequences (Huq and Ali, in press), the base level of all rivers will change following any change in the sea level. The effect on flooding of a higher base level resulting from a rising sea level has already been discussed earlier in this section. The greenhouse effect will also increase the amount of rainfall and storminess, which will further aggravate the flood problem.

POSSIBLE SOLUTIONS TO THE FLOOD PROBLEM

Solutions to the flood problem in Bangladesh can be divided into two basic types: structural solutions and geologic or alternative solutions.

Structural Solutions

Structural solutions call for the engineering of structures such as embankments along rivers, dams, drains, reservoirs, and other structures designed to control the natural flow of rivers. Structural solutions treat the problem section of a river basin in isolation (Rashid and Paul, 1987); and generally do not take into account the possible geologic consequences (Khalequzzaman, in press). Structural solutions are in practice on a limited scale in Bangladesh as part of a flood control project (Rashid and Paul, 1987).

A megascale structural solution to the flood problem in Bangladesh is now under way. The United Nations Development Program and the Government of Bangladesh have outlined a plan for flood control in Bangladesh (GOB and UNDP, 1989; Boyce, 1990; McDonalds, 1991). This plan, referred to in this paper as the flood control megaproject, will be sponsored by the World Bank. The flood control megaproject calls for the construction of hundreds of kilometers of tall embankments along the great rivers of the Bangladesh delta, enormous drains, and "compartments" on the flood plains. Huge areas of the countryside will be divided into embanked "compartments" in which controlled flooding will be managed by intakes from rivers and offtake through the drains (Figure 1). Although the efforts of the World Bank are appreciated, the wisdom of such a scheme as a possible solution to the flood problem is debatable on the basis of adverse consequences that would follow the implementation of this megaproject.

Natural processes can not be prevented by confronting them. However, a comprehensive knowledge of these processes can help us to better plan land use and mitigate their effects by helping us find ways to adjust to the processes while safeguarding the environment. The primary mechanism for any delta growth is deposition of river-borne sediments. The planned embankments will prevent sedimentation on Bangladesh's delta plain, causing riverbed aggradation and subsequent submergence of the areas behind those embankments by the rising sea. Other problems that would follow the implementation of such a megaproject include flash floods, possible shifts in river courses, loss of a huge land area to the project, loss of land fertility, and possible relocation of people. Building such embankments will also create a chronic necessity to maintain them for generations--not a easy task for Bangladesh.

The structure of the embankments under the proposed megaproject in Bangladesh is similar to those built along the lower Mississippi River in the United States of America. Despite enormous expenditures for annual maintenance and very close monitoring of the project by the Army Corps of Engineers, the embankment project has proven to be a complete failure. The embankments were nearly wiped out during the floods of 1973 and 1984 (McPhee, 1989).

Implementation of the flood control megaproject proposed by the World Bank will not solve the flood problem, but rather will create a series of geologic and environmental problems. Bangladesh has been formed by sediment from the rivers that drain it. The country will eventually be wiped out by the rising sea should the major rivers be prevented from depositing their sediment load on the delta.

Geologic Solutions

The basic requirement for formulating a solution to the flood problem is an understanding of underlying geologic processes that cause floods. Flooding in Bangladesh is but a part of the overall hydrodynamic process active in the entire region. Only solutions that are in harmony with the natural processes can prevail. Confrontation with the natural processes will lead to disequilibrium within the hydrodynamic system in the region and to more problems. Therefore, any structural solution will merely be a very short-term solution. In the long run, any type of a "troubleshooter" solution (such as building embankments along the riverbanks where floods have occurred) will almost definitely aggravate the situation.

The geologic solution is more farsighted in nature--it is to permit the delta to grow both vertically and horizontally at a rate that would keep pace with the relative sea level rise in the region (Khalequzzaman 1991). A detailed study of the geologic processes, namely hydrodynamics of the rivers and channels, dynamics of sedimentation, amount and rate of sediment accumulation, rate of erosion and subsidence, and rate of local sea level rise, is necessary in order for the success of any development plans or preventive measures to mitigate the flooding problem. Only a better understanding of all geologic processes can help us to solve the problem of flooding while safeguarding the environment (Stoddart and John, 1984).

Geologic solutions to the flood problem can be viewed in the context of the two most important parameters: land elevation and water carrying capacity of the basin. Increases in land elevation and water carrying capacity of the rivers will reduce flooding propensity in Bangladesh. The following paragraphs discuss possible ways of helping to increase land elevation and capacity of the river

basin. Structural elements such as dams, sluice gates, along with dredging and dispersion of sediments will have to be applied in order to achieve the desired goal of increasing land elevation and capacity of the drainage basin. This will in turn help mitigate the flood problem in Bangladesh.

(A) Dredging and Re-excavation of Rivers: Continuous dredging of the rivers and channels and dispersion of the dredged sediments on the delta plain will not only increase elevation of the land, but will also increase the capacity of the rivers. These factors will in turn reduce the severity of annual flooding. Adequate sediment supply, accumulation and dispersion are primary requirements for accelerated growth of the Ganges-Brahmaputra delta at a rate that is sufficient to keep pace with the rising sea level.

The rivers in Bangladesh carry ample sediment for dredging and dispersion on the flood plains in spite of the fact that the average sediment load of the Ganges-Brahmaputra river system has declined from 2.4 billion tons/year (67% delivered by the Ganges) to 1.6 billion tons/year (Milliman and Meade 1983; Meade, 1983) since the diversion of the Ganges through the Farakka-Barrage damming project. Calculation of the sediment budget in Bangladesh, based on limited data on the rate of sedimentation, shows that only 10-15% of the sediment load carried by the rivers are deposited on the flood plains and delta plains (Figure 2). The major portion of the sediment bypasses the continental shelf to feed the world's largest submarine fan (Bengal Fan), which extends more than 3,000 km south into the Bay of Bengal (Curry and Moore, 1974; Emmel and Curry 1984).

Calculations of sediment budget and accumulation show that only 30% of the present suspended sediment influx of 1.6 billion tons/year in the coastal areas is capable of aggrading an area of 30,000 sq. km, the area of all coastal districts of Bangladesh, at a rate which exceeds the projected sea level rise of 1 cm/year (the rate predicted by the Environmental Protection Agency of the USA for the next century). The same amount of sediment dispersed over a 150,000 sq. km area (greater than the size of Bangladesh) is capable of aggrading at a vertical rate of 0.3 cm/year, which would be enough to keep pace with the present rate of local relative sea level rise (Figure 3). Moreover, there has been a recent increase in the amount of total suspended and bedload discharge of the Brahmaputra River due to massive deforestation of the Tibetan and Nepalese slopes. Soil loss in the Himalayas averages about 60 cm/1000 years. The recent increase in sediment discharge has caused the river bed level to rise about 5-7 m, thus decreasing bankfull stage and increasing its flooding propensity (Alexander 1989a). If dredged and dispersed properly, this extra source of sediment can help the delta to grow.

A volumetric calculation of sediment shows that a 1 m increase in depth of a 1 km stretch of a river with a width of 100 m will generate 100,000 m³ of available sediment from the dredging process. This amount of sediment, if dispersed uniformly on the flood plains over a 1 km² area on both sides of the river, will increase the elevation of the flood plains by 5 cm; and will also increase the discharge capacity of the river by 100,000 m³. An increase in flood plain elevation of 5 cm may not seem very significant; but in an area where the elevation gradient is only 10 cm/km, like the coastal areas of Bangladesh an increase in relative sea level of 5 cm is capable of shifting the shorelines in a landward direction by 0.5 km (Figure 4). The present local relative sea level rise exceeds the rate of sediment accumulation by 0.2 cm/year. At this rate, it will take 25 years for the sea level to rise 5 cm. Thus, occasional dredging of all rivers and channels in the low-lying areas affected by floods, and dispersion of the dredged sediment on the flood plains

will not only increase discharge capacity of the rivers but will also help flood plain accretion to keep pace with the rising sea.

(B) Preventing Land Degradation: Suspended sediments adhere to the stems of plants. Farmers can be advised to leave a few inches of stem remaining from their rice crops during harvesting before the rainy season. They should also be given more information about the problem of soil erosion. Ploughing makes the soil more susceptible to erosion from surface runoff. Wise tilling practices such as putting tall earthen boundaries between large farm lands and contour tilling can prevent sediments from draining out to the channels by run-off.

(C) Flood Preparedness: An understanding of how individuals have adapted to and are affected by floods may suggest new and less costly ways of reducing flood damages (Paul 1984). Indigenous solutions such as the building of suitable housing, shelters and infrastructures also deserves serious consideration (Islam 1980; Rashid and Paul 1987, Alexander 1989b).

(D) Interbasinal Cooperation: Only 7% of the river basin area falls within Bangladesh (Figure 5). Without regional cooperation between the co-riparian nations any major interbasin development activity is almost impossible. In order for any interbasinal flood control project to be successful, it will have to be designed to serve the common interests of the people of the countries concerned. For example, construction of reservoirs in the upstream regions of the Brahmaputra to hold excess water during rainy seasons can reduce flood propensity in Bangladesh. The trapped water can be used to produce electricity during the summer months, to meet some of the irrigation demands for Bangladesh and energy demands of Nepal and India.

Siltation is a major problem for any hydroelectric reservoir. The accumulated material in the proposed reservoir can be removed through pumping into the downstream flow of the Brahmaputra. This excess material can serve as an additional source of sediment for delta growth in Bangladesh, if the material is properly dredged out and dispersed onto the flood plains.

FUTURE RESEARCH DIRECTIONS

In order to determine the factors responsible for the increased propensity of low frequency floods and the individual contribution of each of the causes to the floods, more research should be carried out. Time series and spectral analysis of relevant factors such as amount of precipitation, amount of discharge of the basin, tectonic and seismic events, rate of local relative sea level rise, spatial and temporal variations in the rates of sediment accumulation on flood plains and the delta plain, rate of soil erosion, population growth, intensity of deforestation and other human activities, needs to be carried out in order to better understand the geologic setting of the region and the evolutionary history of the delta. The results of the analyses then can be compared to the flood history for the last few hundred years to understand the "cause and effect" relationship.

CONCLUSIONS

While the heavy monsoon downpour may be an apparent reason for the recent floods in Bangladesh, there are many underlying geologic causes that contribute to the flood problem over a long period of time. The long-term causes of floods include: local relative sea level rise, inadequate sediment accumulation, subsidence and compaction of sediments, damming of rivers, riverbed aggradation, deforestation, soil erosion, excessive development, seismic and

neotectonic activities in the region, and the greenhouse effect.

Formulating solutions to the flood problem requires a comprehensive understanding of the geologic setting of the region in general, and a better knowledge of hydrodynamic processes in Bangladesh. Only solutions that take into account the underlying causes of the flood problem can prevail. Structural solutions such as the building of embankments along the rivers in Bangladesh will not solve the problem, but will result in many adverse environmental, hydrologic, economic, ecologic and geologic consequences.

Since Bangladesh is a small part of a bigger hydrodynamic system that comprises several countries in the region, mutual understanding and cooperation among the co-riparian countries will be necessary in order to formulate any long-term and permanent solution to the flood problem. However, extensive dredging of rivers and reoccupation of abandoned channels in Bangladesh, and dispersion of the dredged materials on the low-lying floodplains can increase land elevations and the capacity of rivers.

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FIGURE CAPTIONS: (Not available on the Internet)

Figure 1. Map showing the layout of the Flood Action Plan. This Map is modified from the GOB and UNDP report (1989).

Figure 2. Diagram showing relationship between sediment accumulation rates and area of deposition calculated for different amounts of sediment loads.

Figure 3. Schematic diagram showing the fate of sediment in Bangladesh. The calculated percentage of total sediment deposited in various environments is shown in parentheses.

Figure 4. Schematic diagram showing the effect of sea level rise on a coastal plain and flood plain with a relatively mild gradient. Note that a rise in sea level of only 5 cm is capable of shifting the shoreline inland by 0.5 km onto the coastal plain.

Figure 5. Map of the Ganges-Brahmaputra basin. Note the Bangladesh comprises a small part of the hydrodynamic system and lies at the receiving end of the basin.