Hydrological Aspects of 2004 Floods in Bangladesh

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ABSTRACT:

In an unusual climatic year of 2004 throughout the world, floods in Bangladesh were no exception. The country experienced a series of flood events, which were unusual in terms of timing, types and magnitudes. The flood recorded on 24 July 2004 was the 4th major event over a span of 17 years. Two major characteristics of monsoon floods of 2004 were the synchronization of peaks on the three major rivers, the Brahmaputra, the Ganges and the Meghna, with an unprecedented early timing of the arrival of flood peaks. While annually flooded areas show a decreasing trend with the growth of flood control projects in the country, the year-to-year variability of flooded area appears to be increasing in recent years. It is likely that flood control projects are protecting and reducing deeply flooded region while spreading the flood volume over a wider region. The analysis showed that peak floods of the Brahmaputra are increasing in magnitudes and variabilities. The year-to-year variation in flood flows of the Brahmaputra closely relates to that of flooded areas of the country, with more variations in recent past plausibly due to erratic rainfall in the upper basins and the influence of flood control projects within the country.

Keywords: Flood 2004, Bangladesh, hydrology, trend

1. INTRODUCTION

The year 2004 was an unusual climatic year throughout the world with significant anomalies in global surface temperature, sea surface temperature, and seasonal precipitation patterns (NCDC, 2005). Examples of anomalous climatic events were cold wave in Turkey and South Asia in January, heat wave in Australia in February, first documented hurricane in the South Atlantic in March, flooding in northern Mexico in April, heavy snow in Kashmir region of India and Tornado in China in May, tornado in the Philippines in June, heat wave in Japan and flooding in South Asia in July, typhoons in Japan in October, tropical cyclones in the Philippines in November and flooding in Malaysia in December (NCDC, 2005).

The anomaly in hydro-meteorological events in 2004 in Bangladesh was no exception to the rest of the world. The country is well known as one of the most flood prone areas of the world because of its unique geographical setting and physiographic features together with a massive and unique hydraulic system. Bangladesh is predominantly a floodplain delta, located at the lower part of the three major river basins- the Ganges, the Brahmaputra, and the Meghna (GBM) (Fig.1A), the total area of the basins (GBM) standing at 1.75 million km^2 of which 93% is located outside the border of the country. Floods in Bangladesh are annual phenomenon, with about 20% of its area being inundated by overflowing rivers during monsoon in a normal flood year. The inundated areas are about 35% in a moderate flood year, and more than 60% in a major flood year. However, floods in 2004 were unusual with respect to timing, types and magnitudes. Floods came early and stayed longer.

2. FLOOD CHARACTERISTICS

2.1 GEOGRAPHICAL CONTROLS

The country is surrounded by hills on its three sides, Rajmahal hills in the west, The Himalayas and the Meghalaya Plateau in the north and Tripura-

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Chittagong hills in the east. The runoff generated in the upstream catchments of the GBM basins in monsoon months from June to September resulting from orographic rainfall coupled with snow melt in the Himalayas principally control floods in Bangladesh. According to Rashid (1991), about 1.18 trillion cubic meters of water flows annually to the sea, of which 1.07 trillion cubic meters or 91 per cent enters Bangladesh from India. The aerial extent of flooding within Bangladesh is principally related to the unique physiographic feature of the country, which is the extensive floodplains of the major rivers and their tributaries and distributaries that cover 80% of the country (Fig.1B). The downstream control that exacerbates the flooding condition is offered by the Lower Meghna (Fig.1B & C), which acts as the single drainage outlet of the three major river systems perennially influenced by tidal back water flows.

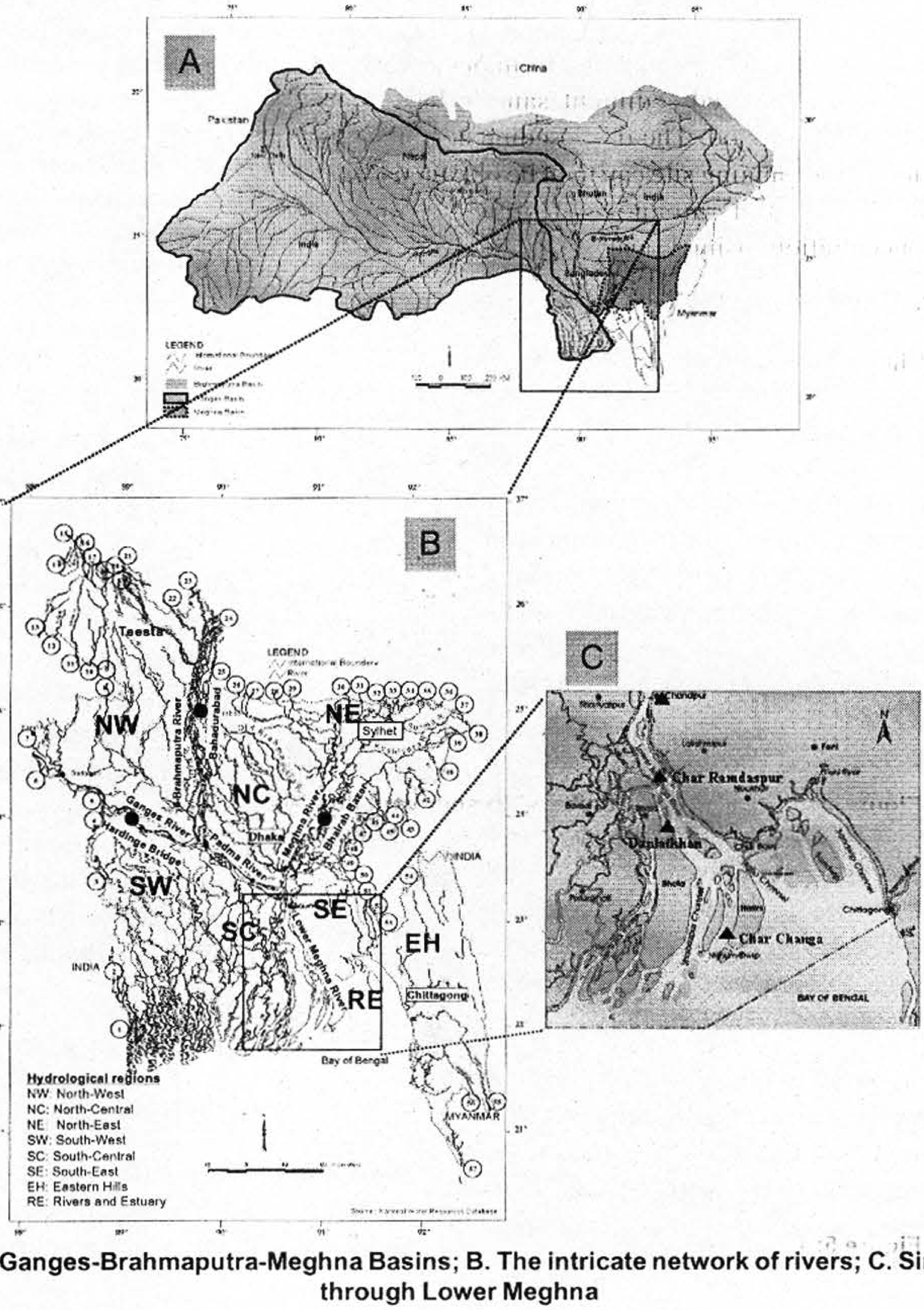


Fig.1: A. The Ganges-Brahmaputra-Meghna Basins; B. The intricate network of rivers; C. Single drainage through Lower Meghna

2.2 UNIQUE HYDROLOGICAL SYSTEM

The country is crisscrossed with an intricate network of around 200 rivers, of which 57 are international rivers originating outside the boundary of Bangladesh (Fig.1B). Among them 54 rivers bring inflows from India including the three major ones, the Ganges, the Brahmaputra and the Meghna. A remarkable aspect of the river system is that all the rivers, except those of the Chittagong sub-region, are hydraulically linked to each other, all rivers being either tributaries or distributaries of the other three major river systems. Flood hydraulics is dominated by the major rivers. The river systems carry enough water from outside the country each year to inundate the catchment inside the country with 6 meters of water (Chowdhury et al., 1997). The Ganges, the Brahmaputra and the Meghna, discharge about 1,42,000 m^3s^{-1} into the Bay of Bengal during high-flow periods (Rahman et al., 1990). The Brahmaputra and Ganges carry about 85% of flood flow that enter Bangladesh. The Brahmaputra has the largest flood flow followed by the Ganges and the Meghna with a flow ratio of 4.4:2.5:1.

Unlike other deltas, Bangladesh's rivers have unusually large seasonal variations of water-flow between dry and wet seasons. The country, therefore, faces two major hazards: floods during the wet season and scarcity of water during the dry season. The hydrodynamic characteristics during flood flows in alluvial rivers in Bangladesh are quite different from low flows.

River floods from major rivers are often accompanied by *rainfall floods*, which result from runoffs generated by high intensity and long duration rainfalls that can not be drained because of high outfall water levels. The northern and north-eastern trans-boundary hill streams (Fig.1B) are susceptible to *flash floods* from the adjacent hills in India in the pre-monsoon months of April and May. The areas adjacent to estuaries and tidal rivers in the south-west and south-central parts of the country experience *tidal floods* twice a day due to astronomical tide from the Bay of Bengal. During spring tide, which occurs fortnightly, large areas are flooded by tidal water. Tide is experienced up to 225 km inland in the wet season and 325 km inland during the dry season. Apart from the aforementioned flood types typical for a normal flood year, approximately 12,000 km^2 of coastal land is prone to occasional cyclonic *storm-surge floods* due to tropical cyclones in the Bay of Bengal during April to June and September to November.

3. FLOOD EVENTS IN 2004

3.1 EARLY FLASH FLOODS

Flood season in 2004 started with the unusual early flash flood in the 2nd week of April in the Sylhet Basin (Fig.1B), a low depression (*haor*) area in the north-east (NE) region covering about 25% of the region. A series of intense storms over an 8-day span from the 12th through the 20th of April 2004 (Fig.2) brought widespread flooding to the Sylhet region. About 500 mm of rainfall occurred over the Khasi Hills, foothills of the Himalayan Mountains, in the northeastern Indian providences of Assam and Meghalaya. As shown in Fig.2, a widespread area of 200 mm of rainfall extends from eastern Bangladesh through northeastern Indian and over northern Myanmar. Such a heavy rainfall in mid-April is unusual.

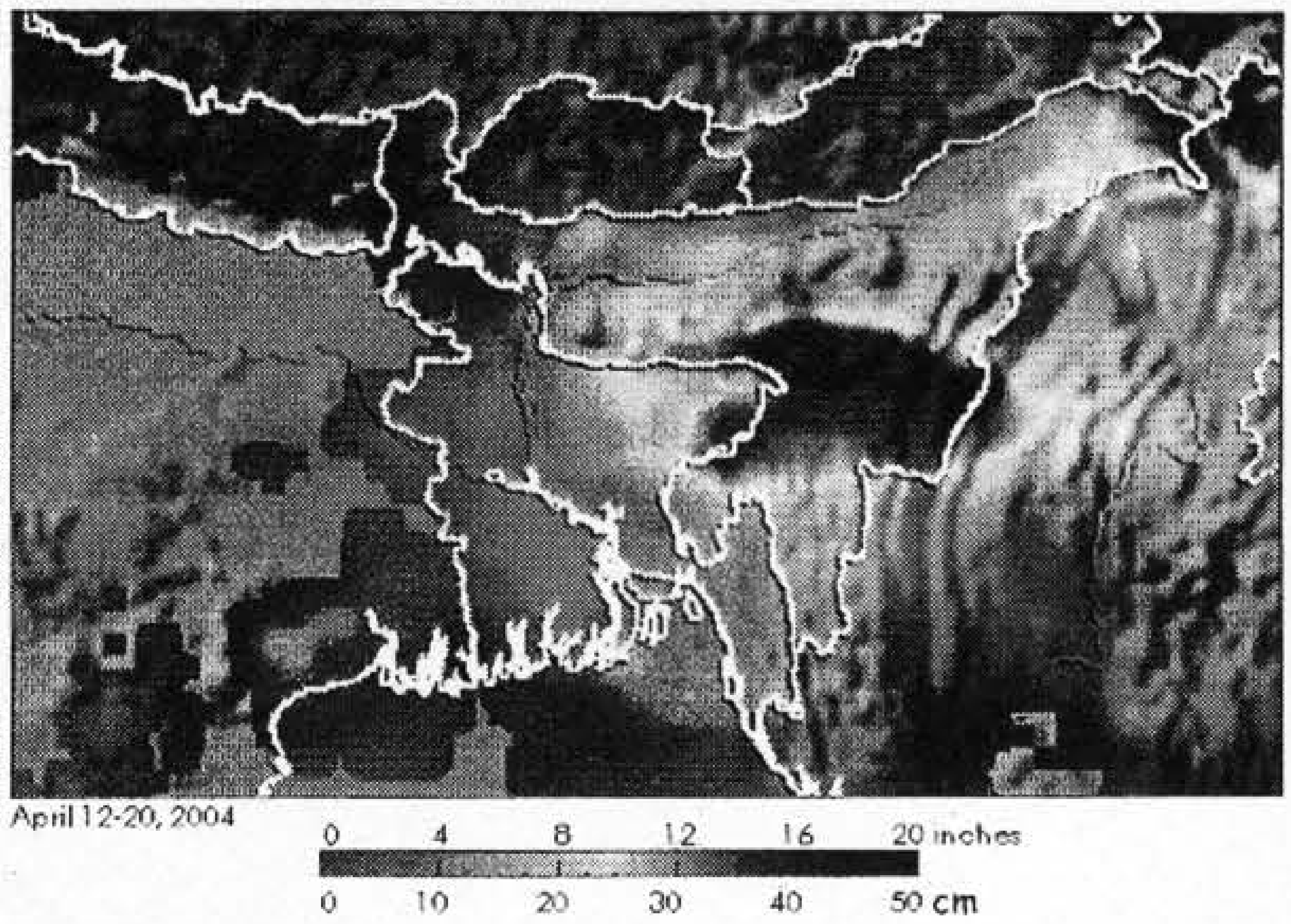


Fig.2: Extensive rainfall in the Meghna basin in April, 2004 [Source: Earth Observatory, NASA]

The magnitude of floods in Surma and Kushiyara, the two major flashy tributaries of the Meghna in the northeast region were significantly high, the Kushiyara recording the highest in the pre-monsoon months (Fig.3).

3.2 UNPRECEDENTED EARLY MONSOON FLOODS

The early flash flood was followed by unprecedented early monsoon floods in 2004, which inundated about 40% of the country, including the capital City, Dhaka. There was excessive early monsoon rainfall, more than 40% than normal (Fig.4), in the hilly regions of the Meghna and the Brahmaputra basins in the second and third weeks of July. There was a time lag of 6 to 10 days between rainfall in the upper catchments and corresponding peaks in Bangladesh. The excessive rainfall resulted in water levels exceeding the 'recorded highest water level' (RHWL) in the Surma, the Kushiyara, and the Meghna rivers. Brahmaputra water level was also very high considering this time of the year. As a result, there were widespread inundations in the Meghna and the Brahmaputra floodplains. There was not much inundation in the Ganges floodplain from the Ganges river flow as it was flowing below the Danger Level (DL) (defined as that water level if exceeded would cause damage to agricultural crops). The flooding situation became the worst when the peaks of the three major rivers coincided on July 24. Just around the time of the peaks, the amount of rainfall started declining, and the rainfall was as low as 30-40% of normal. Consequently, the flooding situation started improving towards the end of July.

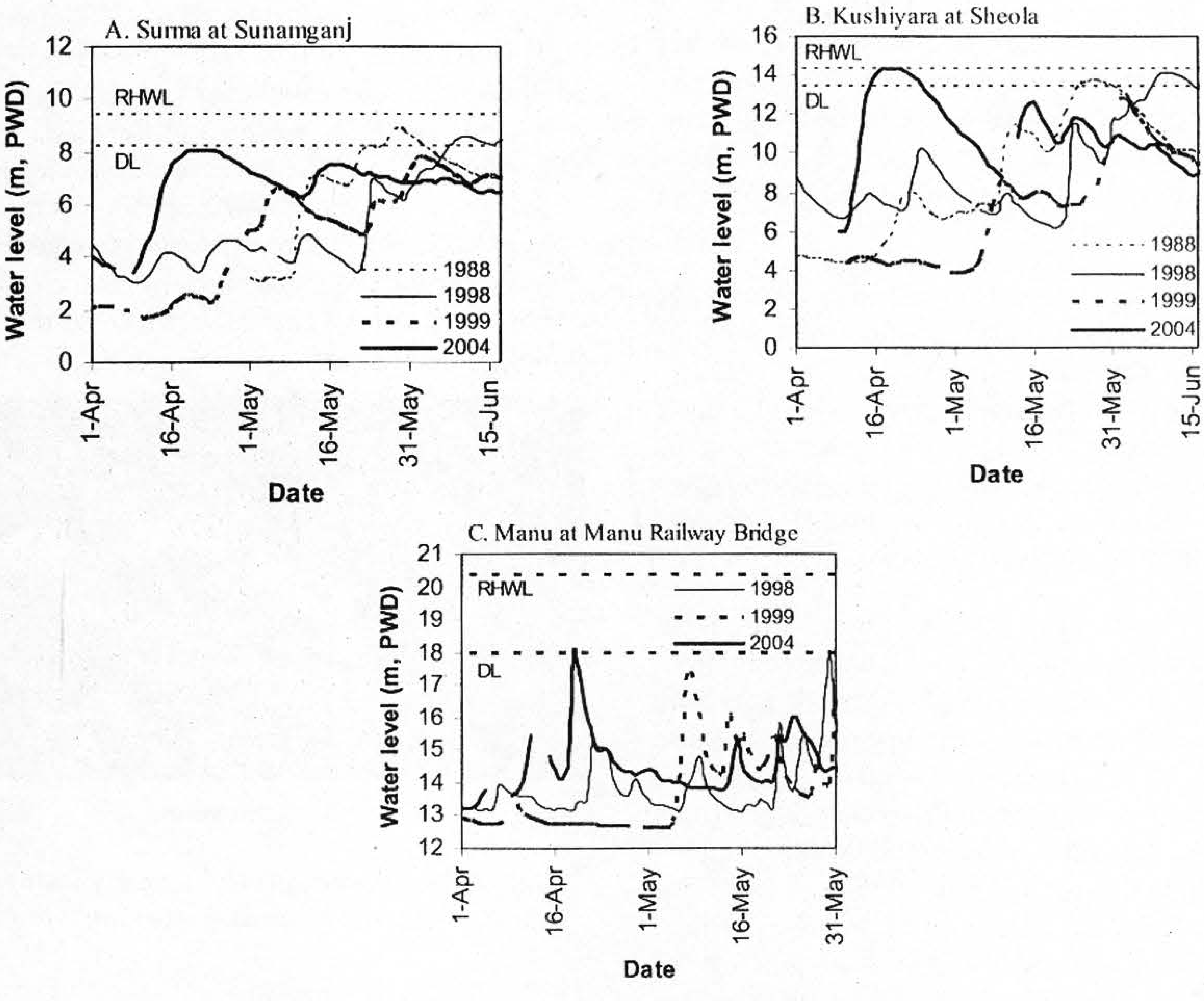


Fig. 3: Water level hydrographs of north-eastern flashy rivers

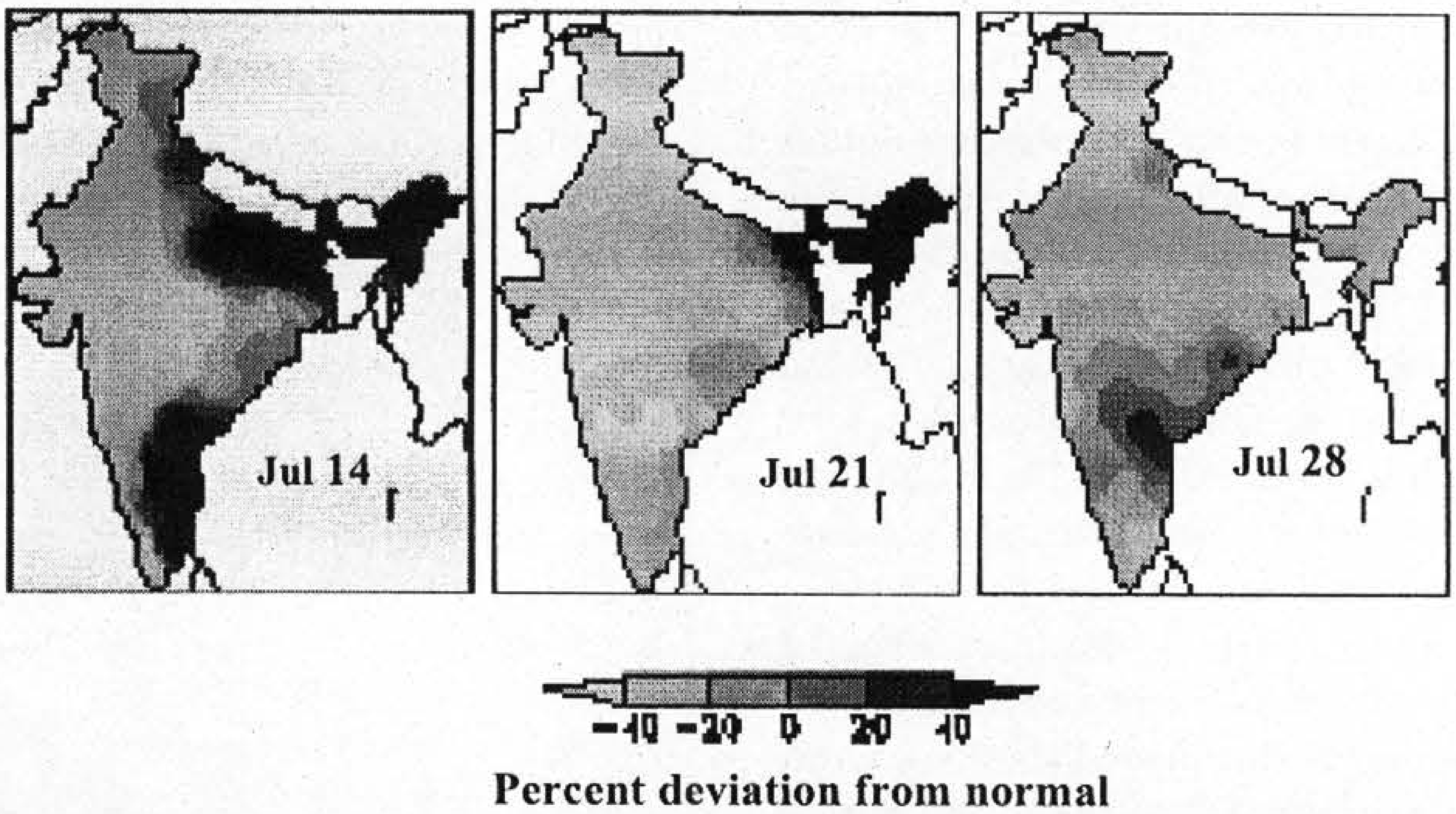


Fig.4: Rainfall in the Ganges-Brahmaputra-Meghna Basins in (A) 2004; [Source: website of Indian Institute of Tropical Meteorology (IITM)]. Figure shows percent deviation from normal rainfall for 7-day periods till the date shown. Figure does not show rainfall in parts of the GBM basins that lie in Bangladesh, Bhutan and China.

3.3 UNUSUAL TIDAL FLOOD IN EARLY AUGUST

Tidal flood swamped three southwestern districts (Barisal, Jhalakathi and Patuakhali) during August 5-6. This occurred as a result of swelling of Tetulia and Karkhana channels of the Meghna estuary (Fig.1C) due to a low in the Bay of Bengal and the slow recession of floodwater in the Lower Meghna at Chandpur.

3.4 UNUSUAL FLASH FLOODS IN AUGUST IN NORTH-WEST REGION

The north-west (NW) region was hit by flash floods in the third week of August. The deluge in four districts (Nilphamari, Rangpur, Lalmonirhat and Kurigram) washed away mud embankments and submerged 30 villages. The Teesta, Dharala and Brahmaputra rivers burst their banks following four days of incessant rain, damaging standing rice crops.

3.5 DEPRESSION IN BAY OF BENGAL CAUSING A SERIES OF UNUSUAL FLOODS IN SEPTEMBER

As the country was in the process of recovering from the waning effects of monsoon floods, the central region, including the capital city Dhaka, was ravaged by rainfall flood in mid-September. This was triggered by a low formed in the Bay of Bengal around September 10 that transformed into a depression while moving into the country from the southwest corner. The result was a heavy rainfall event over a period of 4 days, with Dhaka City experiencing the highest ever recorded rainfall of 341 mm in 24 hours on September 14 (Fig.5). The water logging that occurred in Dhaka City at this time of the year was unprecedented in history. Although the stage in the rivers surrounding Dhaka was low, the drainage system of Dhaka City partly collapsed due to the excessive amount of runoff and faulty operation of the drainage system.

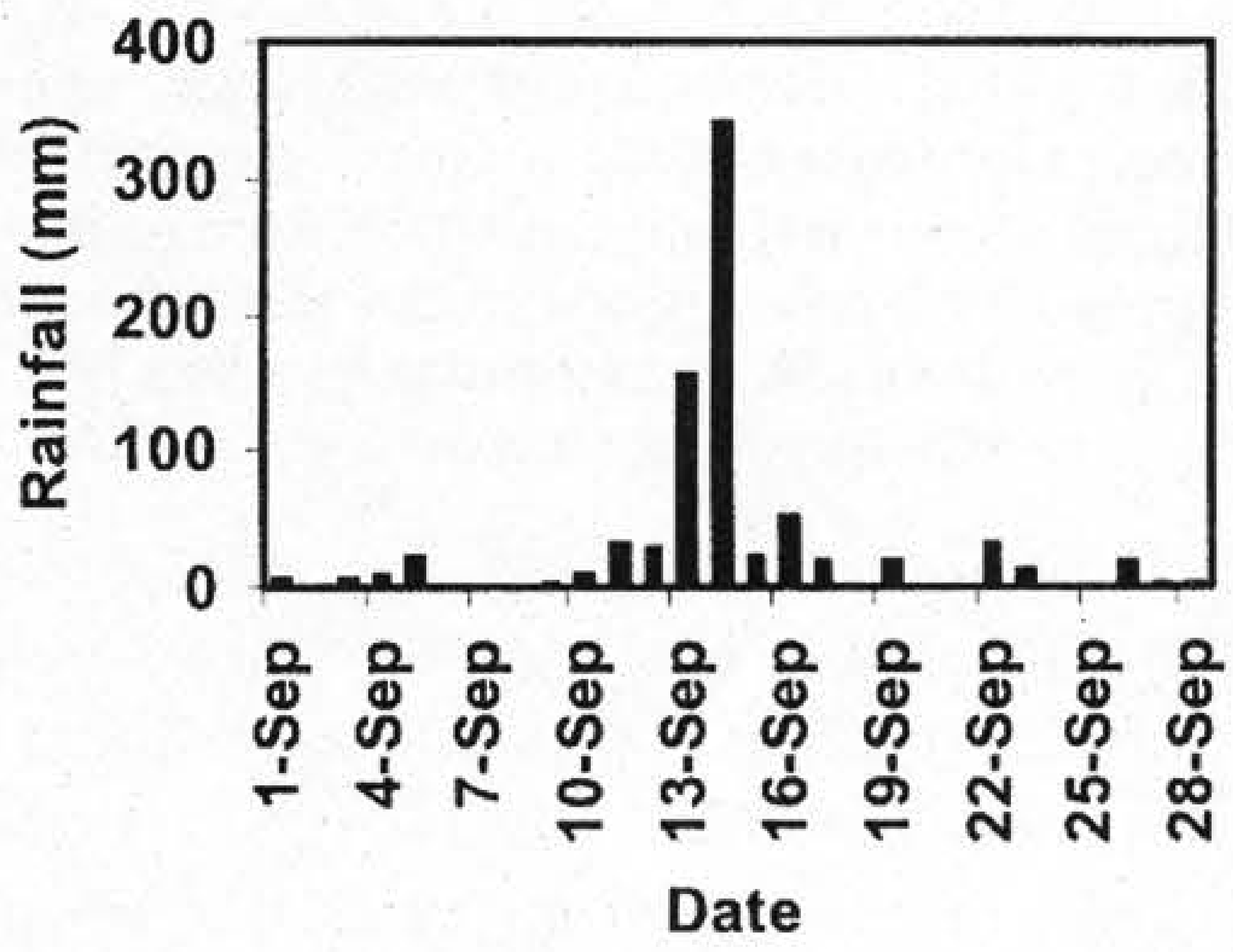


Fig.5: Rainfall over Dhaka in September 2004

The depression that caused the severe rainfall flood in Dhaka City was also responsible for an unusual bout of flash floods in the southwestern border region. The depression after moving out of the country triggered rainfall more than 40% than normal in West Bengal of India in the third week of September (Fig.6). In response to sudden onrush of upstream water, some border-rivers of Bangladesh (Ichamoti, Kodla, Betraboti and Kobadak) in two southwestern districts (Jessore and Satkhira) swelled rapidly over a period of 3 days causing flash floods in the third week of September. Flood waters washed away hundreds of thatched houses and damaged standing crops on more than one hundred thousand ha and shrimp farms on 16,000 ha. It is reported that the sudden burst of water from West Bengal to the southwestern border of Bangladesh was because of the opening of the Moyurakshi barrage in West Bengal, India.

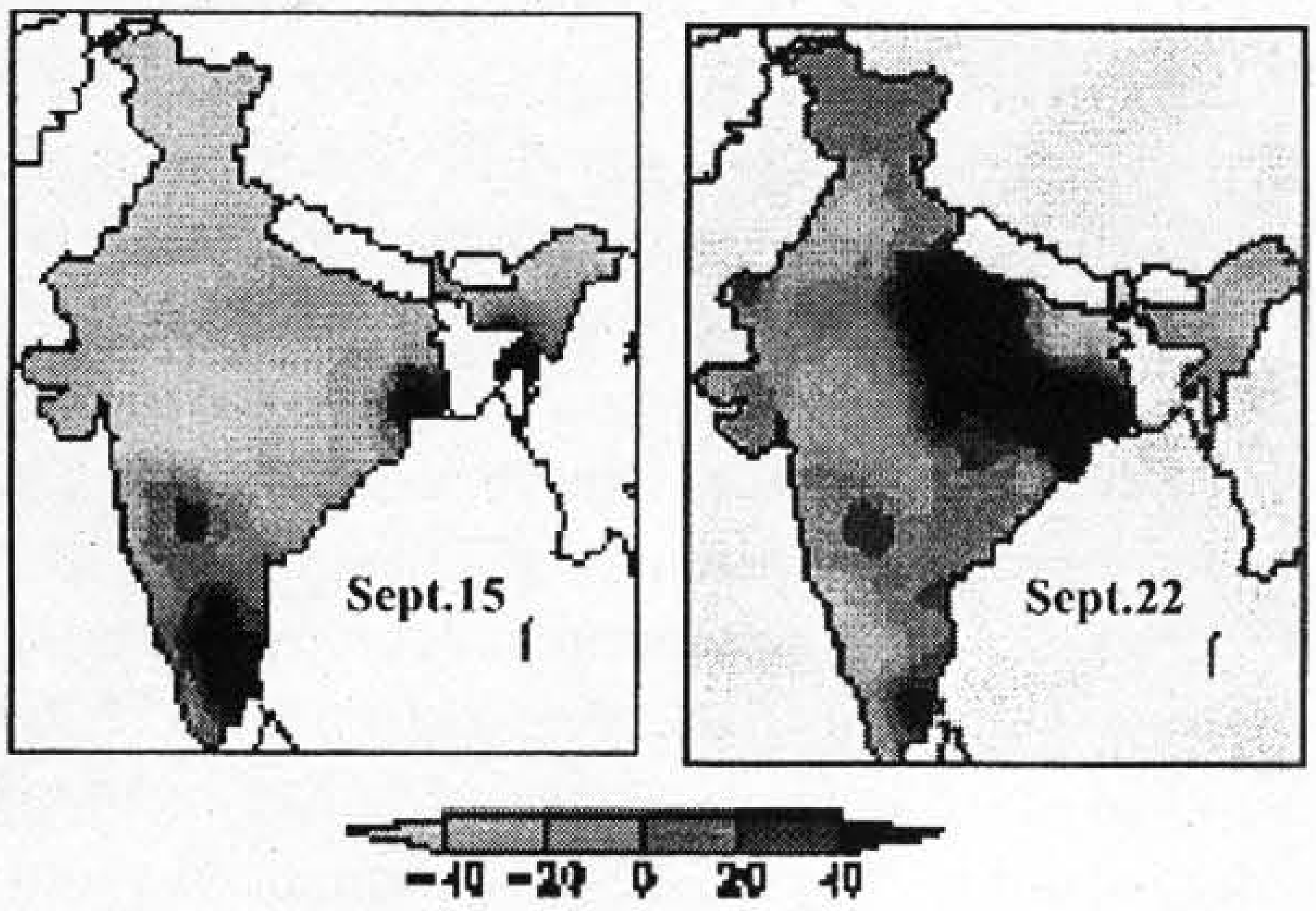


Fig.6: Rainfall over India in 1998 [Source: website of Indian Institute of Tropical Meterology (IITM)]. Figure shows percent deviation from normal rainfall for 7-day periods till the date shown. Figure does not show rainfall in areas that lie in Bangladesh, Bhutan and China.

The effect of the low and subsequent depression in the north-central (NC) region was also extended towards the southeast (SE) region, resulting in a sudden unusual increase of water level (Fig.7) in the Gumti river of the Comilla district (location shown in Fig.1B). The earthen embankment along the river breached on September 14 over a length of roughly 30 m, resulting in flash floods in over 300 villages of Comilla district. The observed water level in the Gumti was the highest ever recorded in September.

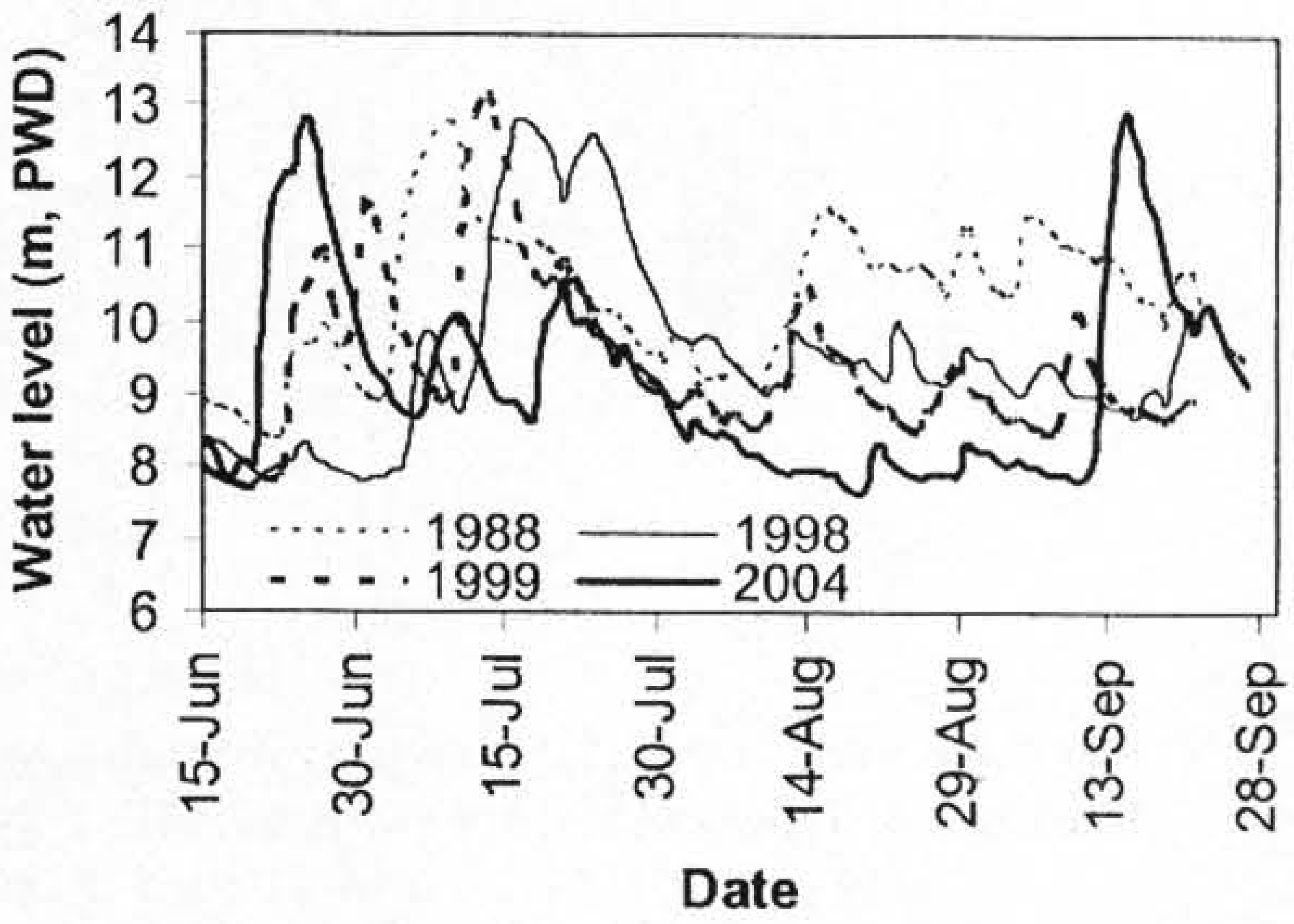


Fig.7: Water level hydrograph of Gumti river at Comilla

3.6 UNUSUAL FLASH FLOODS IN OCTOBER IN NORTH-WEST REGION

The northwest region of Bangladesh suffered flash floods in the second week of October, which was very unusual at this time of the year. The water levels in some rivers in the region (Choto Jamuna, Atrai, Barnai and Padma) rose sharply in response to onrush of floodwaters across the border. The sudden rise of water caused breaches in the embankments at several places that resulted in widespread flash floods in two northwestern districts (Rajshahi and Naogaon). This incurred significant damage to transplanted Aman crop and winter vegetables.

4. HYDROLOGICAL CHARACTERISTICS OF MONSOON FLOOD OF 2004

The monsoon floods in Bangladesh, as discussed earlier, are principally related to these three major river systems. So a key to understanding the hydrological characteristics of monsoon flood of 2004, or that of any year, would be to examine the hydrological behavior of these three major rivers.

The monsoon flood of 2004 was a major flood since the biggest flood of 1998 in the flooding history of Bangladesh. In order to investigate the mechanism of monsoon flood of 2004, characteristics were compared with that of a normal year and a few of the major flood years in recent history.

4.1 MECHANISM OF MONSOON FLOOD IN A NORMAL FLOOD YEAR

In a normal year, e.g., 1991 (Fig.8), the Brahmaputra starts rising in March/April due to snow melt in the Himalayas attaining a peak towards June. It rises again due to monsoon rains and reaches the annual peak in late July to early August. The Ganges begins rising in the end of June to beginning of July and attains the peak in late August or early September. The two distributaries of the Meghna, Surma and Kushiyara reach their peaks between June and August, but the Meghna may not reach the peak until August/ September due to storage in numerous depressions in the Sylhet Basin of the north-east region and backwater effects from the Padma, which also carries the Brahmaputra flood (Chowdhury and

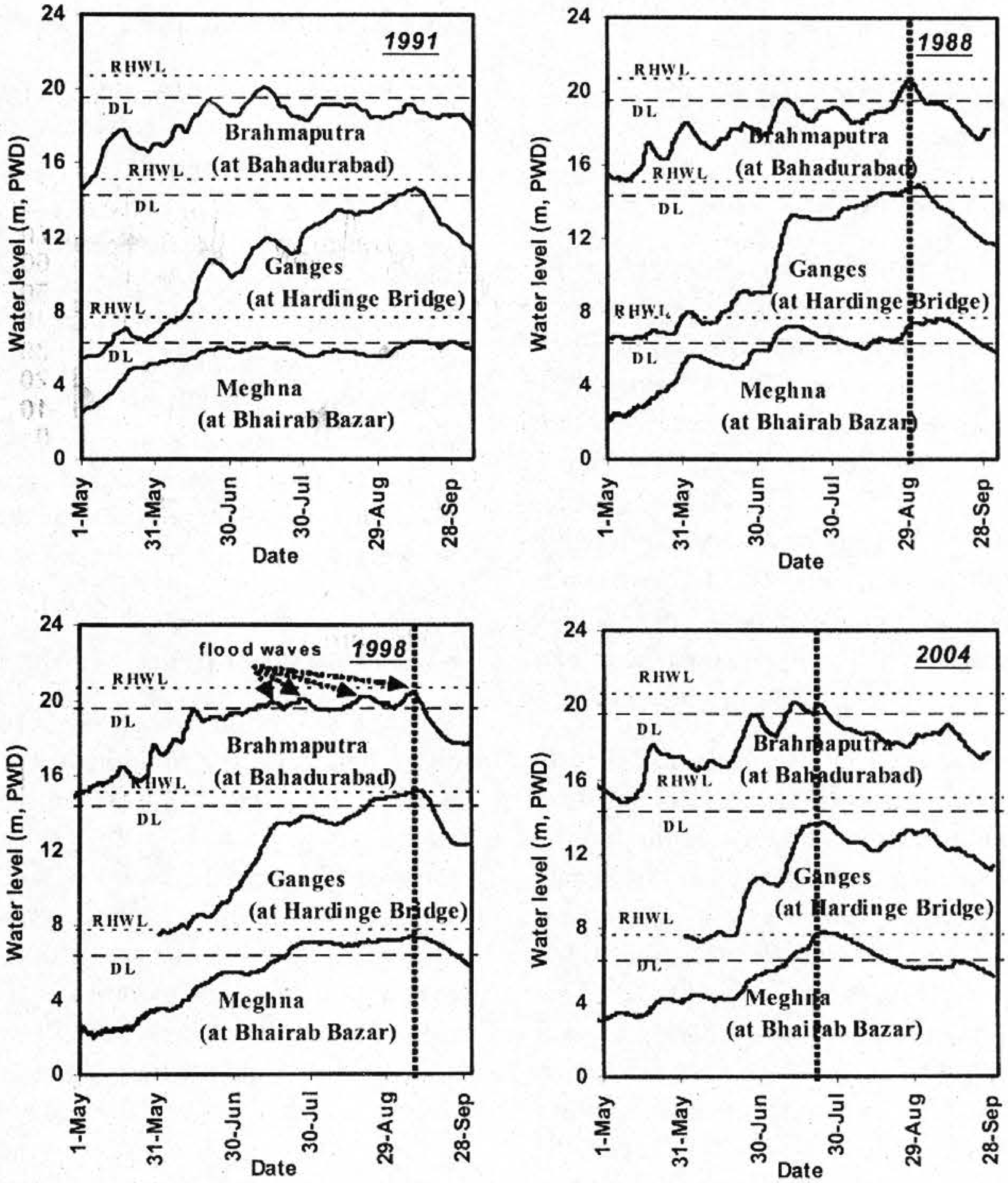


Fig.8: Water level hydrographs of major rivers in a normal flood year and three major flood years

Salehin, 1997). This results in severe flooding in the Meghna basin.

4.2 KEY DETERMINANTS OF EXTENT OF FLOODING

The important elements that determine the extent of flooding are the magnitude, synchronization of peaks, and duration of floods in the major rivers. The first two elements are directly related to the amount of rainfall in the upstream catchments. The last element is also related to the downstream controls of spring tides and monsoon wind set-ups that cause strong backwater effects impeding drainage in the Lower Meghna river.

4.3 COMPARISON OF THE KEY ELEMENTS

4.3.1 Flood magnitude/Peak Flow

The magnitude of peak flow has a direct bearing on extent of flooding in Bangladesh. A frequency analysis of 92 hydrological stations had revealed that the difference between 20-year and 2-year maximum flood levels is within 2 meters while that between 100-year and 20-year levels is within 1 meter (Chowdhury et al., 1997). Hence, smaller differences in peaks of major floods can make a big difference in terms of flood affected area, since it is the spreading of floodwater evenly over a wide and flat floodplain area that slows down the rate of rise in water levels.

In 2004, excessive early monsoon rainfall in hilly regions of the Meghna and Brahmaputra basins in the second and third weeks of July resulted in the highest ever recorded water levels in the Surma and Kushiyara rivers as well as in the Meghna river, and highest ever recorded water level for the month of July in the Brahmaputra river (Fig.8). This caused widespread inundation in the Meghna and Brahmaputra floodplains. There was not much inundation in the Ganges floodplain as the Ganges was flowing 55 cm below the DL. However, the water level was similar to what it usually assumes during a major monsoon flood. As per the results of frequency analysis carried out by IFCDR (1995), the estimated return period of the peak flood discharge for the Brahmaputra was 40 years.

4.3.2 Duration of Floods

Durations of floods in 2004 in the Meghna Basin was considerably lower compared to those in previous major flood years. Meghna River was above the DL for over 7 weeks, while the water level in the Brahmaputra was above the DL for over two weeks. Duration of floods in the Brahmaputra basin was also much smaller than that in 1998, but was equal to that in 1988.

4.3.3 Simultaneous peak flows

Synchronization of peak flows in the major rivers in 2004 was not a historically unusual event. It is a major determinant of the extent of flooding in the country. When the peaks of the major rivers coincided, severe flooding occurred in 1988 and 1998, two of the country's recent major flood years (Fig.8). While synchronization of peaks flows occurred in the months of August and September in the past, the unusual observation in 2004 was its early occurrence in the month of July. However, the major players in determining the extent of inundation were the high flows on the Meghna and the Brahmaputra, as the Ganges flow did not exceed the DL.

4.3.4 Drainage through the single outlet

Peak of the combined flood discharge reached the single outlet, Lower Meghna at Chandpur at the time of spring tide, resulting in an extremely high water level (Figs. 8 & 9). In 2004, this happened quite early, with the water level at Chandpur crossing the recorded highest water level in the third week of July. However, duration of water level above DL at Chandpur was lower than that in other major flood years. High flows in the Surma and Kushiyara and the backing up of water in the Meghna resulted in deep flooding throughout the Sylhet depressions and Surma-Kushiyara floodplains. High flows in the Meghna and Brahmaputra together with the backwater effect at the Lower Meghna carried the flood flow towards the Padma, inundating the adjacent areas of Faridpur, Madaripur and Shariatpur. The water level at the outlet started to go down as soon as the water level in the Meghna started receding.

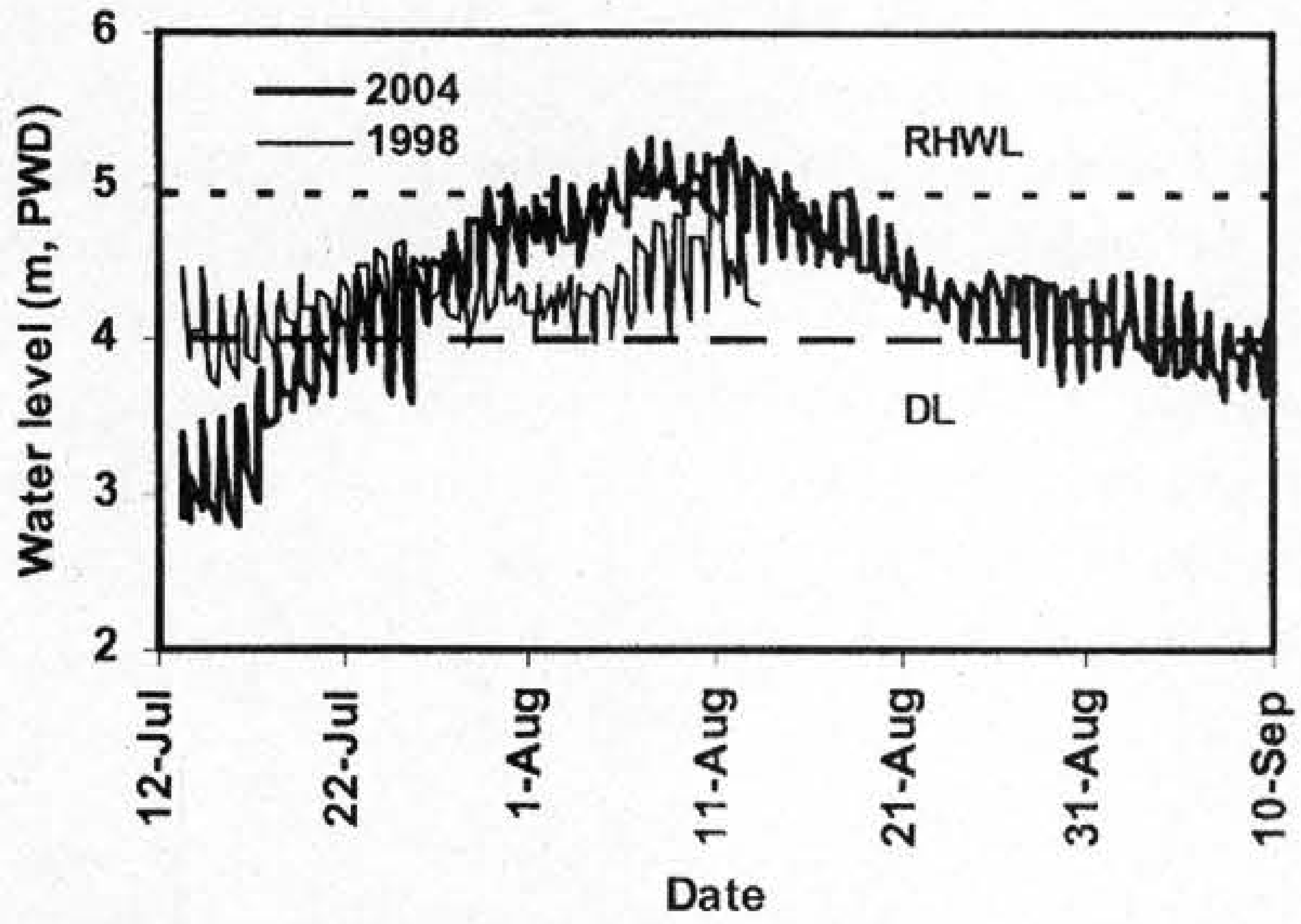


Fig.9: Water level hydrographs at the flood outlet in Lower Meghna at Chandpur

5. IMPACT OF FLOOD CONTROL PROJECTS ON FLOOD REGIME

The low-lying, flat floodplains of the country spread floodwaters from the rivers evenly inundating large areas. In order to protect agricultural floodplains, there has been a steady growth of flood control and drainage projects in Bangladesh since mid 60's through the construction of 12,850 km of embankments, 25,580 km of drainage channels and 4190 sluices and regulators as per Bangladesh Water Development Board (BWDB) list of completed projects as of 1998 (WARPO, 2000). Currently the total coverage area stands at 5.37 Mha, which is about 37% of the total area of the country and 56% of the total cultivable lands.

The variability of annually flooded area and the growth of flood control and drainage projects in Bangladesh over the last 50 years are illustrated in Fig.10. The analysis considered only those projects which had the completion years reported. With the increased coverage of flood protected areas, there has been an expected gradual decline in the flooded area up to mid 1990's. But with all these flood control projects in place, the flooded area increased during major floods. There is clearly an increasing trend in year-to-year variability in the annually flooded area from around the year 1974.

With the ill-planned growth of flood control projects, transportation and drainage networks, the system become unstable during extreme floods. The flood control projects provide protection against normal floods. However, during major floods the damages to infrastructure including embankments are very pronounced thus causing increased flooded area. Flood control embankments suffer substantial damage during large and moderate floods, while damage during smaller floods is also quite high (Chowdhury, 2000). Construction of roads mainly road without sufficient drainage capacity, road alignments transverse to the main drainage paths, blocked drainage channels due to siltation, cross-dams or fishing activities and inadequately sized drainage sluices are increasing flood hazards (WARPO, 2000). For example, ill-planned construction of roads was one of the main reasons for rapid increase in flood depth and duration in the months of September and October in 1995 in the northwest region (Chowdhury and Salehin, 1997).

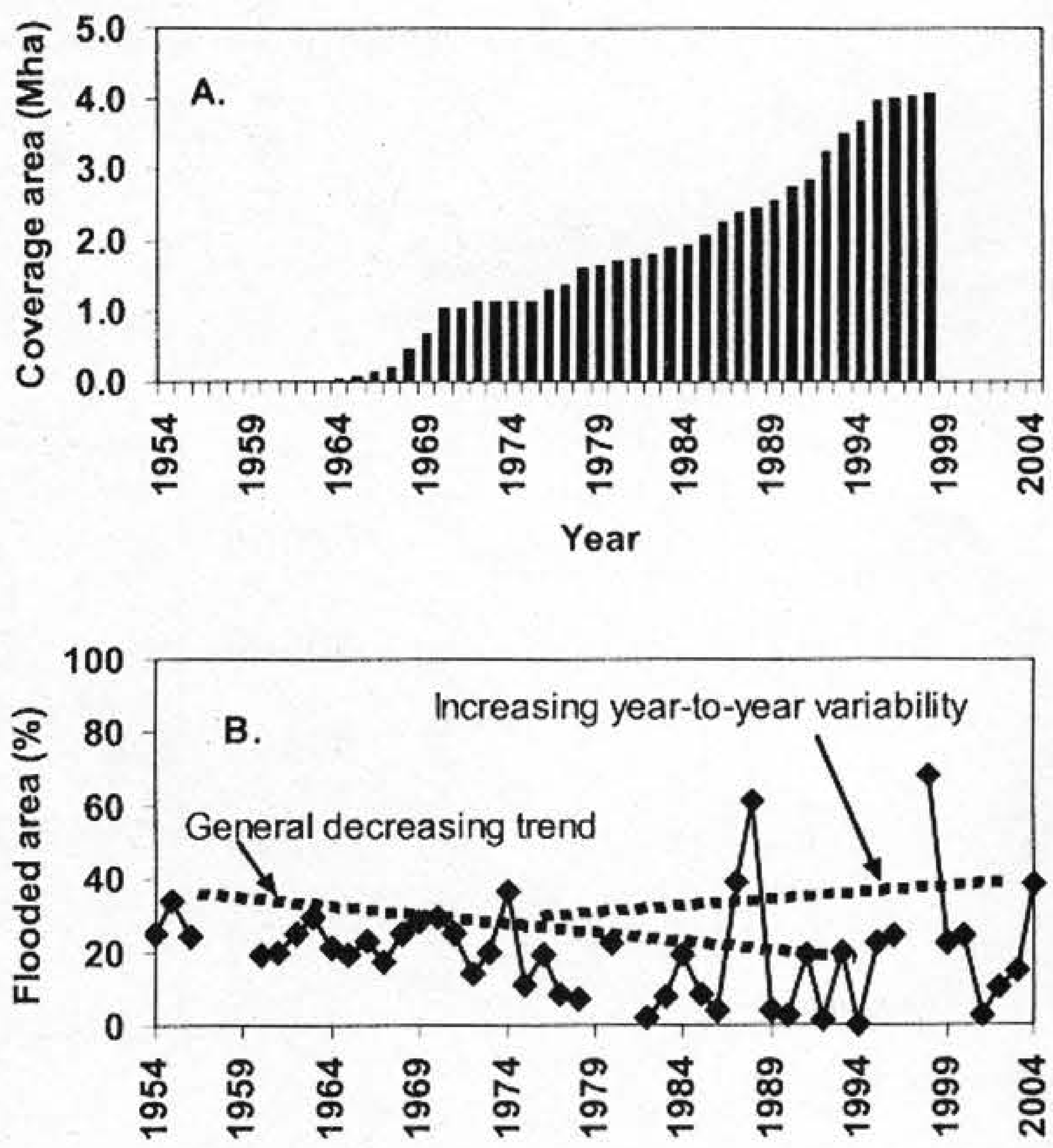


Fig.10: Growth of flood control projects and variability of annually flooded area

Reduction of flood storage area due to filling up of low-lying floodplains and natural depressions is also exacerbating the flooding condition during major floods. The floodplains played an important role by storing about 10% of the total inflow of floodwater through rivers during the 1998 flood (Islam and Chowdhury, 2002). Another beneficial function of floodplains is that it augments the post-monsoon river flow by gradually releasing water from its flood storage (Chowdhury et al., 1997). Sedimentation in rivers and open water bodies may not be ruled out as other contributory factors.

Another question that remains to be answered is whether the increase in the variability in flooded area has any relationship with the flow patterns in the major river systems. As displayed in Fig.11A, the variability in the peak flow of the Brahmaputra, the biggest carrier of flood inside the country, appears to have increased from around the year 1974, which is markedly similar to the change in the variability of flooded area from around the same time. Indeed there is a strong correlation between the two (Fig.11B). It follows that the increasing variability in peak Brahmaputra flow, among other aforementioned factors, is a significant contributor to the increasing variability in inundation area in recent years.

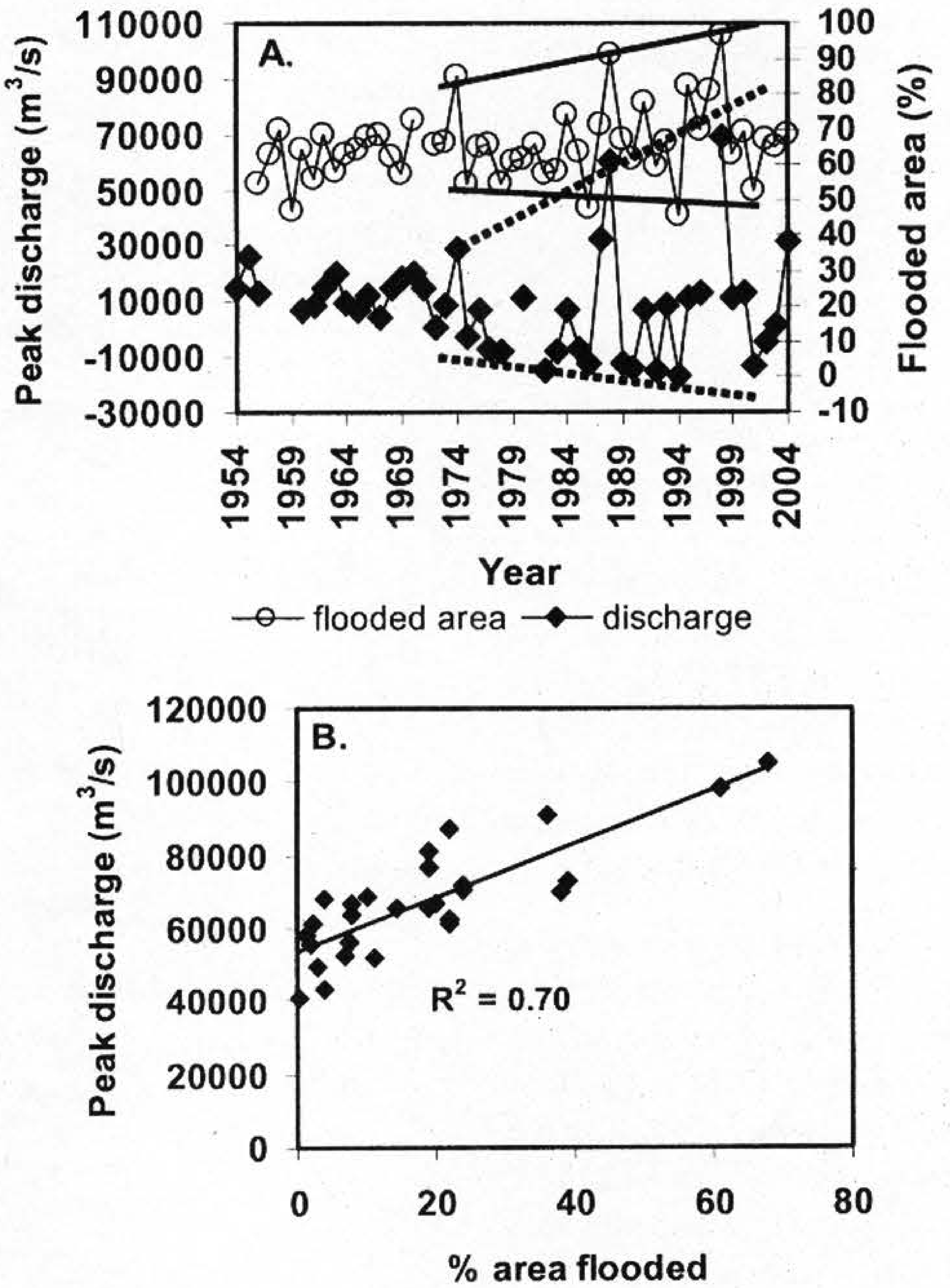
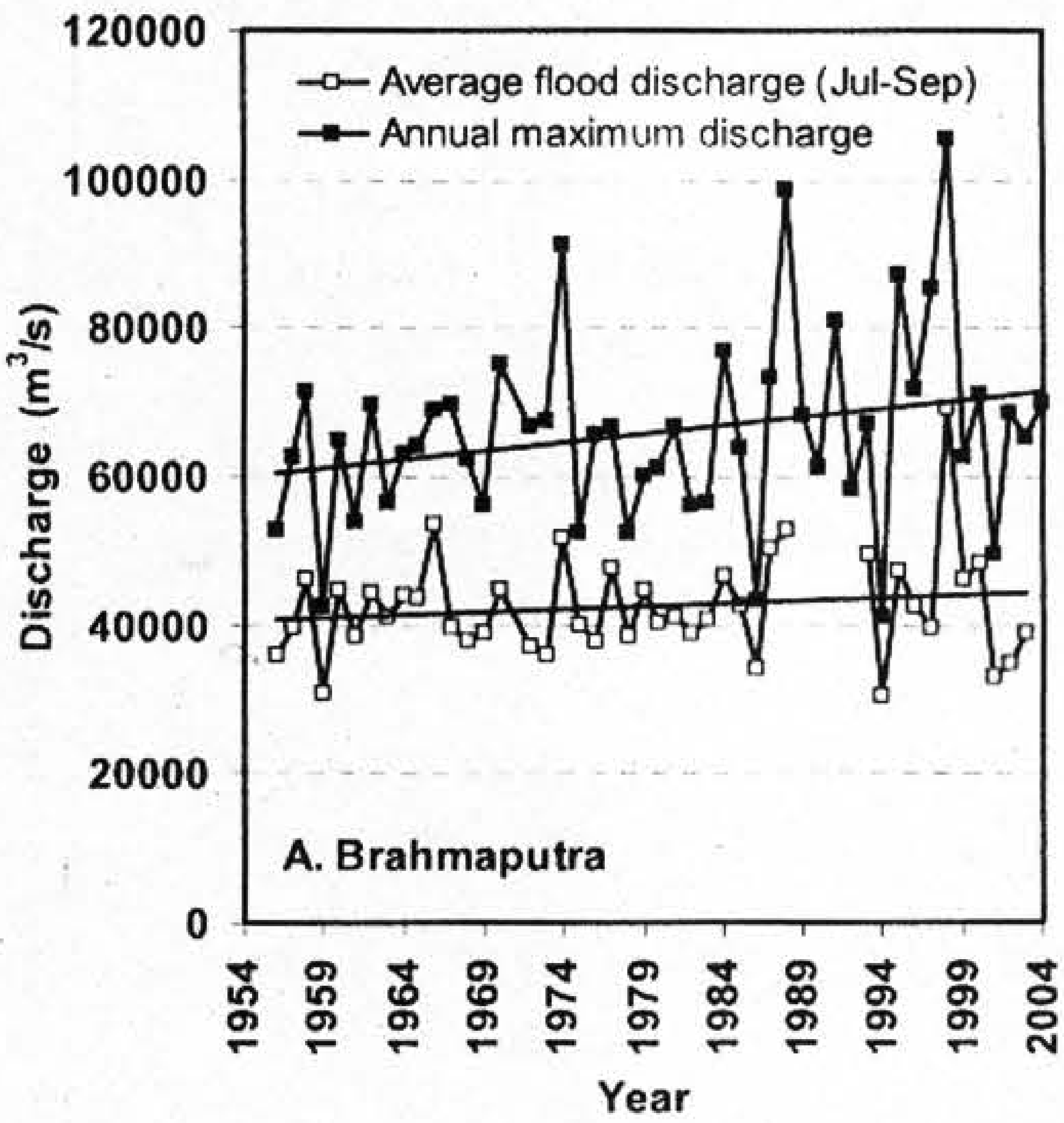


Fig.11: Variability in Brahmaputra flow influencing variability in annually flooded area

6. TREND IN PEAK TRANSBOUNDARY INFLOWS

The results presented in the preceding section imply that any trend in the incoming trans-boundary flows, especially in the Brahmaputra, will have a direct influence on the extent of inundation in Bangladesh. Trend analysis was performed for Brahmaputra and Ganges rivers at Bahadurabad and Hardinge Bridge, respectively, for both peak discharge and average flood discharge (average flow from July to September). Non-parametric Mann-Kendall trend test (Maidment, 1992) was performed for all data series. As displayed in Fig.12, there is a visually pronounced uptrend in the peak flows of both the Brahmaputra and the Ganges. Trend in peak Ganges flow is statistically significant at 5% level of significance, while the same in peak Brahmaputra flow is marginally insignificant. There seems to be a slight upward trend also in both the average flood flows. However, they were found to be statistically insignificant. It implies that the flood flow volume did not change significantly over the years in both the Brahmaputra and the Ganges.



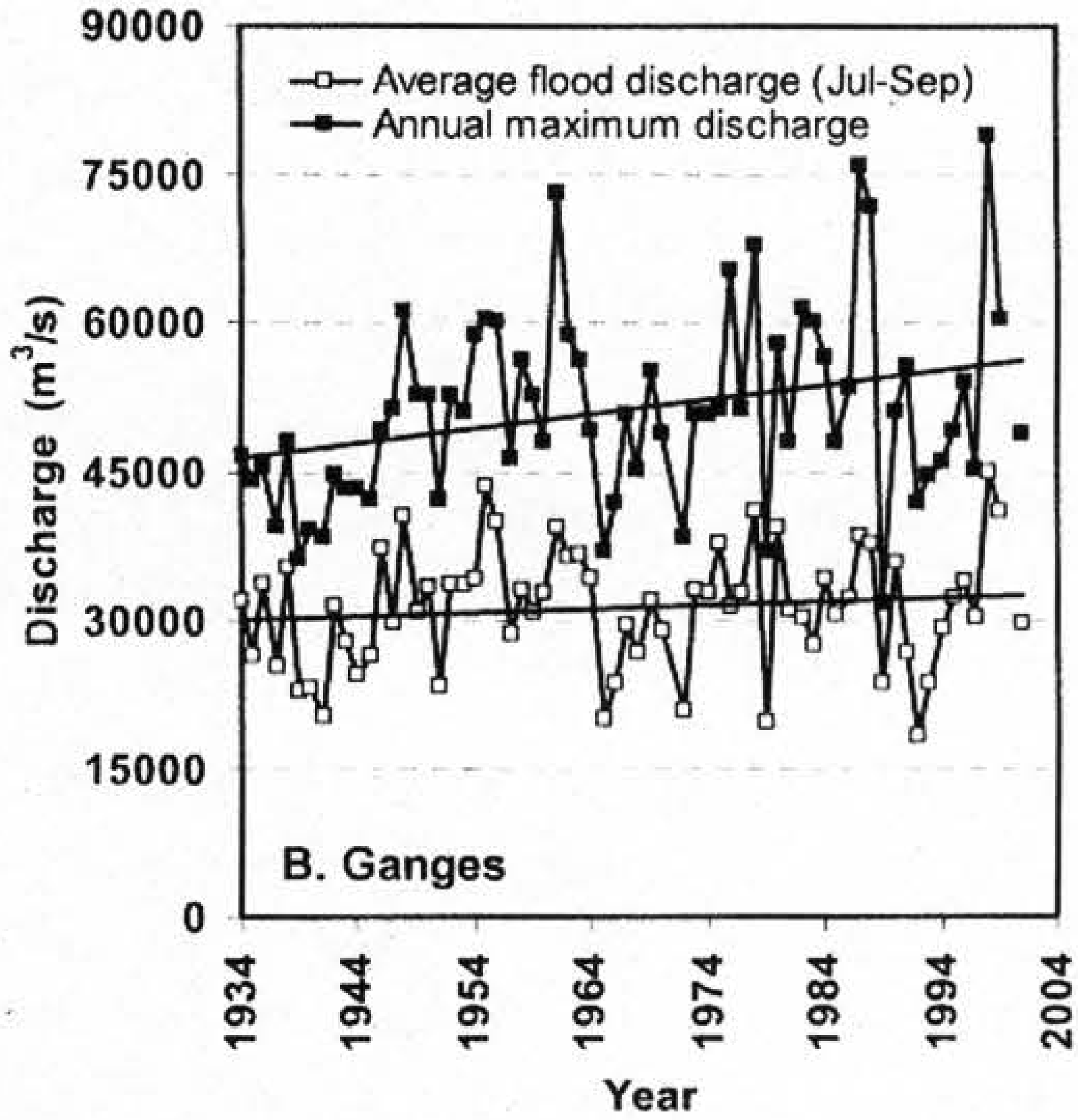


Fig.12: Trend analysis of flow in the Brahmaputra and the Ganges

7. CONCLUSIONS

In an unusual climatic year 2004 throughout the world, Bangladesh suffered from a series of floods. Different types of floods of varying magnitudes occurred throughout the country during the flood. Northeastern part of the country was affected by a series of floods of very high magnitudes throughout the year. The unusual characteristics of flash floods were the earlier onset of floods than usual, and the high magnitudes of floods resulting from high intensity rainfall across the border.

The flood during the peak monsoon turned worst when the peaks of the three major rivers, the Ganges, the Brahmaputra and the Meghna, coincided, inundating almost 40% of the country. Synchronization of the peaks is not a historically unusual event. Unusual was the early occurrence of the synchronization of peak flows in the major rivers in the month of July, which never happened before in the history of floods in Bangladesh. However, the major determinant of monsoon floods in 2004 was the high flows on the Meghna and the Brahmaputra. Historically, the Brahmaputra and the Meghna played more important roles as far as the inundation areas are concerned.

There has been a gradual decline in the flooded area with the increased coverage of flood protected areas. However, there is an increasing trend in year-to-year variability in the annually flooded area from mid 1970's. The increased variability in annually flooded area is due to ill-planned growth of flood control projects, transportation and drainage networks, reduction of flood storage area due to filling up of low-lying floodplains and natural depressions, and sedimentation in rivers and open water bodies.

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