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Floods and the Ganges-Brahmaputra-Meghna Delta

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8.1 Introduction

Bangladesh is a highly flood prone country, reflecting the strongly seasonal regional climate and monsoon run-off of three large rivers from the Himalayas (Brammer 1990; Hofer and Messerli 2006; Brammer 2014), heavy local precipitation during the monsoon and tropical cyclones in the Bay of Bengal (Nicholls 2006). As a result, flooding can occur for multiple reasons, posing a threat to life and damage to economic assets. Of relevance to this analysis, floods can cause damage to ecosystem services, particularly agriculture and associated livelihoods.

In coastal Bangladesh, floods are related to a number of inter-related physical processes, which can be classified according to the main driver: (i) fluvial

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floods, (ii) tidal floods, (iii) fluvio-tidal floods and (iv) storm surge floods. While all types of floods can cause damage and disruption, coastal Bangladesh is best known for storm surge flooding due to large historic death toll associated with some of these events most notably between 1970 and 1991 (Nicholls 2006; Alam and Dominey-Howes 2015; Lumbroso et al. 2017). Fluvial and fluvio-tidal flooding is largely dictated by the flow in the major rivers of the delta due to precipitation and run-off upstream. The study area in this research (see Chap. 4, Fig. 4.2) has a large tidal range (three to six metres) which can cause tidal flooding in unprotected (un-poldered) areas. The magnitude of storm surge flooding due to tropical cyclones is also related to the tide; landfall of a cyclone during high tide can cause more extensive storm surge flooding, while cyclone landfall at low tide may not be noticed in terms of water level. The consequences for the resident population are therefore varied.

Coastal Bangladesh has an extensive system of coastal embankments and polders built since the 1960s with the goal to reduce flooding, manage water levels and enhance agriculture. While reducing the extent and frequency of coastal flooding, these have greatly modified the flood characteristics and associated coastal morphodynamics and rates of subsidence (e.g. Auerbach et al. 2015). Moreover, there are plans for substantial upgrade to some embankments as part of the Bangladesh Delta Plan 2100 (BanDuDeltAS 2014). In this chapter, a general overview of the four types of floods defined above is provided, followed by a summary and refection on the need for further research on flooding in coastal Bangladesh. More details of the flood modelling conducted in this research are given in Chap. 16.

8.2 Fluvial Floods

The Ganges, Brahmaputra and Meghna (GBM) basin and numerous minor rivers provide the main freshwater flow into the northern and central part of Bangladesh (see Fig. 8.1). During the monsoon period (June–October), the volume of water often exceeds the carrying capacity of these rivers, and fluvial flooding occurs.

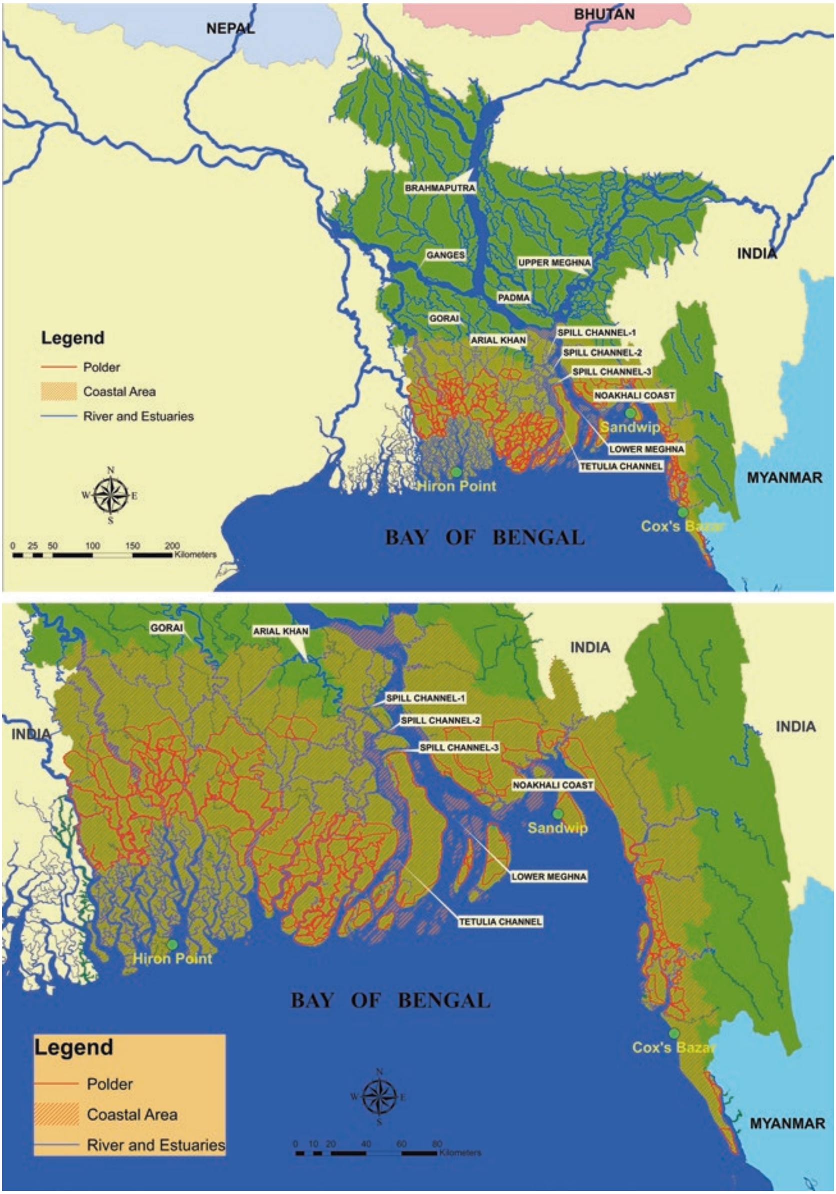

Fig. 8.1 Major river systems (*upper*) and coastal area (*lower*) of Bangladesh showing polders, river systems, main fluvial inflow inlets and tide gauge locations

Table 8.1 Fluvial flooding extents, as percentage of the national area, from 1954 to 2014 (60 fluvial flood events in 60 years) (BWDB 2015)

Extreme flood year (flooded area >24%)		Average flood year (flooded area 20–24%)		Dry year (flooded area <20%)	
No. of events	Percentage	No. of events	Percentage	No. of events	Percentage
15	25	9	15	36	60

The number of historical flood events from 1954 to 2014, categorised by extent, are shown in Table 8.1 (BWDB 2015). Extreme, dry and average flood years are defined by the national area flooded. Twenty-five per cent of all flood events occurred during extreme flood years and caused significant damage. Two typical examples of fluvial floods, one for an average flood condition (year 2000) and one for an extreme flood condition (year 1998), are shown in Fig. 8.2. The location of the discharge measurement stations are the entry points of the rivers into Bangladesh from India.

The Brahmaputra water level starts rising from the early monsoon (June–July) and reaches its first peak in the third week of July. It then falls and rises again and, in an average flood year, attains its second peak in the first week of August. The Ganges has a single peak of flood level occurring in the second week of September. For the Upper Meghna, the first flood peak occurs in the second or third week of May, and, in an average flood year, a second peak occurs close to the second peak of the Brahmaputra. The effect of flow from the Upper Meghna on overall flooding is small as its discharge only represents ten per cent of the combined discharges of Ganges and Brahmaputra Rivers (Islam et al. 2010). The different timing of the flood peaks of the major rivers are mainly due to variations in rainfall in the upper catchments and the travel time to reach the discharge measurement points considered. Synchronisation of the peaks across the three rivers is rare, but has occurred: the floods of 1988 and 1998 (see Fig. 8.2) being examples (Islam and Chowdhury 2002). During peak synchronisation, the second peak of the Brahmaputra is delayed or may occur as a third peak coinciding with the single peak of the Ganges. This triggers significant fluvial flooding in Bangladesh.

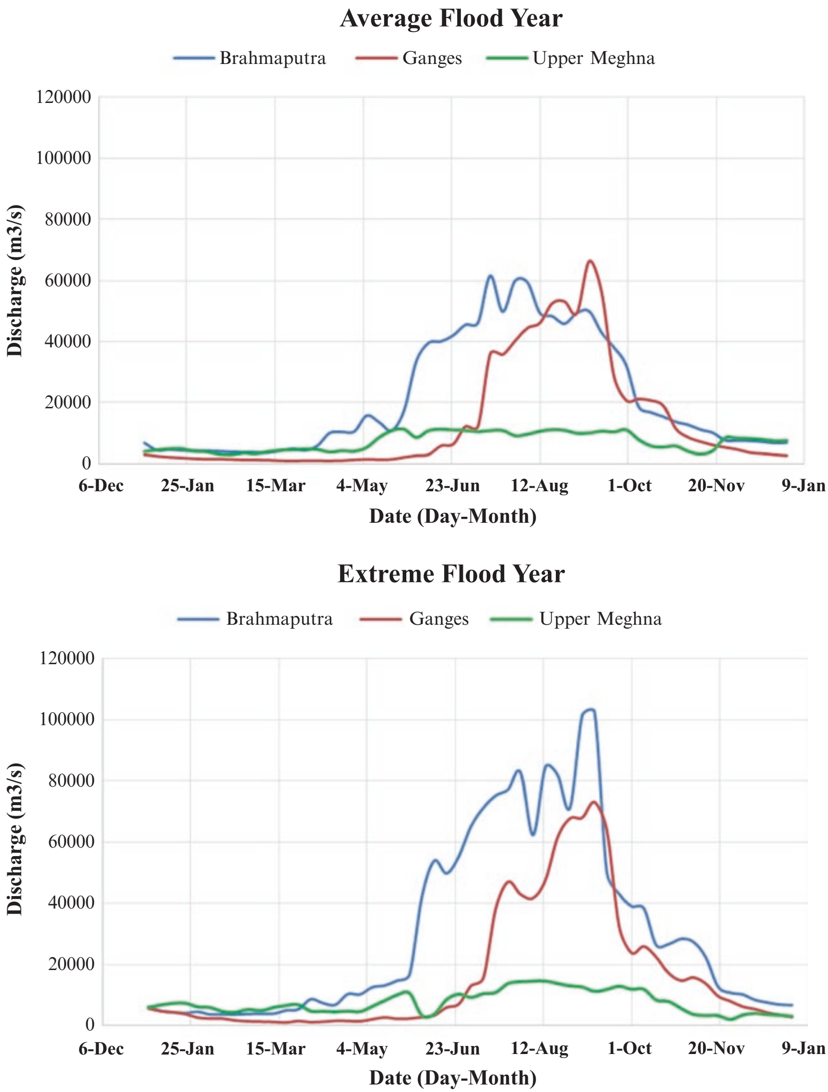

Fig. 8.2 Examples of typical flood peaks for the major rivers of Bangladesh in (***upper***) an average flood year (year 2000) and (***lower***) an extreme flood year (year 1998) (Data source: Bangladesh Water Development Board (BWDB))

Most fluvial flow adjacent to the study area occurs through the Lower Meghna estuary (MoWR 2005; Haque et al. 2016). This can cause inundation directly through the Lower Meghna, or via the estuarine networks that ultimately drains the combined flows of the three major rivers (Fig. 8.1). The drainage rate of fluvial flood water is largely dependent on sea levels. An elevated sea level due to either spring tides or a sustained monsoon may slow drainage prolonging flood duration, as happened during the 1998 flood (Haque et al. 2002). Over the longer term, subsidence and sea-level rise will increase mean sea levels (see Chaps. 14 and 16), influencing the fluvial flooding pattern in the coastal region.

There are few channels to take fluvial flow from the upper part of the country into the study area (Fig. 8.1), and most of these channels are restricted due to sedimentation. This limits flow and hence fluvial flooding. In addition, when polder embankments are considered (see Fig. 8.1 (lower)), only a small part of the study area is susceptible to fluvial flooding as they significantly determine flood extents. The maximum, minimum and average polder heights in the study region are 5.75, 4.50 and 4.79 m, respectively. Areas within the embankments are generally therefore not flooded during average fluvial events by overtopping (because flood water levels rarely exceed the embankment height), but there are incidents when areas within the embankments are flooded due to polder breaching (because embankments are not strong enough to resist the thrust of the fluvial flood). During extreme fluvial events (e.g. floods of 1998), both overtopping and breaching of polders happens.

8.3 Tidal Floods

Tides along the Bangladesh coast are semi-diurnal. The 18.6-year lunar nodal cycle has no influence along the Bangladesh coast, but the 4.4-year lunar perigean cycle modulates the tide by 4 cm (Sumaiya 2017). Tidal range is greatest along the Noakhali coast, immediately east of the Lower Meghna estuary (see Fig. 8.1), and declines to the east and west (Ahmed and Louters 1997). The mean tidal range at Hiron Point near the Sundarbans (west coast) is around 3 m, increases up to 6 m near Sandwip (west coast) and then decreases to 3.6 m further east (Cox's Bazar).

Tides propagate up to 100 km inland along coastal Bangladesh's estuaries (Choudhury and Haque 1990). Coastal flooding due to tides is more pronounced in the central and eastern parts of the coast compared to west coast, reflecting the tidal range.

The construction of polders since the 1960s has eliminated significant tidal flooding in these areas. However, the polders also significantly reduce the area available for sediment deposition. The entire sediment load coming from the catchments of GBM basins drains into the Bay of Bengal through the different estuaries of the coastal region (see Chap. 15). Sedimentation of the river bed has reduced the capacity of the channels (Haque et al. 2016). At high tide, water levels can easily overtop the estuary bank and flood any unprotected land. During extreme fluvial flood conditions, high tides can cause overtopping and/or breaching of the polders. Once overtopped, the flood water inside the polder is unable to drain due to the difference in land elevation caused by confined sedimentation. This creates water logging inside the polder with negative implications for agriculture and other land uses. However, water logging inside polders also happens due to flooding from internal canals (without polder overtopping and/or breaching) and drainage congestion due to unplanned road networks and confined sedimentation.

Monsoon winds need to be considered when assessing tidal flooding in coastal regions. Along the Bangladesh coast, south-westerly and south-easterly winds during the monsoon season (June–October) are termed the monsoon wind. If they exceed 10 m/s, this raises the sea surface at the coast by 0.45 m in the west to 1.65 m in the east (Sumaiya 2017). This slows the fall of the tide and prolongs high water levels (Haque et al. 2002). Hence a combination of the highest astronomical tides and strong sustained monsoon winds give the highest potential for severe tidal flooding (Sumaiya 2017).

8.4 Fluvio-Tidal Floods

Fluvio-tidal flooding is compound flooding caused by the combination of fluvial flows and high tides. This is important in coastal Bangladesh, but has not been described previously. A typical hydrograph of fluvio-tidal

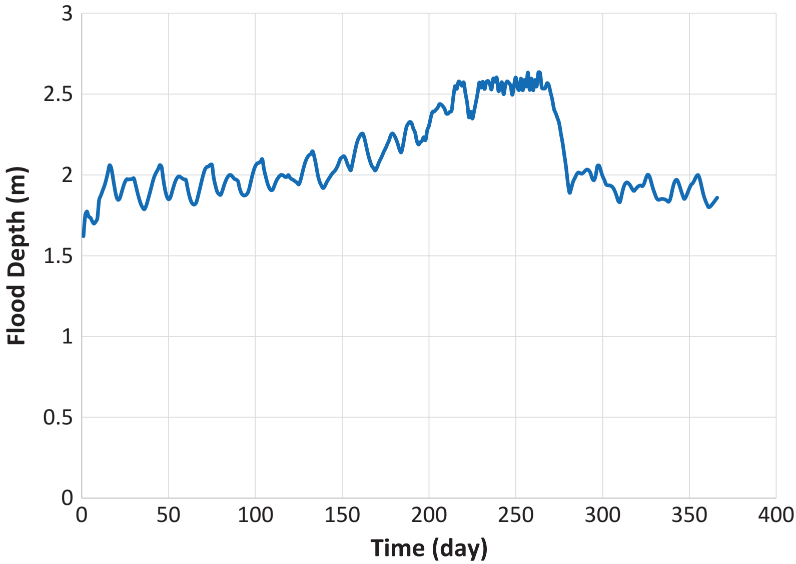

Fig. 8.3 A typical flood hydrograph showing the fluvio-tidal characteristic of floods (Source: model simulation)

flooding shows both rising and falling due to fluvial effects from the monsoon combined with tidal variation due to tidal effects (see Fig. 8.3). Where the fluvial flows are highest at the end of the monsoon, the tidal range is reduced and tidal flooding is reduced as around day 250 in Fig. 8.3.

Figure 8.1 indicates the main channels controlling fluvial flow. During the monsoon, there are large freshwater flows along the Lower Meghna. These enter the study area along three spill channels and then flow south along the Tetulia channel, which is situated to the west of Lower Meghna. The other potential channels from the Meghna into the study area are the Gorai and Arial Khan, but currently these have limited conveyance restricting freshwater flow. The coastal area does not therefore receive any significant fluvial flow during the monsoon except adjacent to the Lower Meghna. Hence, tidal fluctuation plays a dominant role in determining the pattern of flooding across coastal Bangladesh. Due to the dynamic interaction between the fluvial flow and tides, and considering the flood versus ebb dominance of the estuaries (see Choudhury and Haque 1990), the landward part of coastal Bangladesh is characterised by fluvial flood, the middle part is characterised by fluvio-tidal floods and the seaward part is characterised by tidal flood. The exception is around the Lower Meghna estuary. Here flooding is always fluvially dominated by the large Meghna flow as it dominates tidal action during the monsoon.

8.5 Storm Surge Floods

The coastal region of Bangladesh is well known for storm surge flooding with major events going back several centuries or more (Alam and Dominey-Howes 2015); it dominates the global death toll due to storm surges over the last century (Nicholls 2006). The primary cause of storm surge flooding is the landfall of tropical cyclones—the magnitude, location and extent of flooding depend largely on cyclone intensity, its landfall location and time of landfall relative to the tide. The event has two inter-related components. One is the high wind speed of the cyclone leading to storm surge, and the other is the resulting land inundation from the sea and rivers/estuaries. Note that an intense cyclone does not always result in significant flood event. For example, in May 1997, a cyclone with wind speeds of 275 km/hr made landfall near the Noakhali-Chittagong coastline. This is the highest wind speed ever recorded in Bangladesh, and the landfall location is one of the most vulnerable locations for cyclone landfall. However, landfall occurred during low tide, and there was no inundation and only 155 people died. In 1991, when a cyclone with wind speeds 50 km/hr lower (225 km/hr) made landfall almost at the same location as the 1997 cyclone, there were about 138,000 deaths (Ali 1999; Dube et al. 2004); one of the most devastating cyclones in terms of human consequences in Bangladesh's history. The variable that distinguished these two cyclones was landfall timing. The 1997 cyclone occurred at low tide, while the 1991 cyclone occurred at high tide, generating extreme water levels exceeding 8 m in a few places. For the Bangladesh coast, when a cyclone makes landfall during high tide, it has more potential for generating extensive storm surge flooding and associated damage.

Since 1991, major efforts have been made to mitigate these surge events (Lumbroso et al. 2017). These include flood forecasts and warning systems and the construction of robust surge shelters where the resident population can take refuge during these events. As a result fatalities have been greatly reduced by two orders of magnitude during recent major cyclones (e.g. Cyclone Sidr in 2007) compared to earlier events.

8.6 Summary

As coastal Bangladesh is the drainage route of the fluvial flows of the Ganges-Brahmaputra-Meghna River systems, the nature of fluvial floods in the region depends on the flooding patterns from these major rivers. The tidal range is large (between 3 and 6 m) and increases from west to east. Due to high tides, the unprotected land along the coast (outside the polders) is regularly flooded at high tide. Extreme astronomical tides combined with strong monsoons intensify the flooding situation; historical data shows that sea levels generated by tropical cyclones making landfall at high tide have the most impact on flood extents and associated damage. Polders and coastal embankments have stopped most fluvial and tidal floods in coastal Bangladesh. In the case of surges, forecasts, warnings and shelters have collectively great reduced fatalities during cyclones.

This chapter has focussed on describing the sources of flooding in coastal Bangladesh individually. As indicated in this chapter, it is increasingly recognised that floods occur due to multiple causes—so-called compound flooding (Leonard et al. 2014). Generally, it may therefore be more beneficial to consider flooding for Bangladesh in a more systemic manner: considering all sources, pathways, receptors and consequences. This allows analysis of the changing flood system, as illustrated for the United Kingdom by Evans et al. (2004a, b), to support national policy. Some examples of compound events have been shown here in terms of fluvial, tidal and surge events interacting. In the future, it would be useful to use this type of approach to analyse sources of coastal flooding in Bangladesh. The effects of polders on tides, morphodynamics and land elevation (subsidence) also deserve more attention.

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