Chapter 18
Characteristics of Flood in the Meghna River Basin Within Bangladesh

M. Shahidul Islam and Afrin Sharabony

Abstract Meghna is the third largest river in Bangladesh, and its basin is primarily flooded by torrential rain-fed water coming from Assam, India and also from local rainfall. Within Bangladesh, the Meghna catchment area is divided into upper Meghna and lower Meghna basin. The hilly portion in the north and north-west of the upper Meghna basin is characterised by flash flood nearly in every year and usually in the months of May and June (early monsoon flood). The second peak appears as regular riverine flood during the June–July period and inundates a greater portion of the Meghna floodplain. The flood in the lower Meghna basin is fluvio-tidal in nature and highly driven by south-western monsoon winds. The flood of this year (2022) is also catastrophic in nature, showing two peaks: the first peaks (May) of flash floods have created huge damages in the hilly areas of Sylhet and Sunamganj, and during the second peak (June), a greater portion of the basin remains deeply inundated, and all communication remains cut-off with the capital. Like other previous flood, the flood of 2022 also shows that excessive rainfall in the Indian portion of the catchment is the main cause of unusual flooding in the Meghna basin. The flood management of this region is thus requiring timely flood forecasting and accurate risk assessment. It is thus urgent need of regional cooperation among the co-riparian countries. The major area of cooperation includes real-time data sharing, sharing information on flood forecasting, exchange of knowledge and technology and collaborative research. It shows that the flood problem issue of this region is technical in nature, but its solution is largely political. All concerned countries thus need to be politically committed to resolve the problem and to reduce the suffering of millions of people of this region.

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1 Introduction

Bangladesh is situated in a unique location in the Indian subcontinent, and this location has leaded the country susceptible to regular annual flooding. Ganges-Brahmaputra and Meghna (GBM) are three major rivers crossing through the country, and combine flow finally discharges into the Bay of Bengal. The sediment carried by the GBM rivers system has formed one of the largest delta systems of the world – the GBM delta – which covers about 80% area of Bangladesh. Meghna is the third largest river in Bangladesh which is primary rain fed, and its basin contains 29 subbasins (Mohammed et al., 2018). Average flow of GBM rivers 1,009,000 million m^3 and sediment more than 1 bill tons (Mahmud et al., 2020; FFWC, 2021). This river basin experiences early flash flooding in the hilly areas and regular riverine flooding in the floodplain areas almost in every year. However, in some years, this flash flood and riverine flood become catastrophic in nature, as has been experienced in this year (2022). The severity and inundation scale of this exceptional flooding is site depended and largely been controlled by hydro-meteorological inputs. Excessive rainfall in the entire Meghna catchment area is the main cause of such catastrophic nature of floods. This chapter is an attempt to evaluate the nature and characteristic of flood in the Meghna basin area within Bangladesh, with special attention to flood of 2022.

2 Meghna River Course

The Meghna River is originated from the rainiest part of Shillong Plateau in Assam state of India. Travelling 400-km Barak as main source, it enters Bangladesh at Amalshid in Sylhet district and bifurcates into Surma in the north and Kushiyara in the south (Fig. 18.1). The Surma on its right bank receives tributaries originated from the Khasi and Jaintia hills. Due to steep hill slopes and heavy rainfall, all the tributaries are subject to annual flash floods. Kushiyara on the other hand, on its left bank, receives flows from tributaries, such as the Monu, Gumti and Khowai rivers originating from Tripura, India, and are the sources of flash flood in this southern part of the catchment, although less violent than that of the north. The lowlands and haors in between Surma and Kushiyara rivers are unique basin-shaped geomorphology, being deeply flooded and are the immense source of biodiversity. The floodplain in between is also characterised by meandering channels and many abandoned river courses. Surma and Kushiyara rivers finally rejoined near Bhairab Bazar and take the name as Meghna, until it joins the Ganges (Padma) near

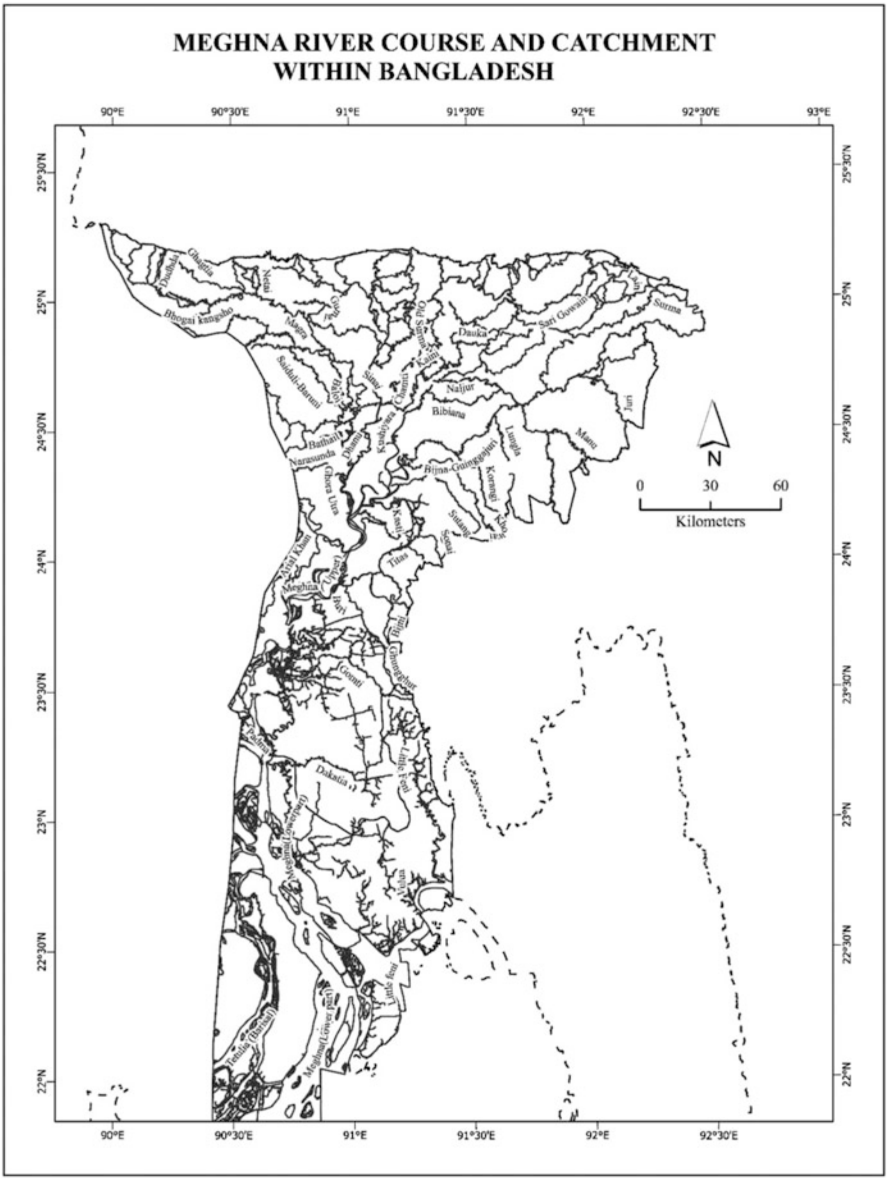

Fig. 18.1 Rivers of Bangladesh showing Meghna River course and catchment. (Source: Banglapedia, 2021)

Chandpur (Fig. 18.1). The catchment up-Chandpur is widely known as upper Meghna River in Bangladesh. Upper Meghna River also receives hilly steams originating from the Meghalaya and Assam of India. The catchment below Chandpur down until the estuary is the lower Meghna basin, which is fluvio-tidal in nature.

3 Meghna River Catchment

The total area of the GBM catchment is 1.6 million km^2 of which only 7.5% is within Bangladesh and remaining 92.5% lies outside the country (India, China, Nepal and Bhutan). Among these three river basins, the Meghna River catchment is the smallest one and occupies about 65,000 km^2 of which 43% belongs to Bangladesh, occupying 24% of the territory (Masood & Takeuchi, 2016) (Fig. 18.2). It comprises fertile alluvial lowland, has formed extensive plain land mass and support 170 million people (Paszkowski et al., 2021).

The upper Meghna River (UMR) catchment is located in the world's highest rainfall regime with an average precipitation of 5800 mm y^1. The morphology of the upper Meghna River basin is distinctive in nature and can be characterised by the presence of alluvial ridge, natural levee, back swamps, depression (haor), abandoned channels, oxbow lakes and extensive non-tidal plain lands.

The lower Meghna River (LMR) starts from the confluences with the Padma River at Chandpur and finally flows into the Bay of Bengal. It is one of the largest rivers of the world and at its mouth receives the combine flow from three mighty rivers, the Ganges, Brahmaputra and upper Meghna. The lower Meghna River is tidal in nature, which has profound influence on delta morphology. This portion of Meghna River is highly dynamic and experiences significant morphological changes, either by erosion or accretion. There are numerous islands in this portion of river course, which are subject to regular bankline shifting.

In lower Meghna River basin, tide is the predominant force to shape up the morphology of the floodplain. Major geomorphological features are the mud flats and tidal floodplain, with distinctive spatial variation in their nature and fluvio-dynamic characteristics. Enormous water and sediment supply from the GBM system has led to rapid morphological changes of the lower Meghna River (LMR) basin, including significance impact on natural environment and social-cultural settings. This highly dynamic LMR basin experiences intense hydro-morpho-ecological changes and the fertile soil, which supports farmers to engage in agricultural activities and fishermen to fishing.

The Himalayan and Burma Arcs are the two sources of water and sediment supply, which are being carried by the GBM river system to shape up the morphology of GBM delta. The LMR basin shows high seasonal variation in sediment and water discharge. The annual average water discharge of the LMR is 34,600 m^3s^{-1} and mean annual flood discharge rate of 97,000 m^3s^{-1} (Sarker & Thorne, 2009), and the tidal rage is 4 m (Allison et al., 2003).

The lower Meghna floodplain is characterised by plain land of less than 5 m above MSL and very gentle slope. Both banks of LMR occupy Holocene sediments of deltaic and tide-dominated plain land. The floodplain along the left banks of the Meghna River is slightly elevated due to tectonic cause and shows gradual eastward rising up of its elevation (Bakr, 1977).

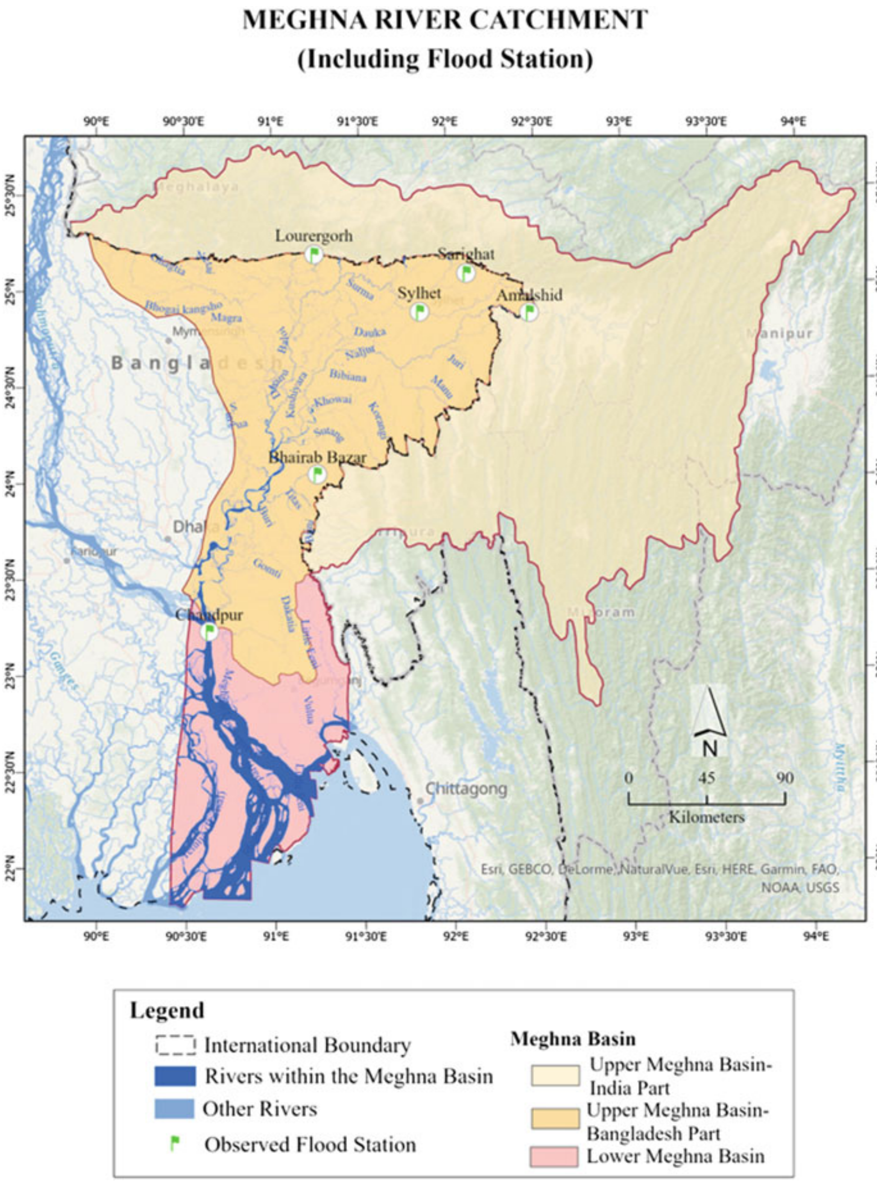

Fig. 18.2 Meghna River catchment area. (Source: IUCN, 2018)

In the lower Meghna River, the freshwater flow from upstream is halted and reduced naturally and by human interventions, particularly from the Ganges and Brahmaputra sources in the west. As consequence the lower reach of the Meghna basin is predominantly under strong tidal effects. Tide generated in the south-west and south-east of the bay finally finds its way toward the Meghna estuary, where the tidal amplitude rises up to 4–6 m, particularly during the monsoon spring tide. Tide along Bangladesh coast propagates up to 100 km inland. Tide-dominated coastal flooding is well noticed in the south central and eastern part of the coast than the west. In the lower Meghna reach, the flood is thus fluvio-tidal in nature. However, unlike the south-west, the LMR receives proportionately more freshwater and remains relatively fresh throughout the year, showing comparatively a lower salinity intrusion and salinity remains largely unchanged despite immense tidal effect. In this part of the Meghna river there remains a balance between fresh water influx and relative tide level rise.

4 Flood Characteristics of Meghna River

In hydrological regime, flood is defined as a sudden peak of river discharge to overflow the riverbanks and inundate the floodplain for a certain period of a year. It could be a regular inundation, without any loss of properties and such floods are desirable. It could also be beyond the expectation level, crossing the danger level and destroying live and properties for a short span of time varied from a few days to a few weeks. On an average the annual flood inundates 20% of the country, including a greater portion of Meghna floodplain. However, some year the flood become catastrophic in nature, inundating larger portion of the floodplain than it is expected. Some of the major flooding years covering more than 25% of the country are shown in Table 18.1. Figure 18.3 shows the hydrographs of floods of Meghna River of the severe flooding years 1998, 2017 and 2020 at three different stations within the catchment.

Flood in a river basin may result from various causes, of which some important causes are heavy torrential rainfall, channel hydraulics and backwater effects from tidal amplitudes. Floods in Bangladesh are usually classified into four categories: flash flood, regular riverine flood, tidal flood and cyclone-induced storm surges. Flood discharge data for Brahmaputra-Jamuna Ganges-Padma and Meghna Rivers are collected by BWDB at Bahadurabad Ghat, Harding Bridge and Bhairab Bazar, respectively. The combined flow of Brhamaputra-Jamuna and Ganges is measured at

Table 18.1 Year-wise flood-affected area in Bangladesh

Year	Flood-affected area		Year	Flood-affected area	
	km^2	%		km^2	%
1955	50,500	34	2004	55,000	38
1969	41,400	28	2007	62,300	42
1970	42,400	29	2015	47,200	32
1974	52,600	36	2016	48,675	33
1987	57,300	39	2017	61,979	42
1988	89,970	61	2019	45,747	31
1998	100,250	68	2020	59,028	40

Source: FFWC (2021)

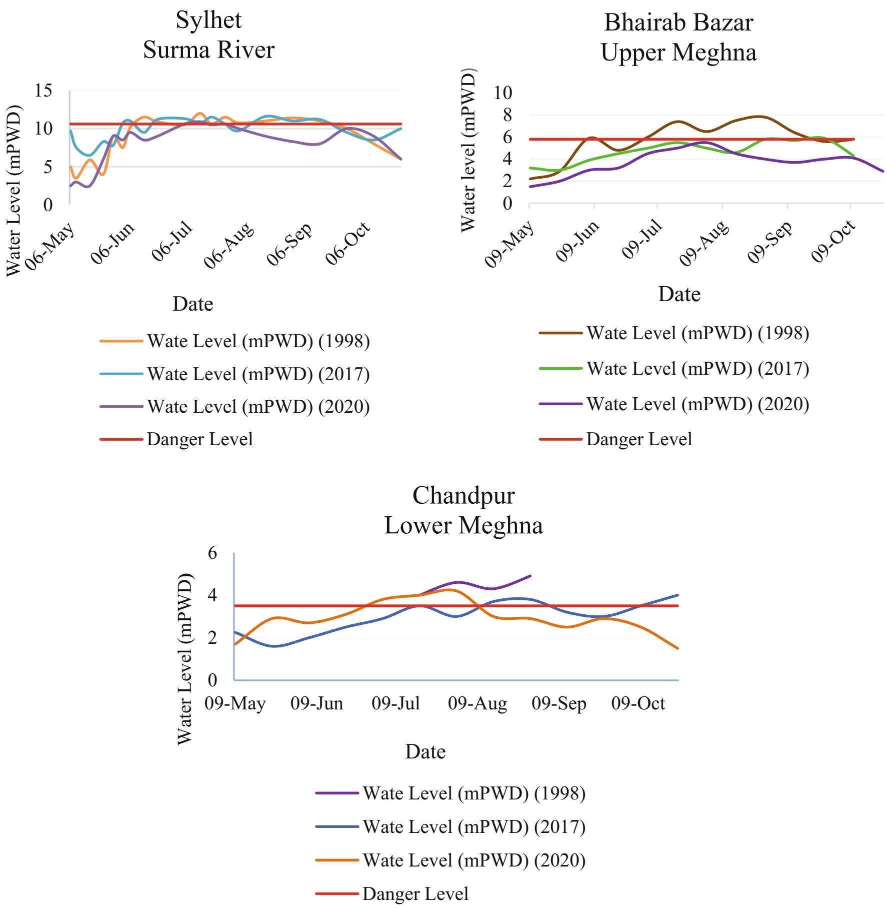

Fig. 18.3 Hydrograph of extreme flood years in Meghna basin. (Date Source: FFWC, 2022)

Baruria and Brahmaputra-Jamuna and Ganges-Padma is recorded at Mawa. Combined discharge data of Brahmaputra-Jamuna, Ganges-Padma and Meghna are collected at Chandpur.

Flood in Meghna River basin incorporates all the above categories, with regional and spatial disparity. In the upper part of the basin within Bangladesh, due to the presence of small hillocks, relativel steep slope of the ground, narrow and small river types and excessive torrential rainfall are characterised by flash flood, particularly in the onset of monsoon period. Local rainfall in the upstream hilly areas flows downward without any further delay and produces the flash flood in Bangladesh territory. There is a difference of timing of flood peaks among three major rivers, which is because of the variation of rain pouring in the catchments and difference of travelling time of water flows from the upstream. In a normal year, the upper Meghna River receives first flood peak in the 3rd or 4th week of May, and second peak occurs closed to the second peak of Brahmaputra River. Synchronising the peaks of all major rivers is rare, and in such case, the flood level becomes severe in nature. The occurrence of the peak floods of Meghna River, when coincides with the peaks of the Ganges and Brahmaputra flood, the extension, depth and duration of flood at lower Meghna basin become severe. It is further intensified when effects coincide with the high tide and backwater effect. Backwater effect is an important cause of flooding in the Meghna course, particularly in the LMR, as was observed in 1997 and 1988. During that flood the water at Bhairab Bazar station remained above danger level for consecutive 68 days (Mirza et al., 2003). Mirza et al. (1998) also have given the illustration of such flood synchronising and tidal impact of flood amplification during the 1987 flood.

It is believed that the flow of upstream water is halted at the Meghna mouth due to dynamic action of the Bay of Bengal. The bay appears to work as a barrier wall of water due to south-west monsoon wind, tidal amplitude and occasionally cyclonic depressions. South-west monsoon piles up water in the north-east corner of the bay, particularly in the Meghna estuary, and intensifies the flood inundation. Meghna mouth is the drainage route of the Ganges-Brahmaputra-Meghna water flow. Water congestion at Meghna mouth scales up the tidal inundation, particularly during the spring tidal stage. The unprotected area outside the embankment becomes more vulnerable due to tidal flooding.

However, there do not exist reliable observational evidences of backwater effect of flood in Bangladesh. Ali (1995) has shown that it is the monsoon wind that has impact to hold up floodwater in the Meghna mouth. The inflow and outflow of floodwater through the month largely depend on strength balance between the freshwater discharge and south-west monsoon wind.

4.1 Meghna River Flood 2020

Severe flood was caused by the upper Meghna River systems in 2020 which affected low-lying lands of northern and north-western regions of Bangladesh. Flood affected 40% of the country in 2020. In October 2020, in the Meghna basin, out of 28 rainfall monitoring stations, 21 stations recorded more rainfall than the normal of the month. The basin received 34.39% more rainfall than monthly normal during the month (FFWC, 2021) (Table 18.2). Due to this flood, 635 schools were damaged in Sylhet in 2020 (Iqbal & Rahman, 2020). Nearly 1.3 million homes were damaged, hundreds of thousands of people were marooned, and hundreds died (www.bbc.com). The Government of Bangladesh has allocated total 8210 metric tons of rice, and each district received 200 metric tons of rice (reliefweb.int). Figure 18.4 shows the DEM of the Meghna basin, and the flood inundation of the Meghna basins area is shown in Fig. 18.5. The water levels at three stations (Sylhet, Bhairab Bazar and Chandpur) of monsoon flood of 2020 are shown in Fig.18.6.

During the monsoon 2020, out of 29 water level (WL) stations, the flow was above the danger level in 17 stations, which were in coexistence with local monsoon

Table 18.2 Monsoon rainfall statistics of 2020 in Meghna basin

Month	Meghna basin
May	−11.34%
June	7.39%
July	10.49%
August	−35.07%
September	32.89%
October	45.65%

Source: FFWC (2021)

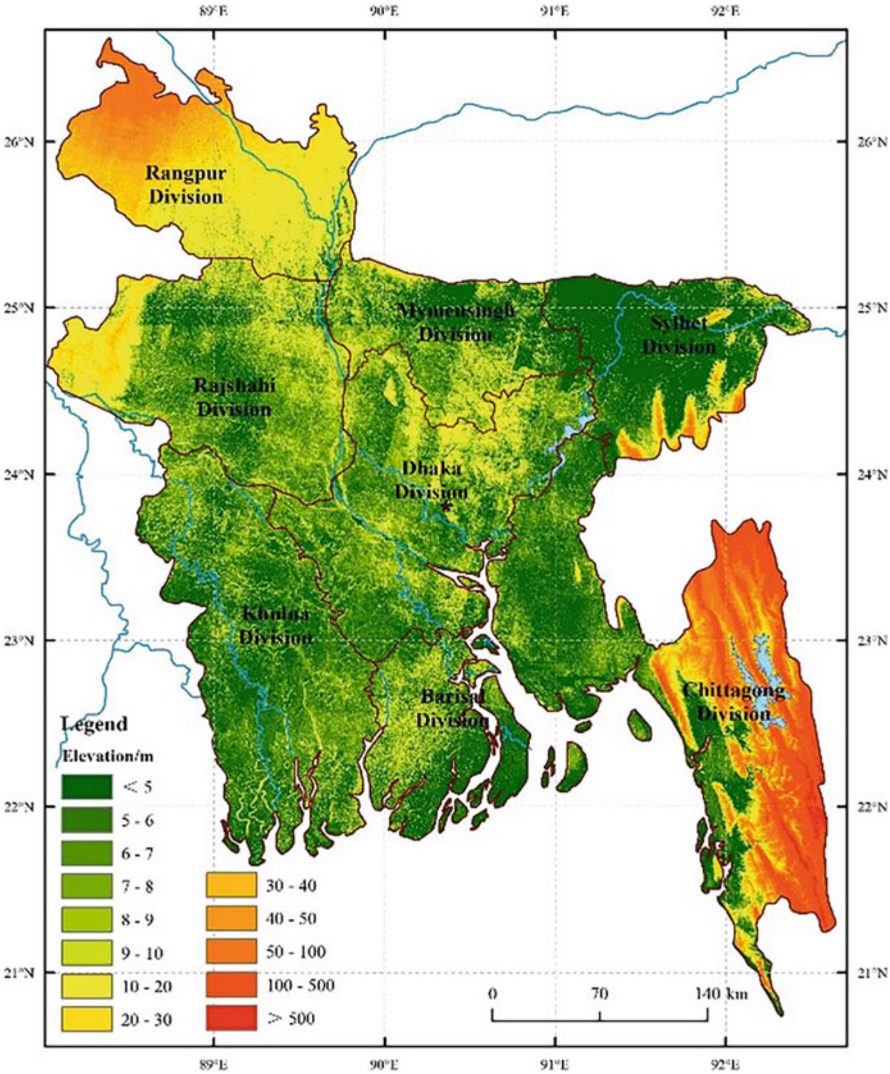

Fig. 18.4 DEM of Meghna basin. Source: (Jiang et al., 2021)

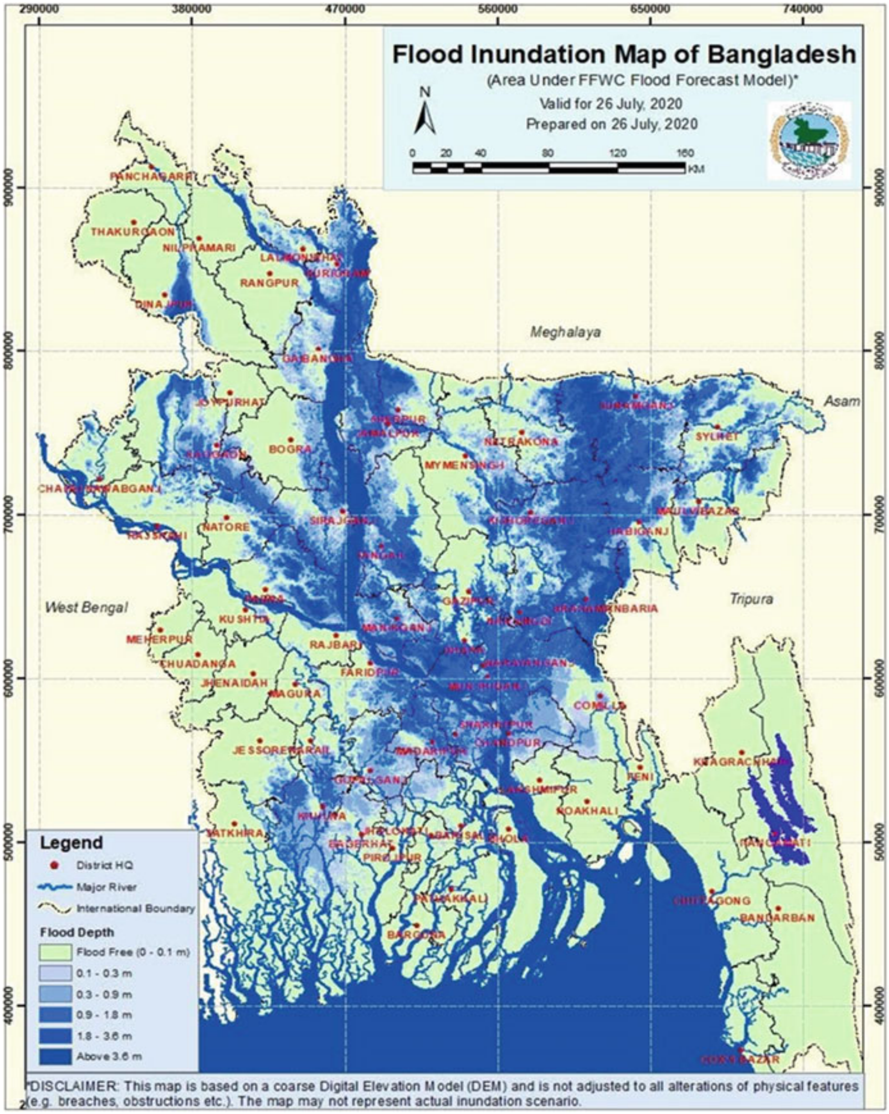

Fig. 18.5 Flood 2020 (26 June) inundation of Meghna basin. (Source: FFWC, 2021)

rainfall intensity. In Meghna basin there are 19 rainfall stations of which in 9 stations received 7.23% more rainfall than normal in June 2020 (FFWC, 2021). The basin received 10.21% more rainfall in July, 2020, which was 29.08% more than normal in September. Because of rainfall intensity, there were two peaks of monsoon flood in the Meghna basin, which occurred during June–July and late September for period of 26 days. Because of backwater affect and tidal influence, the flood prolonged for a period of 40 days at lower Meghna regime (FFWC, 2021).

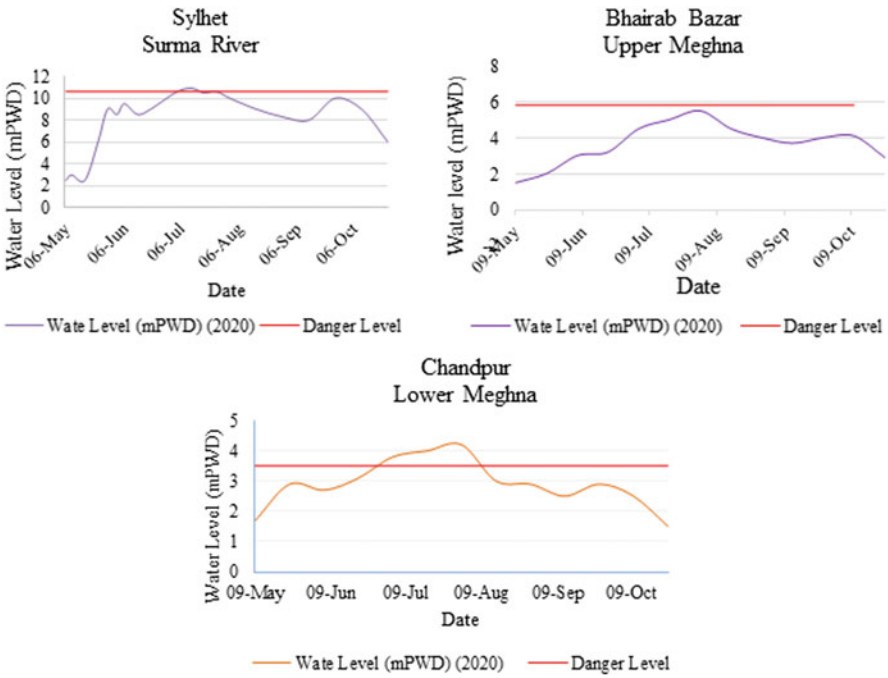

Fig. 18.6 Hydrograph of Meghna basin in 2020. (Source: FFWC, 2021)

In the upstream region, the monsoon 2020 flood characteristic was distinctive. That year the basin had experienced severe incidents of flash flood with multiple peaks, which affected the the basin very badly. It shows at least five to seven fluctuations crossing the danger level at different points of the Surma River flows, starting from May 2020. Some of the important peaks occurred in 3rd of June (for 1 day), 25th of June to 4th of July (for 9 days) and 9th–24th of July (14 days), mostly covering the Surma and Kushyara catchment area. Due to tidal water effect, the floodwater coming from the upstream Meghna during June and July period was blocked at Chandpur point, which also led to intensified flood events. Sunamganj, Nterokona, Sylhet, Brahmanbaria and Chandpur regions experience fold of short to moderate in duration. The Kushyara river also showed similar fluctuation lasting from 3 to 6 days throughout the monsoon.

4.2 Meghna River Flood 2022

The flood of 2022 is a typical one to understand the flood characteristics of the Meghna River basin. It shows two flood peaks: one is per monsoon (mid-May) flash flooding event, and another one is monsoon (mid-June) riverine flooding event (Fig. 18.7). The pre-monsoon peaks of stronger flash flood hit north-eastern region of Bangladesh which is more severe than the floods in last two decades. Extensive flash flooding has affected 4 million people, and nearly 13 upazillas have been flooded including Kanaighat, Gowainghat, Companyganj, Jaintapur, Zakiganj, Sylhet Sadar, Fenchuganj and many more (Islamic Relief Bangladesh, 2022). According to FFWC, among 39 rivers of the north-eastern part of the country, in 33 rivers, water level has risen, and 4 rivers have exceeded their danger level including Surma, Kushiyara, Jadukata and Sarigowain (Prothom Alo, 2022).

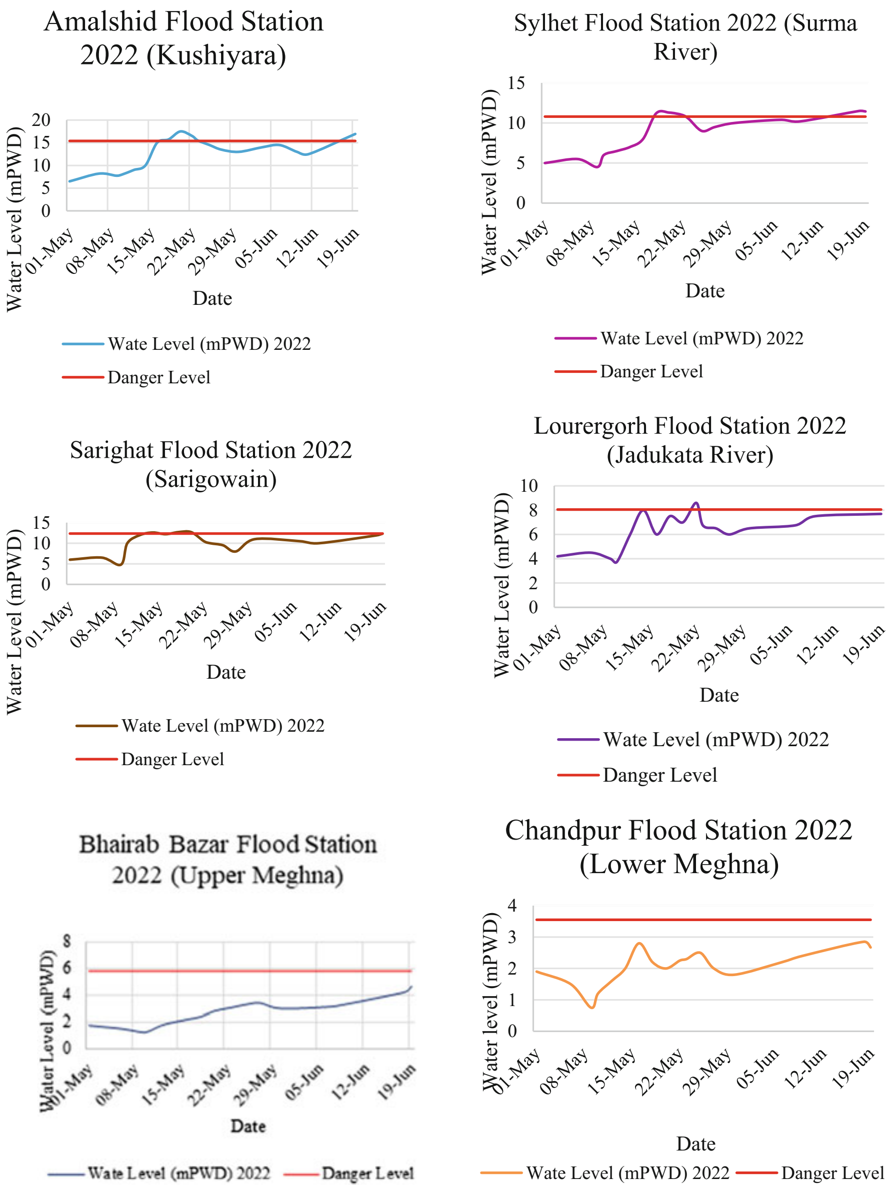

Fig. 18.7 Hydrograph of Meghna basin (2022). (Source: FFWC, 2022)

Seventypercent of Sylhet district and about 60% of neighbouring Sunamganj have been submerged (AFP, 2022).

The second peak of monsoon flood hit the upper Meghna basin due to excessive rainfall in the upstream catchment. It has been reported that on 17th of June only in 24 h, 972-mm rainfall was recorded in Cherrapunji (Assam, India) (Prothom Alo, 2022). As consequence of that, most parts of Sunamganj and Sylhet district become severely inundated. Local rainfall is also high in Sylhet region. Sylhet metropolitan areas have been inundated this time, and greater Sylhet division has broken all previous records of flood inundation and damages. About 90% of the low-lying areas of the division is under water and isolated from the country.

One of the characteristics of the flood of Bangladesh is that it moved from Meghna basin to Brahmaputra basin, and the first peak of Barahmaputra coincided with the second peak of the Meghna flood, as has been observed in 2022 (Prothom Alo, 2022).

Transport system and power stations have been drowned in Sylhet and Sunamganj, and as a result around 0.15 million families were cut off from power supply (UNICEF, 2022). At least 3000 ha of rice paddy fields have been damaged by the flooding. Around 873 educational institutions in Sylhet have been shut down due to the flood crisis. People are suffering from diarrhoea, respiratory infection and skin diseases (The Daily Star, 2022).

The flood has inundated about 1137 ha of agricultural land, and 205 km^2 area has been inundated. About 69,165 people of 10 unions have been affected by this flash flood in Goainghat upazila of Sylhet district (IFRC, 2022).

5 Floodplain Morphology

Based on hydrology and physiographic condition, Bangladesh is divided into 30 agro-ecological zones, (AEZ) of which six zones – middle Meghna River floodplain, lower Meghna River floodplain, young Meghna River floodplain, old Meghna River floodplain, easterm Surma-Kushiyara floodplain and Sylhet basin – cover the Meghna floodplain morphology (Table 18.3). These AEZs include distinctive geomorphic units, including back swamps, haors, abundant channels, oxbow lakes, tidal flats and char lands. Based on inundation depth of these AEZs, there exists four categories of floods: shallow flood, when flood depth is less than 1 m and natural levee remains above flood level; moderate flood, when flood depth varies between 1 and 2 m; deep flood when flood depth exceed 2 m and all levees are submerged; and highly deep flood, when the low-lying floodplains and back swamp remain under more than 3 m water depth in Meghna basin area, and one-third of the flooded area is the deeply flood zone and can be characterised by a portion of permanent water bodies throughout the year, such as the haor areas of Sylhet district.

Table 18.3 Agro-ecological zones of Meghna basin

SL	Region	Sub-region	Area (km^2)	Location
1.	Arial Beel	Arial Beel	144	Dhaka, Munshiganj
2.	Middle Meghma River Floodplain	Middle Meghma River Floodplain	1555	Kishoreganj, Brahmanbaria, Comilla, Chandpur, Narsindi and Narayanganj
3.	Lower Meghma River Floodplain	(a) Calcareous, flood protected; (b) Calcareous, unembanked; (c) Noncalcareous, flood protected; (d) Noncalcareous, unembanked	909	Chandpur, Lakshmipur and Noakhali districts
4.	Young Meghma Estuarine Floodplain	(a) Nonsaline; Central Bhola; (b) Nonsaline; Meghma Estuary Charland; (c) Nonsaline; North Bhola; (d) Saline; Central Bhola; (e) Saline; Noakhali, Hatiya and Meghma Estuary; (f) Saline; Sandwip and South Bhola	9269	Chittagong, Feni, Noakhali, Lakshmipur, Bhola, Barisal, Patuakhali and Barguna districts
5.	Eastern Surma-Kushiyara Floodplain	Eastern Surma-Kushiyara Floodplain	4622	Sylhet, Moulvi Bazar, Sunamganj and Habiganj districts
6.	Sylhet Basin	(a) Central and Southern; (b) Northern; (c) Western	4573	Sunamganj, Habiganj, Netrokona, Kishoreganj and Brahmanbaria
7.	Old Meghma Estuarine Floodplain	(a) Dhaka-Narayanganj-Demra Project Aiea; (b) High; Old Meghma Estuarine Floodplain; (c) Low: Daudkandi-Habiganj; (d) Low: Dhaka- Shariatpur-Barisal; (e) Low: Eastern Kishoreganj; (f) Low: Gopalganj Beels margins; (g) Low: Habiganj-North Brahmanbaria; (h) Low: Titas Floodplain; (i) Medium Low; (j) Very poorly drained: Laksham-Begumganj	7740	Kishoreganj, Habiganj, Brahmanbaria, Comilla, Chandpur, Feni, Noakhali, Lakshmipur, Narsindi, Narayanganj, Dhaka. Sariatpur, Madaripur, Gopalganj and Barisal districts

Source: FAO (1988) and Rahman et al. (2019)

Within Bangladesh, the topography of Meghna basin is relatively flat and low lying, except a few hillocks in the north and east. The floodplain morphology of the basin is being continuously changing due to rapid siltation, accretion and erosion.

5.1 *Sedimentation*

The Himalayan and Burma Arcs are the two sources of water and sediment supply, which are being carried by the GBM river system to shape up the morphology of GBM delta. This part of the sedimentation pulse is supposed to be affected by past mega-seismic events (Brammer, 2014). Regular sediment supply, seasonal fluctuation of sediment influx and earthquake-driven sudden sediment pulses collectively lead to the modification of river morphology.

Datta and Subramanian (1997) have shown that fine to very fine sand grains occupy more than 76% of total grain composition. The remaining portion is dominated by silt and clay. In case of Meghna River, the bed sediment is well sorted than other major rivers. All the bed sediments are positively skewed indicating the domination of finer particles. The suspended particles are finer in case of Meghna than those of Jamuna River.

Wilson and Goodbred (2015) have shown that about one-third of total load of 1 billion tons of sediment is being retained in the Meghna estuary and it is the main source of land formation in the central part of the coast. The LMR is characterised by seasonal fluctuation of sediment flux ranging from 0.8 g l^{-1} to 9 g l^{-1}.

Sediment flux in the coastal belt is seriously been disrupted by constructing polders in the coastal belt, particularly in the south-west. During the 1960s aiming to increase agricultural outputs by halting saline water influx into the floodplain, massive polderisation programme was undertaken, which finally not only halted saline water but also the sediment influx into the floodplain. In the central part of the coast, particularly in LMR basin, such type of human interventions are minimum, although many other interventions, such as char development project, Muhuri irrigation project and coastal afforestation project, have been implemented. All these projects are somehow related to the sediment budget and sediment accumulation rate in the lower Meghna basin area.

Siltation is one of the most striking oceanographic features of the continental shelf zone of the northern Bay of Bengal. Due to high sediment accumulation in the Meghna estuary, the navigation becomes a serious problem, across the Meghna River mouth. Roy and Islam (2016) have shown that in the Meghna estuary of less than 5-m water depth, the turbidity is very high and reveals the suspended sediment concentration of 1.9 g l^{-1}, which is more than 2 g l^{-1} near the shore and is not significant ($<$0.3 g l^{-1}) beyond the 10-m water depth. Due to season of low water discharge from the river network, this turbidity is mainly triggered by the bottom sediment re-suspension induced by the action of tide and wave energy.

5.2 *Riverbank Erosion*

Riverbank erosion is one of the major disasters in Bangladesh. It creates direct and indirect sufferings of 1 million people annually and loss of their properties. It is one of the major causes of rural-urban migration. It is estimated that in three decades more than 100,000 ha of land has been lost and 800,000 people have been displaced due to riverbank erosion in Bangladesh (Sarker & Thorne, 2009). The long-term sustainability and economic stability of the people have been threatened due to instability of the riverbanks.

Active tectonic settings of the Meghna catchment, due to its location in between Himalayan and Burmese Arcs, are one of the main causes of higher erosion rates in the right bank of lower Meghna River compare to its left bank, which leads to westward shifting of lower Meghna course (Mahmud et al., 2020). The westward shifting of Brahmaputra River to its present course along the present Jamuna is widely documented, and it has its long-lasting impact on 20–30 km westward avulsion of the Meghna River course (Sarker et al., 2011). Present-day Titas might be a remnant of old Meghna River. Widening of the LMR is also associated with bankline shifting and channel equilibrium. Changes in annual run-off and existences of frequent extreme flooding events lead to channel widening to keep the hydraulic equilibrium of the LMR. Expansion of existing chars and emergence of new chars also related to excessive erosion on both sides of the river.

Riverbank stability of the Meghna River is also related to the textural composition of grain sizes in the riverbanks. LMR banks mostly composed of weakly consolidated, stratified fine-grained particles of varying coherent of recent origin. They are easily subject to bank-line failure and lead to enormous damage of fertile lands and displacement of people. Seasonal fluctuations of river discharge are also the leading force to bankline instability and hydraulic changes of river geometry. The discharge of the LMR varies less than 10,000 $m^3\ s^{-1}$ during the dry season to more than 50,000–100,000 $m^3\ s^{-1}$ during the monsoon (Wilson & Goodbred, 2015). Extreme flooding events, (as observed in 1987, 1988, 2004, 2007 and 2020) might have sudden and remarkable instability and period shifting of banklines of the LMR.

Due to wave action and tidal affect, the morphology of the lower Meghna basin may alter significantly. The Meghna River at Chandpur has historically been experiencing enormous bankline erosion, and over the last five decades, it has been found that the left bank is continuously receding.

6 Climate Change Impact

Most climate mode shows that under projected climate change scenarios, the intensity of rainfall in Meghna basin will increase. Mirza et al. (2003) have shown that at 2 °C temperature rise of the mean peak discharge of the Meghna River will increase by 19.9%, with an increase of current peak discharge of 14,060 $m^3\ s^{-1}$ to 19,861 $m^3\ s^{-1}$. Under 4 °C and 6 °C global temperature rise, the projected peak discharges would be 20,940 $m^3\ s^{-1}$ and 22,470 $m^3\ s^{-1}$, respectively.

Mohammed et al. (2018) in another model-based study have shown that the flood magnitude in Meghna River basin would be more severe in the future due to global climate change. They have projected that at temperature rise of 1.5 °C, 2 °C and 4 °C in 100 years return period, the flood intensity of Meghna basin will increase by 15%, 38% and 81%, respectively, which is much higher than that projected for the Ganges and Brahmaputra basin. It is most likely that the combined high flow events of GBM river and also individually for Meghna River will increase in future. They have shown that annual discharge of the Meghna basin increases linearly with basin-wise increase of precipitation. Similar alarming projections are found by a number of studies for greater South Asian region (Mishra & Lilhari, 2016; Turner & Annamalai, 2012, Immerzeel, 2008).

Kamal (2013) also has shown that anticipated climate change likely to have significant impact of flood intensity of lower Meghna River, with significant seasonal variability. The peak flow may increase by 4.5–39.1% during the monsoon, with a decrease of 4.1–26.9% during the dry season, indicating a high seasonality due to climate change impact.

Water and sediment supply in the Meghna catchment is largely been affected by climate change. Kamal (2013) has shown that due to climate change, the peak flow of the GBM river may increase up to 39.1% during monsoon and may decrease up to 26.9% during dry season by the end of this century. Such a projection would lead Bangladesh, particularly the Meghna basin, more vulnerable of intensified monsoon flood inundation in one hand and during dry period to prolonged drought on the other hand.

6.1 Hydrological Impact

Due to its geographical location, the Meghna basin experiences water-induced hydro-meteorological disaster at regular intervals. Climate change will tremendously affect the local hydrological cycle, which would intensify the occurrence of water-induced disasters. Rivers of the upper Meghna basin are comparatively the smallest, steep and relatively flashy. These flashy rain-fed streams might invite localised short-duration flooding event more frequent and more intensified under the changing climatic condition in the future. The intensity, duration and extent of such flash flood might have significant effect on local topography, hydrology and water resources.

The hydrological impact of climate change in the Meghna River basin is well apparent. It shows spatio-temporal variations of rainfall intensity and run-off, which would be more visual in the future. Climate change would intensify the precipitation and run-off, particularly in the north-eastern part of Bangladesh, which mostly occupies the Meghna River basin. It is projected that in the near future the precipitation and run-off in this region would increase by 30% (Masood & Takeuchi, 2016). The flood inundation would be higher due to lower ground elevetion compare to upstream part of the Mehgna basin, which is the main source of rain water. Therefore, there is more likely of occurrence of frequent and intensified flash flood in the north-eastern hilly regions of Bangladesh in the future.

6.2 Cyclonic Impact

Bay of Bengal is the breeding ground of cyclonic depression, many of which turned to storm surges before landfalling along the coastal belt of Bangladesh. Record from all previous major cyclone shows that because of the funnel shape of the estuary, the common pathway of cyclone movement and landfalls is across the Meghna estuary (Fig. 18.8). It has been found that due to shallow continental shelf, the surge is amplified while travelling the lower Meghna valley and creates massive destruction. In case of cyclonic events, this area also being inundated and submerged by storm water surges for a couple of hours, creating huge casualties and loss of properties, as had been experienced in 1970 and 1991 cyclones, when more than 500,000 and 143,000 people were killed, respectively (Hossain & Mullick, 2020) (Table 18.4).

In terms of extent and duration, the storm surge-induced floods are different than those of riverine floods but of severe effects on coastal region. Rahman et al. (2019) in their model study have shown that under the climate change-induced projected sea-level scenarios, the inundation level due to storm surges in the Meghna estuary would increase in the future and would affect the livelihood of about 9 million people. Rahman et al. (2015) have shown that due to climate change the upstream river flows as well the severity and intensity of cyclone-induced storm surges will increase in the future, leading more coastal people, particularly along the Meghna estuary and lower Meghna basin, vulnerable to suffering. The subsidence and river bed sedimentation will intensify the flooding problem (Islam et al., 2002; Goodbred et al., 2003; Rahman et al., 2015). Polders across the coastal belt play an important role to reduce storm surge effects, but the people outside the polders, in case of polder failure, and people inside the polders become highly vulnerable to storm surge-induced flooding.

7 Ecosystem Services of Meghna Floodplain

Floodplain ecosystem provides employment opportunity and livelihood to local people through providing goods and services. They act as a source of safety net and a way to poverty alleviation of poor people. Ecosystem services of Meghna floodplain offer the opportunity for the rich people to accumulate more resources and area of tourism and recreation. It provides alternative livelihood for the poor people. Farmers and fishermen are two important folks directly dependent on floodplain ecosystem services. However, the efficiency of ecosystem service-based livelihood and poverty-alleviation efforts depends on how local people get access to the nature-based solution. Meghna floodplains, particularly the low-lying hoar areas, are the rice and fish treasure of the country, supporting direct or indirect livelihood for 20 million people.

Fertile soil, freshwater, nutrients, tidal force and sediment inputs are some of the common nature-based components to explore ecosystem services in the Meghna

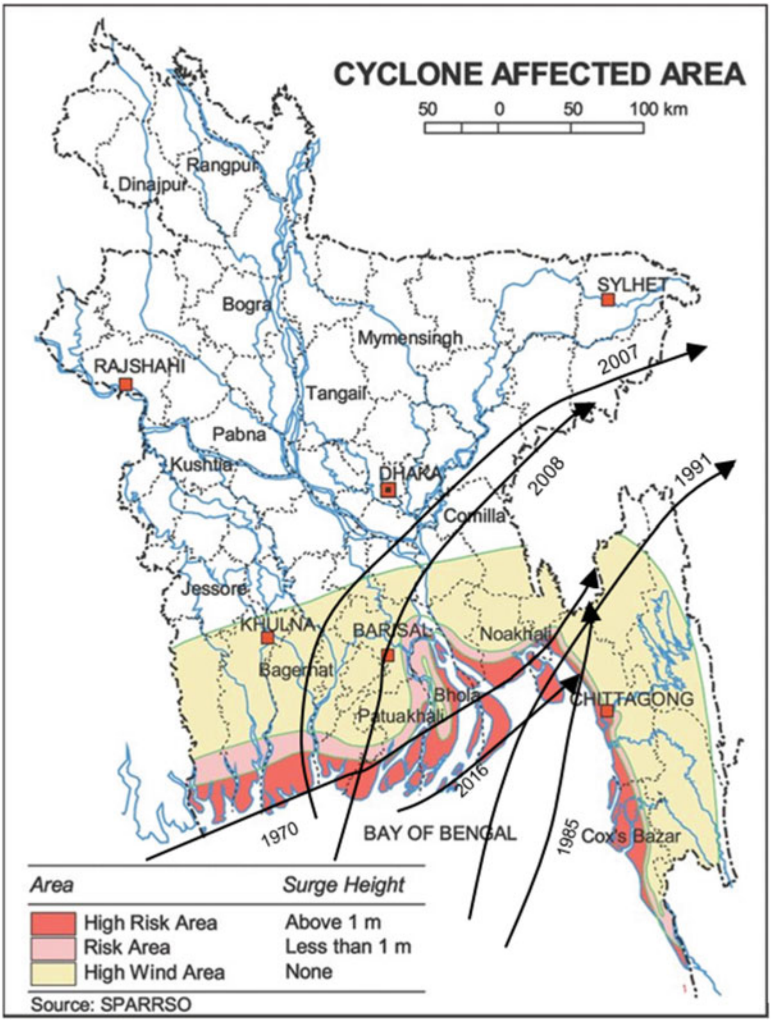

Fig. 18.8 Cyclone paths of previous cyclones. (Source: SPARRSO; Rahman et al., 2019)

basin. They provide ideal condition for fertile and resourceful ecosystem. The most common benefit from this fertile ecosystem is to provide productive agriculture, fisheries and navigation, which proved safety net for local poor people. The reliance ecosystem services of the Meghna floodplain remain important for poverty prevention and poverty alleviation. It addresses nearly all the major goals of the SDGs, particularly goals 1, 2, 3, 4 and 15.

The ecosystem services of the basin area is interconnected and interdependent, and there remains a significant trade-off between different ecosystem services, such as the conflicts between agriculture and fishing, as commonly noticed in the haor and

Table 18.4 Cyclone passing through Meghna basin (Hossain & Mullick, 2020)

Year	Date	Wind speed (km/h)	Affected area	Deaths
1970	12 November	223	Khulna, Chattogram coast (landfall at Hatia)	500,000
1985	25 May	154	Noakhali, Cox's Bazar coast (landfall at Sandwip)	11,069
1991	29 April	225	Patuakhali-Cox's Bazar coast (landfall north of Chattogram)	143,000
1997	19 May	225	Coastal belt of Bangladesh	126
2007	15 November	215	Coastal belt of Bangladesh	3363
2008	8 May	85	Coastal belt of Bangladesh	3500
2016	19 May	110	Chittagong	26

low-lying areas. Upper Meghna River basin includes about 4000 km^2 haor areas, which become deeply flooded during the monsoon. The economy of local people is hindered by flood damages nearly in every year. It is one of the major source causes of local poverty and threat to local economy. However, the opportunity of nature-based solution is also immense in the haor area, which can be harnessed sustainably and in harmony with nature. Imparting the local harsh natural condition, it is possible to improvise local agricultural product, fisheries, livestock, forestry and many other nature-based solutions.

Similarly, agriculture and shrimp farming, fish larva collection and biodiversity conservation in the floodplain and coastal area are in conflicts. Converting of agricultural land and forest coverage into shrimp farming is an important challenge to nature-based solution and source of ecosystem services, as commonly noticed in the lower Meghna tidal floodplain areas.

Another important challenge to floodplain ecosystem services is the transformation and mobility of services and access to the nature-based resources. Social structure and policy tools are the mechanisms to ensure rural poor people to ensure their access to ecosystem service available in Meghna floodplain areas. The ownership of land and water resources is also a challenge. Community access to publicly own nature-based domain, such as beel, haor, river and wetland services, to ensure ecosystem services needs to be available for rural poor people. The social mechanism of how people perceive their presence to common nature-based services in the floodplain area is an important element of ecosystem services and nature-based solution. In Meghna floodplain region despite highly productive ecological system, poverty persistence and nature-based solution yet need more attention to connect.

8 Floodplain Economy

The Ganges, Brahmaputra-Jamuna, Teesta and Meghna Rivers are the lifeline of millions of around 500 million people of South Asia. They cover a catchment area of about 175 million ha and supply water for agriculture, fishing, industry, navigation, industrial and household activities. The source of water of these rivers are either ice meeting in Himalayan region, torrential rainfall in the catchment area or cyclonic events.

Seasonal flooding is a blessing to farmers in one hand and disastrous to the other hand. Soil fertility in the floodplain is improved due to seasonal inundation, which invites people to settle in the floodplains and engage themselves in agricultural activities with hope of good harvest. However, unusual floods can be disastrous, and people living the low-lying floodplains are always under the threat of losing their harvest. In lower Meghna basin, the fertile soil and unique topography are contributory to the economy by providing water for agriculture, fisheries, navigation and biodiversity conservation. The floodplain of lower Meghna River provides ecosystem services for agricultural production, fishing and ecological nourishment.

Compare to Ganges and Brahmaputra basin, the proportionate of Meghna basin within Bangladesh is higher (43%). The area inside Bangladesh territory is relatively flat, has formed extensive floodplain and is the rice and fishing ground of the country. The boro rice production during the dry season and fish catch during the monsoon are two important economic activities of the local people and driving sources of national economy. The basin produces 16% of total rice production (Quddus, 1970) and supports the livelihood of 20 million people. The annual production of boro at this region is about 3 million metric tons, which accounts 12% of total annual rice production. However, this important agricultural bowl of the country is being affected by pre-monsoon (April–May) and monsoon (June–September) flood nearly in every year, causing damages of people's livelihood. The agriculture and standing crop of this area is frequently affected by advances of floods and flash flood events, as has been observed this year (2022).

It is projected that in the near future the precipitation and run-off in this region would increase by 30% (Masood & Takeuchi, 2016). This would intensify flash flood in this region, which would destroy agricultural products and fisheries. To protect the standing crops from climate change-induced intensified flash flood incident, it is necessary to take protective steps before harvesting and supporting farmers with adaptable crop varieties.

The lower Meghna River is the prime fishing location in Bangladesh and is an important source to fill the national demand. However, the catch in an estuary and river mouth largely depends of seasonal variation of tide, local weather condition and flood intensity. Rising tide level created lateral expansion of flood inundation and more waterlogging, whereas low tide created navigation problems to the fishermen. The fish catches at the Meghna River estuary, which is an important sector of local employment and economy, are largely of naturally determinant and seasonally controlled. During the monsoon, due to bad weather condition, the catch is very often jeopardised, and local fishermen have to take shelter to a safer place, suspending their catches.

9 Flood Management

It has been mentioned earlier that the Meghna basin area is highly vulnerable to annual flooding. The top priority of flood management in this region is, thus, to reduce the damages of standing crops and ensure the food security. Effective flood management requires timely flood forecasting and accurate risk assessment. It can help the decision-makers to take appropriate mitigation measures. Hydrological modelling can help to take appropriate flood adaptation and mitigation measure. However, appropriate application of hydrological modelling in Meghna basin is difficult because 60% of the basin area is located outside Bangladesh. Without accurate rainfall data of upper catchment area and water flows data of upstream rivers, the flood simulation model is not reliable and dependable. Climate change-induced regional hydro-climatological changes remain another challenge to flood modelling. Moreover, the massive human interventions in the catchment, particularly the completed and proposed cross-dams and water controlling measures in the upstream areas make the flood situation in Meghna basin uncertain and unmanageable. It is, thus, necessary to adapt basin-wise management strategies and measures.

Basin-wise flood management requires the reduction flood intensity, reduction of flood damage, ensuring food security, ensuring poverty alleviation, promoting local economy and conserving basin environment. As much of the basin lies outside Bangladesh, it is thus nor realistic to manage flood and water resources of Meghna River and make any flood management plan success by Bangladesh alone. Due to increasing seasonal and annual variation of river flow, most of which is rain fed from upstream and climate change driven; it is difficult to manage flood and water resources of Meghna River singly by Bangladesh. Climate change-induced impact of Meghna basin is expected be more prominent in the future and requires cooperation among co-riparian countries. It requires sharing and cooperation in aspects of flood management among the concerned countries. Both flood and drought can be managed with regional cooperation among the co-riparian countries. To achieve that long-term basin-wise planning and sustainable water resource management, plan is prerequisite. There is also a requirement of a good coordination between the academia, practitioners, professionals, bureaucrats and politicians of the concern countries.

The enhancement of end-to-end early warning system should be an area of urgent need. Transboundary cooperation among and within the South Asian countries, which includes around 10% of world population, requires international cooperation. The major area of cooperation includes real-time data sharing, sharing information on flood furcating, exchange of knowledge and technology and collaborative research. All riparian countries, such as Bangladesh, India, China, Nepal and Bhutan, require adopting basin-based approach to address flood and water resource-related issues. It can be done under an umbrella of hydro-meteorological services. Regional cooperation on hydro-meteorological issues will enhance regional economic and political stability and towards the achievement of nearly all targets of SDG-6.

10 Conclusions

Flood, floodplain ecology and livelihood of local people are closely links in Bangladesh. In Meghna River basin, rice and fish are two important nature-based resources, which supports national economy and significantly contribute to national GDP. However, unusual and unexpected flood in the basin is a threat to the lives and livelihood of people. The local economy of Meghna basin improvises local economy due to existence of harsh natural environment, such as in haor areas and coastal areas. Such areas are very poorly connected to the city centres, and due to poor communication of urban economics, access to industrial and service sectors is very negligible. Employment opportunities in industries and poor access to urban facilities lead local people to depend more on nature-based solution for their lives and livelihoods. In the Meghna basin, one of the worst accesses to Dhaka City, people cannot find their works in the capital or nearby cities and are forced to live in poverty with nature at home. Any disruption of natural ecosystem services and nature-based solution either by unusual flood or by drought in dry season is a threat to their livelihood and source of poverty. However, in order to create employment opportunities and promote local economy, it is necessary to mitigate flood damage and improvise nature-based solution at grassroot level.

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