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Aznarul Islam · Pravat Kumar Shit ·
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Balai Chandra Das *Editors*

Floods in the Ganga–Brahmaputra–Meghna Delta

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Floods in the Ganga–Brahmaputra–Meghna Delta

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Foreword

The famous American geographer, Gilbert F. White (1911–2006), observed that, while floods may well be "acts of God," flood damages result from "acts of man." The rivers that ultimately feed to the great Ganga-Brahmaputra-Meghna (GBM) delta are indeed part of the natural world, and that world has traditionally been viewed as a sacred creation, held in reverence through religions practiced by the inhabitants of the river basins. However, with its very high population density (about 200 persons per square kilometer) plus the infrastructure associated with perhaps 150 million total inhabitants, this region is obviously at very high vulnerability for immense flood damages.

The rivers that drain to the GBM delta derive their flow from five different modern nations. The Ganga has tributaries that drain the Himalaya Mountains of India and Nepal, extending into parts of Tibet (China). Brahmaputra tributaries extend from India to Bhutan, and the main course traverses the Himalaya Range through the Tsangpo Gorge, draining much of southern Tibet (China), where the mainstem is known as the Yarlung Tsangpo. Along with the Meghna, these rivers converge in Bangladesh and break into the distributary components of the delta. Of these, the Padma and Hooghly are especially noteworthy, lying near the megacities of Kolkata and Dhaka, with respective populations of about 15 million and nearly 23 million.

This present book deals the floods and the associated hazards posed to the GBM delta, the world's largest, covering an area of more than 100,000 km^2. Deltas develop where rivers come to rest as they enter bodies of standing water, in this case the Bay of Bengal of the Indian Ocean. Deltas occur where river gradients are at their lowest, and their entrained sediments get deposited in channel bars (alluvial islands), or when the rivers leave their banks and spill into adjacent land that is built up by the sediment accumulations of successive inundations. Given that these low-lying lands are naturally inundated, they are really portions of their associated rivers. Thus, human habitation of such lands is literally "in the river," even though the flood-prone land is not continuously inundated.

The GBM rivers are laden with sediment derived from the intense erosion of the world's greatest mountain range, the Himalaya. This circumstance is the result of special geological history. About 35 million years ago, the northward-migrating subcontinental plate of peninsular India collided with the southern margin of the Asian continental plate. The compression zone of this collision created the Tibetan Plateau and the great Himalayan Mountain Range. Sediments derived from these mountains filled a trough that was created to the south of collision zone, and the modern Ganges River flows eastward along the axis of this trough. The combination of very high mountains with south Asian Monsoon, bringing extremely heavy seasonal precipitation, produces the immensely high rates of erosion, water runoff, and sediment yields that characterize this region.

Though it is fed by some of the world's greatest rivers, the GBM becomes a tidally dominated delta at its mouth. The lower tidal reaches of the rivers are at high risk from the occasional tropical cyclones and from progressive impact of rising sea level. The great cyclone of November 1970 was one of the world's worst disasters for the loss of life, resulting in over a half million deaths. Progressively rising sea level associated with global warming is exacerbating the hazard for future tropical cyclones.

The tidally dominated lower reaches of the delta are spread across an east-west distance of about 300 km, with the nation of Bangladesh to the east and the Indian state of West Bengal to the west. The coastal margins of the delta comprise the world's largest mangrove forest. Unfortunately, the progressive destruction of this forest is limiting its positive role in moderating the impacts of tropical cyclones, further exacerbation their potential hazard.

The many flood-related problems described in this book contrast with the great reverence for the region's rivers. It can be hoped that the religious tradition of that reverence can inspire the kind of stewardship that will both mitigate the flooding hazard and produce a sustainable relationship between the rivers and the humans that inhabit them.

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Preface

A few years back, when travelling flooded Bengal, a graduate student from Ahmed Draia University said, 'You have too many water resources to manage, but we die from dehydration'. He uttered the serious truth of the Earth's extreme contrast of climate. Rather, extreme contrast of all – the soil, the water, the air, the life and the living. In India, better all over the world, the threat of water scarcity is increasing day by day. It is reported that even the Bengal basin will come under the threat of permanent drought in near future. The lowering of groundwater level in the Bengal basin is ringing the alarm. Discharges of rivers are diminishing rapidly. Some rivers have dried out and got lost. Many lakes and swamps have ceased to exist.

Yet our fellows get killed under flood water! Our cattle and poultry get washed away. Each year, either here or there, floods toll our lands, our properties. We, from the Ganga-Brahmaputra-Meghna delta, suffer the pains of floods. It goes beyond our capacity for utilization and management. The flood erases all differences in terrain. Even barriers of international border crossings disappear under flood water and make the landscape uniform. People of different nations feel the pain and suffering of floods the same way. Regarding floods, India and Bangladesh have fellow feelings. Moreover, during the Covid-19 situation, we became accustomed to online communication to come closer.

In 2020, when the Covid-19 pandemic locked down the entire world, Dr Aznarul Islam took the initiative to introduce ourselves to each other, and eventually, we came closer to thinking on a single point with multi-dimensions – the flood. We felt the urge to work and invited articles on 'Floods in the Ganga-Brahmaputra-Meghna Delta' and did pile huge responses from worldwide contributors, which offered us the opportunity to be selective. We are very much thankful to our authors who contributed to this volume. Their thought-provoking contributions made this volume knowledgeable. We are also equally thankful to our compadre authors, whose articles do not appear as chapters in this volume but who made us feel blessed with their articles rich in noesis.

We are grateful to Dr Guido Zosimo-Landolfo, Editorial Director/Asset Manager of Springer Nature Switzerland AG, for signing the agreement on this project and providing the opportunity of using their prestigious pages for manuscripts of our eminent authors.

We hope, the outcomes of this volume will flood the thoughts of scholars, faculties, planners and stakeholders returning us the apt worth.

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Midnapore, West Bengal, India — Pravat Kumar Shit
Khulna, Bangladesh — Dilip Kumar Datta
Dhaka, Bangladesh — M. Shahidul Islam
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Dilip Kumar Datta has published many journal articles and book chapters in the area of sediment geochemistry, hydrochemistry, water resource management, and in application of ICT in agriculture. He has collaborated widely with researchers from allied disciplines from home and abroad, in research projects supported by both national and transnational organizations such as NWO and APN. He has supervised numerous undergraduate and graduate students for their research work leading to academic degree programmes.

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Chapter 1
Floods of Ganga-Brahmaputra-Meghna Delta in Context

Sandipan Ghosh, Suvendu Roy, Aznarul Islam, Pravat Kumar Shit, Dilip K. Datta, M. Shahidul Islam, and Balai Chandra Das

Abstract The Ganga-Brahmaputra-Meghna (GBM) delta is the world's one of the most populated regions and has the highest concentration of population affected by floods. Millions of people become displaced, and tens to hundreds die each year of the flood incidents. Principally, the heavy rainfall and cyclonic storm are the key drivers of floods in the GBM delta. Although the GBM system covers a vast area of varying topography, diversified lithology, heterogeneous soils, and varying vegetations, the delta formed by the rivers is one and unique geomorphic unit. In this chapter, we focused broadly on the geology, relief, and river systems of this geomorphic unit. We also discussed the nature of floods in the region and their causes – natural and anthropogenic. The seasonality of floods in the GBM delta is also addressed in this chapter. This is not the age of combating floods, but rather the age of coexistence of man with floods. We illuminated this issue of living with floods. Finally, we outlined the prime theme of all other chapters.

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Keywords Riverine floods · Tidal floods · Monsoon regime · Dams · Embankments · Flood management · Living with flood

1 Backdrop

The Global Flood Database (Tellman et al., 2021) has reported about 3054 flood events worldwide during the 2000–2018 period only from different sources (mostly from news reports); however, the organization has successfully mapped 913 flood events in 169 countries using satellite imageries, which were cumulatively inundated about 2.23 million km^2 of land with a major concentration in Southeast Asia (Fig. 1.1). During this time period, the most severe rain-induced flood event has been noticed in the adjoining area of the Ganga-Brahmaputra-Meghna (GBM) delta on 21 July 2007, when about 27 million human population were directly affected by flooding over an area of 78.8 thousand km^2 and about 5 million population were displaced with 1071 causality (Global Flood Database (cloudtostreet.ai) (Fig. 1.1). The table of the top 15 flood events over the GBM basin, including some parts of Myanmar, shows, except one, all the 14 events occurred mainly due to intensive rainfall during the monsoon period (July–October), only with an average exposure of 19 million population (Table 1.1). The region holds over 10% population of the world from the two most populated countries, India and Bangladesh (Rasul, 2014). Although the GBM basin spatially covers about 174.5 million hectares and comprises five countries, i.e., India, Bangladesh, Bhutan, Nepal, and Tibetan China (Rasul, 2014), however, the major concentration of severe and devastating flood events have been frequently observed only in the north and eastern India and over

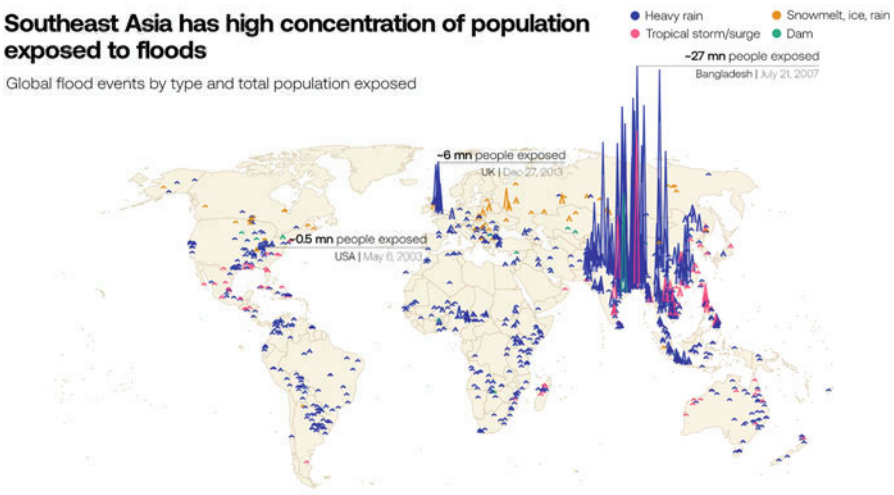

Fig. 1.1 Exposer of the global population to the flood events during 2000–2018. (Source: after The Global Flood Database, Global Flood Database (cloudtostreet.ai) accessed on December 2021)

Table 1.1 List of top 15 flood events over the GBM basin including some parts of Myanmar as per data provided by Global Flood Database (cloudtostreet.ai)

Date	Population exposed	Population displaced	Causality	Duration (Days)	Cause
7/21/2007	2,77,12,991	50,00,000	1071	86	Heavy rain
09/09/2010	2,31,37,894	1,40,000	0	21	Heavy rain
8/30/2008	2,16,31,628	6,00,000	0	9	Heavy rain
8/18/2008	2,15,29,060	1,00,00,000	400	37	Heavy rain
07/12/2007	2,14,88,636	1,11,00,000	96	90	Heavy rain
6/20/2004	1,98,55,086	4,00,00,000	3000	109	Heavy rain
10/01/2010	1,93,62,985	5,00,000	15	11	Tropical storm, surge
7/25/2016	1,84,56,496	25,000	42	32	Heavy rain
09/01/2018	1,72,13,562	1000	20	6	Heavy rain
06/11/2003	1,68,22,143	95,00,000	600	121	Heavy rain
7/21/2002	1,65,41,422	2,50,000	380	25	Heavy rain
07/03/2007	1,64,86,188	30,00,000	958	81	Heavy rain
08/02/2018	1,64,24,780	25,000	0	8	Heavy rain
9/16/2012	1,55,26,445	200	45	2	Heavy rain
8/15/2011	1,48,30,495	70,000	158	48	Heavy rain

entire Bangladesh, in particular the delta region of GBM (Fig. 1.2). The area of the GBD delta is approximately 1,00,000 km^2 and is also a habitat for over 170 million people (Edmonds et al., 2020; Auerbach et al., 2015; Paszkowski et al., 2021).

The GBM delta is a unique example of multilateral interaction between water (fresh and saline), land (including livelihood), and forest, which consists of distinguished features like the world's largest and most populated delta (Paszkowski et al., 2021); about 75% of the Himalayan water (~1200 km^3) drains here with containing about 1 billion tonnes (BT) of sediment annually (Reitz et al., 2015; Allison, 1998; Wilson & Goodbred Jr., 2015; Paszkowski et al., 2021); the interplay between higher sediment input and tidal forces makes this region an active zone of land formation and degradation by accretion – erosion and aggradation – and progradation processes (Sarker et al., 2011), holding largest mangrove system of the world (Sundarbans) (Spalding & Leal, 2021) and facing significant changes in the processes of geomorphology naturally and anthropogenically (Paszkowski et al., 2021). The period of formations is still active since the early Holocene (~12,000 years) as a part of the Bengal Basin, which is a result of about 8500 km^3 of sediment deposited from the Ganga, Brahmaputra, and Meghna Rivers (Goodbred Jr. et al., 2014). The GBM delta is also experiencing active tidal action ranging from 3 m to 6 m high with an influence up to 100 km inland (Haque & Nicholls, 2017).

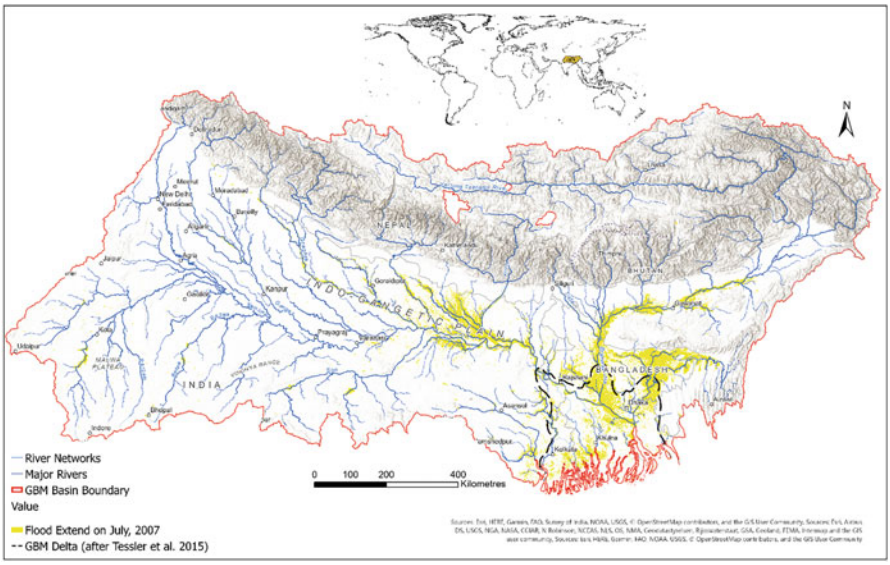

Fig. 1.2 The outline of the Ganga-Brahmaputra-Meghna (GBM) basin marked with its deltaic zone (in black dashed line) after Tessler et al. (2015) and showing the extension of the most severe flood during July 2007 as per mapped by Dartmouth Flood Observatory (DFO). (Sources: Esri, HERE, Garmin, FAO, Survey of India, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community. Sources: Esri, Airious DS, USGS, NGA, NASA, CGIAR, N Robinson, NCEAS, NLS, OS, NMA, Geodatastyrelsen, Rijkswaterstat, GSA, GEoland, FEMA, Intermap and the GIS, user community. Sources: Esri, HERE, Garmin, FAO, NOAA, USGS, © OpenStreetMap contributors, and the GIS User Community)

2 The Ganga-Brahmaputra-Meghna Delta: A Geomorphic Unit

The cradle of the GBM delta is the tectonically active Bengal Basin (Fig. 1.3), which spans the western margin of the Indian Shield or Craton, getting maximum sediments from the Himalayan Rivers. The basin is situated at a plate boundary of the Indian Plate, Burma Plate, and Eurasian Plate, as a continent–continent collision (forming the Himalayan Arc). Flexural subsidence over a broad area, in addition to faulting, folding and localized compaction, allows the subaerial portion of the GBM delta to trap and store ~30% of the 1.1 billion tonnes of sediment delivered to the fluvial system by the rivers (Reitz et al., 2015). The important studies (Bandyopadhyay, 2007; Auerback et al., 2015; Reitz et al., 2015; Akter et al., 2016; Rudra, 2018; Wilson & Goodbred Jr., 2015; Becker et al., 2020; Paszkowski et al., 2021) revealed that the GBM delta is fed by the combined sediment load of ~1 billion tonnes by the fluvial system of Ganga, Brahmaputra and Meghna and most of the delta lies within 20–25 m from present mean sea level. The course of the Ganga, Bhagirathi, Jamuna, Meghna, and other rivers divides the Bengal Basin or

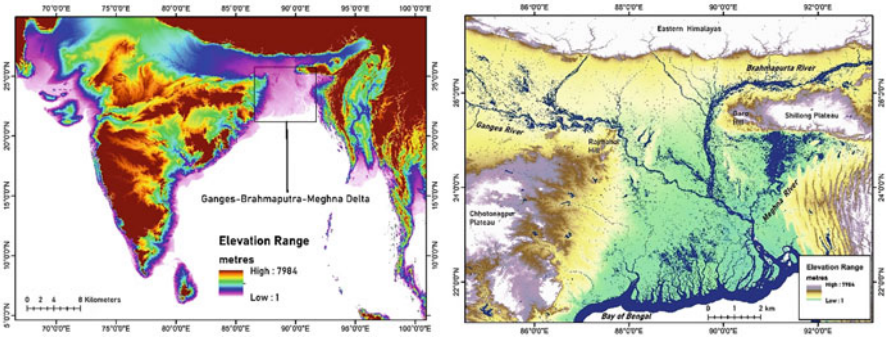

Fig. 1.3 Location of Ganga-Brahmaputra Delta at the eastern part of Indian Craton, showing the fluvial system and seasonally inundated region

undivided Bengal into six geological regions. These regions are: (1) the plains adjoining the Himalayas of North Bengal, (2) the Barind region between the Ganga and the Jamuna, (3) the Rarh region west of the Bhagirathi, (4) the delta east of the Bhagirathi and south of the Ganga, (5) the Meghna Basin, and (6) numerous coastal areas consisting of numerous river creeks and islands.

The GBM delta has morphologic and stratigraphic attributes of an upland fluvial fan, a lowland fluvial delta plain below the backwater transition, a tide-dominated portion amalgamated to its seaward edge, and a large, actively prograding subaqueous-delta clinoform. It is, therefore, best characterized as a composite delta system. Although much of the GBM delta is robust in terms of its construction and maintenance through the Holocene, there are some portions of the delta where sediment supply is insufficient to offset subsidence rates or erosion. These areas are considered most at risk of flooding (e.g., from monsoons, cyclonic storm surges, and high astronomical tides) or erosion (from tidal action). The three regions undergoing this type of decline in the landscape are located in the Sylhet basin, along the Indian tidal delta plain, and at the fluvial-tidal transition in the western and central areas of the delta.

The main geomorphic characteristics of this delta are mentioned as follows (Steckler et al., 2022).

- The GBM delta originated with the opening of the Rajmahal-Garo Gap in the Plio – Pleistocene while it acquired its present form during the Late Holocene after the sea level near its present position following the mid-Holocene transgression.
- The entry of the Ganga (at the Rajmahal Hills of Chotanagpur Plateau) and the Brahmaputra (at the Garo Hills of Shillong Massif) form the apex of the GBM delta, with maximum inputs of water and sediments since Palaeocene. The upper part of this delta exhibits fan-like behaviours of rivers and the apex serves as a principal node of river avulsion. Similarly, the peninsular rivers of India also have formed the vast span of fan-delta at the west (10–40 m elevation range), as a part

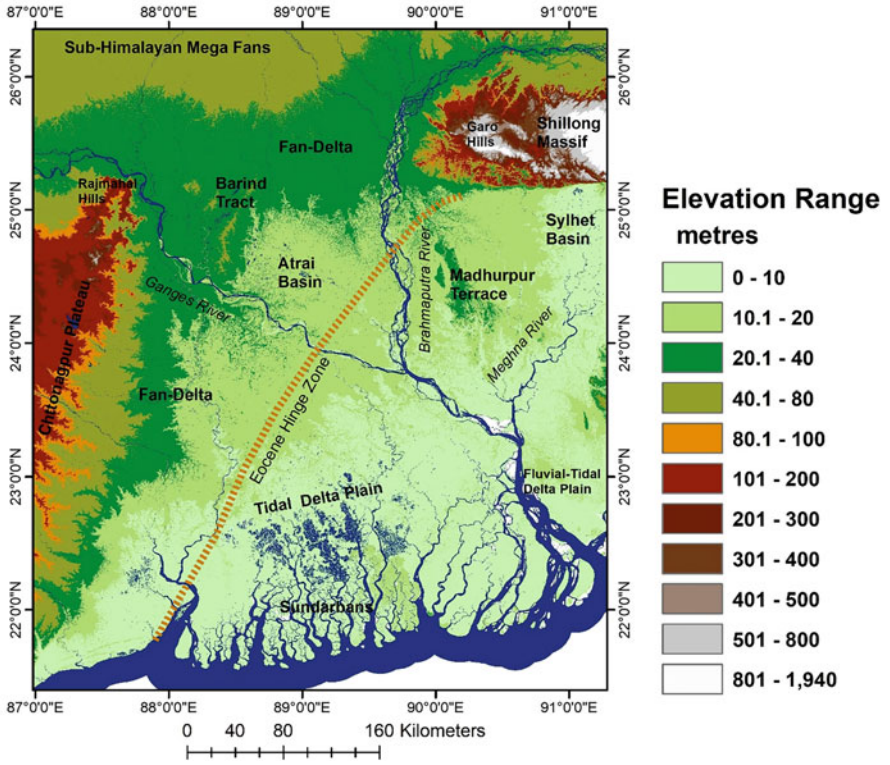

Fig. 1.4 Topographic variation of GBM delta and its important geomorphic units

of Bengal Basin's shelf deposits (Fig. 1.4). Downstream of fan deltas the relief becomes less and the topography is very flat, defining the low-lying tidal or fluvial-tidal delta plain and coastal swamps (Sundarbans).

- In the northern part of the GBM delta, mega-fans of Himalayan Rivers (viz., Teesta, Torsa, Mahananda, Jaldhaka, etc.) are observed. Downstream of the rivers, the dominance of fan deltas, and bed-load alluvial channels are the major landforms. Braided rivers of the Brahmaputra fluvial system undergo rapid channel aggradation, lateral migration, and avulsion.
- The fluvial delta parts of the region also exhibit braided pattern with intensive bank erosion, and some alluvial reaches shows anastomosing pattern where channel braids are reconnected again downstream with mature islands. Many rivers (like Bhagirathi-Hooghly and Meghna) show active meander belts where the channel shows increasing lateral migration and bank-line shifting with the development of oxbow lakes, abandoned channels, and meander scars (Fig. 1.5). The active river-mouth distributaries, in between Padma and Bhagirathi-Hooghly, have developed ~5000 km^2 of large coalescing islands toward the Bay of Bengal. This tidal mud-flat region of more than 100 islands is recognized

Fig. 1.5 Aerial views of river morphology and pattern: (**a**) Braided Brahmaputra River with its tributary confluences, (**b**) mature fan-delta of Ganga River at downstream of Farakka Barrage with its bifurcated western branch Bhagirathi-Hooghly River, (**c**) anastomosing pattern of Meghna River, and (**d**) active deltas of tidal mud-flats at the river mouth of Padma. (Image collected from Google Earth Pro)