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Bengal Delta, *Char*land Formation, and Riparian Hazards: Why Is a Flexible Planning Approach Needed for Deltaic Systems?

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Abstract: A comprehensive understanding of the dynamic characteristics of geomorphological, ecological, and human systems is essential to explaining complex *char*land (mid-channel island) processes and crafting and implementing policy measures. This work demonstrates that the characteristics and outcomes of riparian hazards are determined by the interactive dynamics between hydrogeology and human conditions, which constitutes a novel contribution to the literature in this research area. We further contend that such dynamic social-ecological systems demand a flexible, adaptive management and planning approach. The present research has three key interdisciplinary objectives: (i) to analyze the salient features and characteristics of the geomorphological and riparian systems of the Bengal Delta; (ii) to analyze the evolutionary discourse of the legal systems concerning eroded (diluvion) and accreted (alluvion) land in Bangladesh; and (iii) to assess the characteristics of the coping and adaptation strategies employed by *char*land inhabitants. The findings of this research reveal that delta-building processes, which are characterized by dynamic shifts in the river channels, along with the erosion and accretion of *char*lands have made Bangladesh's land and water systems very dynamic and unstable. The destabilization of these systems increases the inhabitants' vulnerability to riparian hazards, which consistently results in the displacement of settlers and, consequently, a serious deterioration in their socioeconomic status. At present, Bangladesh does not have an effective institutional framework and structure for resettlement planning; therefore, the formulation of a comprehensive national resettlement policy with adequate flexibility to adapt to changing scenarios is urgently needed.

Keywords: accretion; Bengal Delta; erosion; floods; hazards; river channel migration; resettlement

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1. Introduction

Located in the southern plains of the Greater Himalayan continental system, the Bengal Basin is a relatively recent geological formation that is characterized by recurrent channel shifts, riverbank erosion and slumping, and *char*land (mid-channel island) accretion and erosion. *Char*lands are depositional in character, typically taking the form of sandbars that emerge as islands within the river channel or as land attached to the riverbanks. As a result, the Bengal Basin, which mainly consists of the Brahmaputra-Jamuna and Meghna floodplains and the Ganges delta, is one of the most dynamic landscapes on Earth. However, as Alam and Curray [1] note, despite containing more than 20 km of Tertiary-Holocene sedimentary fill, "the present status of our understanding of the sedimentary geology of the Bengal Basin appears to be still in its early stage". Historically, human occupation of this land has been marked by recurrent displacement, frequent movement and resettlement, and the need to continually adjust cropping patterns. We posit that, given the dynamic and unpredictable geomorphological and socioecological processes in the Bengal Basin, an adaptive land and water resources management strategy is critical to mid- and long-term planning and policy decisions related to this region. Akter et al. [2] argue that the three mighty rivers have developed the Bengal Delta to its present form, which covers an area of 10^4 sq. km. They found that the instability of the fluvial system could be attributed to two major elements, namely, the introduction of about 10^{12} m^3 of water with 10^9 tons of sediment per year, and that these "rapid changes cause the delta to become dynamic" [2].

More importantly, studies of riparian hazards have hitherto mainly been pursued from either a hydrological, fluvial morphological, or social science perspective. The highly disparate frameworks of these approaches limit the scope of such research endeavors, especially their ability to explain the interactive dynamics of the combined geophysical (Earth's physical systems) and social systems. Considering such gaps, the present study applies an interdisciplinary lens to investigate the characteristics of riparian hazards and employs an empirical case study of the Bengal Delta in Bangladesh to better understand how humans have adapted to the dynamic formation of this area. As such, this study does not seek to contribute solely to scientific knowledge; rather, it strives to advance integrative interdisciplinary knowledge rooted in the science, social science, and policy domains.

The interdisciplinary approach taken in this study consists of three parts (Figure 1). First, we analyze the characteristics of the geomorphological and fluvial systems to illuminate the erratic nature of river channel shifts in the Brahmaputra-Ganges-Meghna (BGM) river systems and the resultant formation of *char*lands. Second, we explain how water and land resources have historically shaped human occupancy and settlement on the floodplains and *char*land. And third, we examine the interfaces between the geophysical/hydrological systems and the human uses of the floodplains and *char*lands that give rise to riparian hazards and risks. This final area highlights people's coping and adaptation strategies (Figure 1).

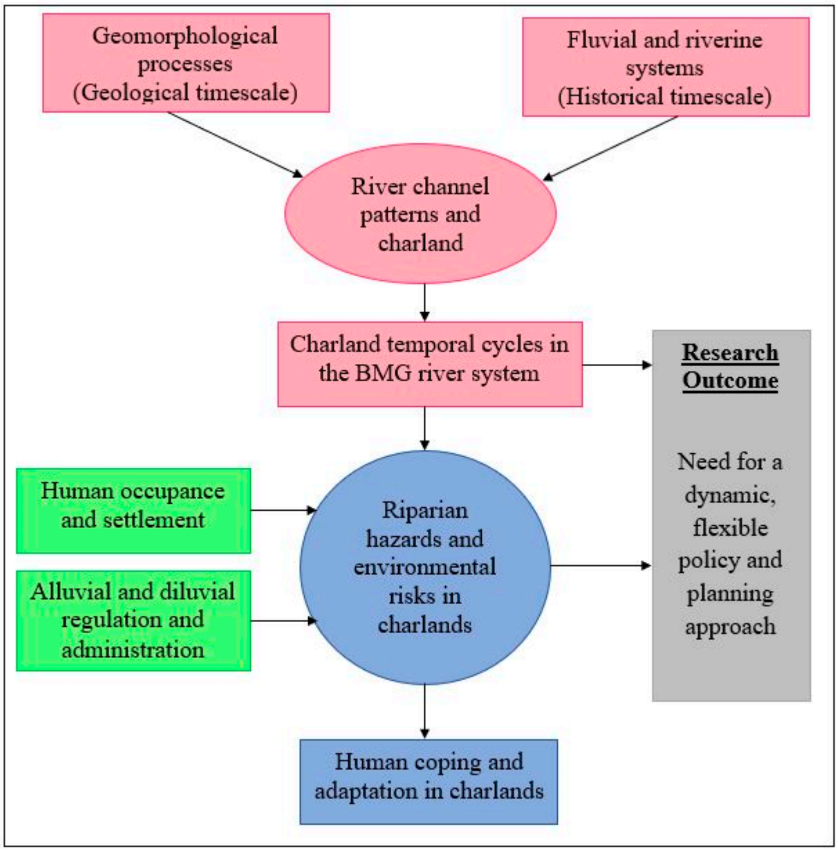

Figure 1. Interdisciplinary conceptual framing of the present study.

The 147,570 sq. km territory of Bangladesh, which consists primarily of deltaic and floodplain formations, is among the most rapidly changing landform systems in the world. Water bodies and water flows in Bangladesh are present in various forms, providing an ecological context characterized by fertile land and an ample supply of fresh water. These water bodies include river flows as well as *beels* and *jheels*, which act as water reservoirs that support the livelihoods of millions of people. More than 700 rivers, including three of the mightiest and largest river basins in the world, drain more than 140,000 cu m/s (4.9 million cu f/s) into the Bengal Basin during the monsoon period, with nearly half of this water volume entering the basin during the dry winter season. Beginning in the Himalayan Mountain ranges and covering a catchment area of 1,650,000 sq. km [3], these river systems carry down a total of 1 trillion cubic meters of water and sediment at a rate of 1 billion tons annually [2,3], helping the delta deposits in the Lower Meghna River estuaries.

Over millennia of evolution, the dynamic river channel systems of the Bengal Basin have created one of the largest deltas in the world through the deposition of bedloads and suspended sediments, as well as highly complex drainage systems characterized by both *braided* and *meandering* rivers. River channel migration, the formation of mid-channel sand bars and shoals (*char*land), and rapid riverbank slumping are the main drivers of the dynamic delta-building process. Although riverbank slumping and erosion result in land, settlement, and crop losses each year, this eroded land re-emerges down stream to form small islands—known locally as *chars*—which provide new opportunities for resettlement and livelihood reconstruction.

*Char*land management in Bengal has historically been hampered by disputes, violent conflicts, and local and regional political influence [4–7]. Since the Permanent Settlement of the late 18th century in British India, the *char*lands have fallen under the legal jurisdiction of the state or certain individuals, with no satisfactory provisions for the re-settlement of people displaced by river erosion and flood disasters. As Sarker et al. [3] have observed, the people displaced by riverbank erosion along the *chars* have no other option but to settle on accreted land nearby, thereby creating a unique socioeconomic and sociocultural environment. In addition, Sarker et al. [3] further found that these displaced populations generally have minimal access to education, health, and extension services to help them cope with catastrophes related to flooding and erosion. Drawing upon his experiences over more than half a century researching the *char*lands and their approximately 2 million inhabitants, Hugh Brammer [8] argued that the interests of the *char* inhabitants would best be served through a balanced approach based on the use of environmentally friendly structural interventions to fortify embankments. Given the dynamic *char* environment and its resultant uncertainty, it would be prudent to explore the potential benefits of participatory research and adaptive planning strategies. While the inhabitants of both mainland and *char*land areas have adapted to these dynamic socioecological conditions over centuries and created new avenues through local and indigenous innovations, their documentation and analysis have largely remained poor and scant.

The present study addresses the above-discussed knowledge gaps by focusing on three key research topics: the dynamic features of the physiographic and riparian systems of the Bengal Delta; the historical and contemporary evolution of the legal and management systems governing eroded (*diluvion*) and accreted (*alluvion*) land in Bangladesh; and the policy and planning implications of learning from *char*land dynamics and the inhabitants' adaptive capacity vis-à-vis institutional interventions. The energy of a river causes diluvion or erosion of the bank, bed, or headward soil. There are three types of diluvion or erosion in rivers: headward erosion, vertical erosion, and lateral erosion. Erosion occurring in rivers is driven by several processes, including hydraulic action, abrasion/corrasion, attrition, and corrosion. The term, alluvion, is derived from the Latin word "alluvium", which means to "wash against". Deltas are formed by the accumulation of sediment deposited in floodplains and estuaries by rivers when their velocity slows due to changes in their gradients and/or standing bodies of water.

2. Methods

2.1. Study Area

The geomorphological context of the present study is the Bengal Basin, which occupies about 200,000 sq. km of territory in India, Sikkim, and Bangladesh and is bordered by the Himalayas to the north, the Shillong Plateau and the Arakan Yoma to the east, the Rajmahal Hills to the west, and the Bay of Bengal to the south (Figure 2). Thus, the Basin extends from the northeast to the southeast through the Garo-Rajmahal Gaps. Given the basin's immense area, this study concentrates primarily on the lower quarter of the basin, extending from the Indian border along the Ganges River near the district of Rajshahi to the Brahmaputra-Jamuna River from the Indian border near Kurigram, and through the Padma and Upper and Lower Meghna to the southern islands of Bangladesh (Figure 2).

Figure 2. Geographical setting and location of the Bengal Basin and the Ganges-Brahmaputra-Meghna River system. Source: Modified from Esri, HERE, Garmin, FAO, NOAA, USGS, @ OpenStreetMap contributors, and the GIS User Community.

Kazipur Upazila (sub-district) in Serajganj District (located along the Jamuna-Brahmaputra River) and Shibchar Upazila (located along the Ganges Padma River) were selected as the two focal points for the empirical case study examining the adaptive strategies employed by inhabitants of the basin. These Upazilas were selected because a large proportion of the geography in these locations consists of *chars* and river channels that are subject to erratic shifts due to erosion, riverbank slumping, and deposition.

2.2. Sources of Data and Survey Methods

This study was designed to generate three types of data. First, inventories of the geological, fluvial, and morphological features of the rivers and the land were created using various international archival sources and web-based search engines. Second, a set of historical data relating to land tenure systems in colonial Bengal and post-colonial India and Bangladesh was generated via extensive archival and web-based bibliographic searches. And third, data sets were generated for Kazipur Upazila based on empirical sociodemographic and socioeconomic surveys conducted by the first author of the present study and for Shibchar Upazila based on the work of Islam et al. [9]. In the Kazipur Upazila study, a total of 320 randomly selected households (247 located on *char*land and 73 (the control group) located on the mainland) were surveyed. The surveys were conducted with the head of the household using an interview format and a structured questionnaire [9]. This empirical study was approved by the University of Manitoba's (Canada) Joint Faculty

Research Ethics Approval Board. In the Shibchar study, a total of 101 *char* inhabitants were randomly selected and interviewed.

2.3. Data Analysis

The historical and existing literature was synthesized to map the historical processes that have shaped the evolution of the major rivers and land, the *char*, and overall delta formation in the study area (i.e., present-day Bangladesh) (REFS). The analysis of the river and land-formation systems and the *char*-formation processes enabled an in-depth investigation of the basin's major hydro-morphological characteristics. The findings of recent studies on water levels, discharge, and sediment transportation were compiled and analyzed using triangulation (i.e., cross-validation). In addition, the Landsat (TM and MSS) images used in the ISPAN study [10] to analyze the erosion, accretion, and widening of the Brahmaputra-Jamuna River were employed to provide current concrete evidence of the dynamism characterizing the shifting of the river channel and the formation of floodplains and deltas. Further concrete examples were substantiated using Coleman's [11] and Stene and Haque's [12] studies of major river channel migration over longer periods. The socioeconomic empirical data were processed using Statistical Package for the Social Sciences (IBM-SPSS Version 29, Chicago, IL, USA) software and analyzed using non-parametric statistical tests.

3. Dynamic Bengal Delta and Charland Formation and Its Associated Hazards

3.1. Morphology of Bengal Delta Formation

This section begins by examining the geomorphologically active and unstable character of the Bengal Basin region, particularly in relation to its land and related forms (e.g., the formation and erosion of *char*lands in the Bengal Delta and riparian floodplains). In doing so, we highlight the active tectonic, hydrological, and morphological properties of the Bengal Delta and the fluvial systems of the Ganges-Brahmaputra-Meghna (GBM) rivers. Next, we analyze the differences in the formation of *chars* within the Bengal Basin's diverse geomorphological regions, followed by an overview of the historical evolution of the land tenurial system, human habitation, and institutional (e.g., the state) management of *char*land.

The Bengal Basin is situated at the confluence of the Indian, Burma, and Tibetan (Eurasian) plates (Figure 2), occupying an area of about 200,000 sq. km. The present-day territory of Bangladesh accounts for about 25% of this area. As Alam and Curray [1] have observed, in the Indian sub-continent, a considerable volume of orogenic sediment was transported down through the basin from the eastern Himalayas in the north and the Indo-Burman Ranges in the east during the Tertiary-Holocene period, resulting in an extra 20 km of sedimentary deposits in the basin (Figure 2). Recent research findings based on stratigraphic and developmental analyses have revealed that tectonic factors and the supply of sediment have influenced the Ganges-Brahmaputra-Meghna systems more profoundly compared to other major delta systems [13]. According to Goodbred et al. [13], tectonics function as a critical continental control in the deltaic system of the Ganges and Brahmaputra rivers. This role is mainly filled by active tectonics (i.e., tectonic-plate-related activities versus passive-sedimentary tectonics), which change the formation of the delta in the Basin area and affect sedimentary volume and distribution.

In studying *char*land formation, it is important to identify and analyze critical elements associated with recent tectonic and fluvial sedimentary activity. In addition, these elements are also relevant to delineating patterns in land occupancy, ecological changes, and the changing needs of development planning. One excellent example of a recent tectonic event is the intense earthquake that occurred in 1950 in Assam, India (Richter mag. 8.7), as it severely impacted the middle and lower reaches of the Brahmaputra River. The 1950 earthquake noticeably altered the slope and physiography of the northern regions of Bangladesh and changed the courses and morphological characteristics of several tributaries of the Brahmaputra River [14].

Elsewhere, Poddar [15] notes that the 1950 Assam earthquake also caused slope failures, which resulted in the deposition of large volumes of sediment into the Bengal Delta and caused a considerable rise in the sediment load in the estuaries of the Ganges-Brahmaputra rivers (forming *chars* in the Noakhali district of Bangladesh) in the following years. Several other tectonic features and events have significantly impacted the deltaic system of the Basin, influencing the drivers of river channel courses, avulsion, sediment distribution, faulting, earthquakes, and other tectonic activities. Fergusson [16] found that a vertical displacement near Mymensingh, Bangladesh, was caused by the 1782 earthquakes in the Sylhet region and that this tectonic event had contributed to the avulsion (a process of gradual land erosion and river channel shift) of the Brahmaputra River. As recorded in then-surveyor Major James Rannell's maps, the main channel of the Old Brahmaputra River completed its shift from its previous course east of the Madhupur Terrace region to its current channel (i.e., as the Brahmaputra-Jamuna River; also see [7]) between 1782 and 1830.

The large sediment load, which initially (from the Pliocene onwards) arrived from the west and northwest and later (since the later part of the Pliocene and Pleistocene) from the eastern Indo-Burman ranges, filled the Bengal Basin, contributing to the formation of very complex deltaic and riparian systems. Curray and Moore [17] estimated various parameters of the undersea fan of sediments carried down from the Himalayas by the Ganges-Brahmaputra-Meghna system, determining a width of approximately 1000 km, a depth of over 12 km, and a length of more than 3000 km. These major rivers comprise the surface of the Bengal Basin.

3.2. Fluvial-Riverine Systems

Understanding the dynamic nature of land and *char* formation in Bangladesh requires attention to the geomorphic settings, patterns in historical shifts in river courses, and the processes of *char*land accretion (deposition) and erosion. On rounding the Rajmahal Hills, the Ganges River flows into Bangladesh near Rajshahi and moves east and southeastward until it meets the Brahmaputra-Jamuna River in Manikganj district. After joining the Brahmaputra-Jamuna River, the Ganges continues on until it meets the Meghna River near the city of Chandpur, becoming the Padma River [6]. Spate [18] divided the Ganges Delta into three areas: the *moribund*, *mature*, and *active* regions. The moribund and mature regions capture most of northwestern and north-central Bangladesh, including Kushtia, Jessore, Faridpur, and northern Khulna. As such, these zones do not receive extensive silt or diluvion deposits [19].

Over the last 300 years, the morphologies of the moribund and mature delta regions have been profoundly impacted by the eastward migration of the Ganges' main channel, as it served as the primary driver of geomorphological and hydrological changes for these areas (Figures 3 and 4). These sequential shifts and the dynamics of the moribund and mature delta-building processes have been described in detail by Ahmed [20], Haque [7], and Akter et al. [2]. In their work, Sarker et al. [3] pointed out that the Ganges and the discharges from the Old Brahmaputra and Meghna Rivers flow into two distinct estuaries, contributing to delta formation (Figure 4). As can be seen in James Rannell's map, which was produced based on land surveys conducted from 1764 to 1776 (Figure 5), the Ganges estuary was located close to the northern upstream reach of the Tetulia River. After the Ganges estuary joined with the Brahmaputra-Jamuna River, which occurred by 1830, the active delta-building estuary shifted towards the east, resulting in the formation of both the moribund and mature regions of the delta (Figure 6).

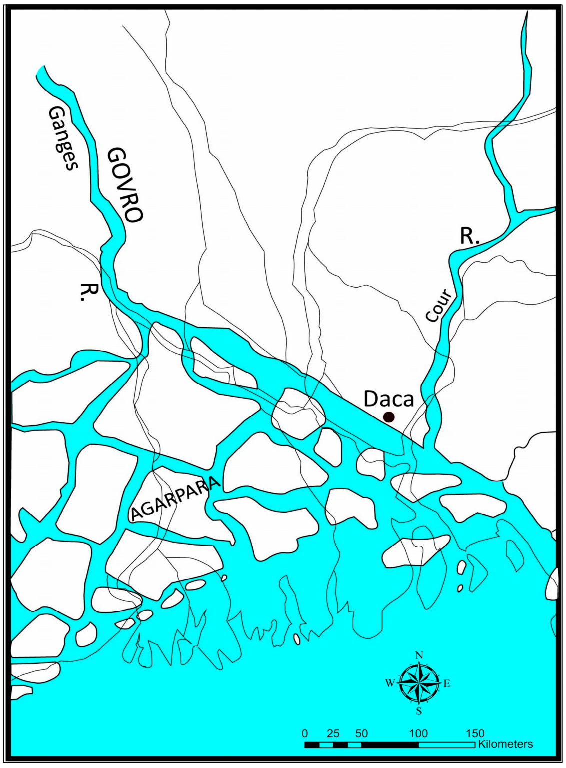

Figure 3. Jao de Barros's map (1550 AD).

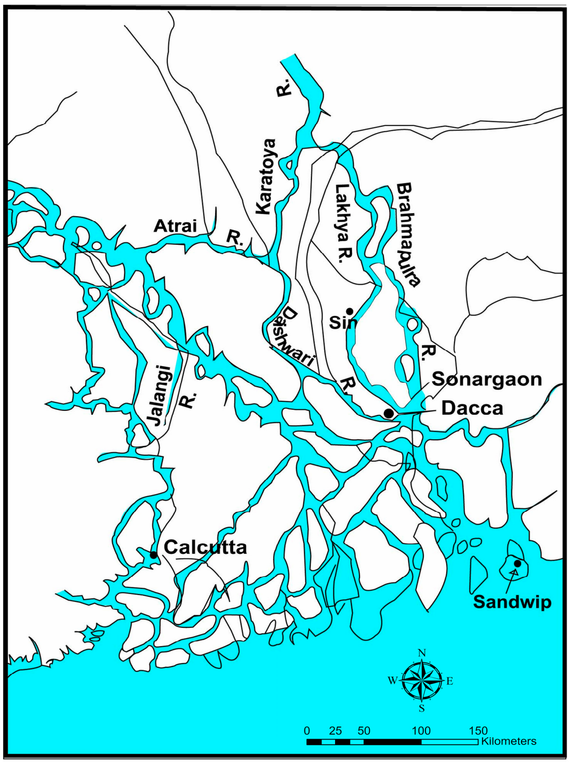

Figure 4. Van den Brouche's map (1660 AD).

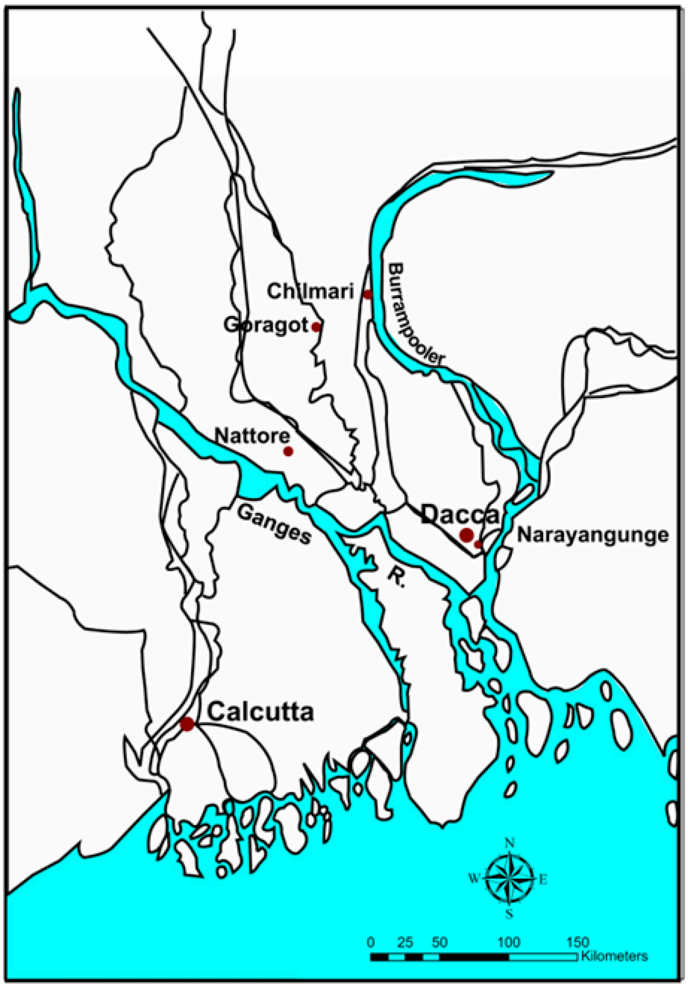

Figure 5. Major James Rennell's map (1764–1776).

3.3. River Channel Patterns and Charland Formation

The characteristics of river channel patterns, which can be categorized as either *straight*, *meandering*, or *braided*, are largely determined by various geomorphological variables, such as the slope, discharge, and bed material size [21–23]. Several scholars have classified both the Ganges and Brahamaputra-Jamuna Rivers as having *braided channel patterns* (based on a bird's eye view of channel configuration), as the presence of *chars* divides these rivers into multiple channels, which alternately converge and diverge over the river's length [11,14,24]. The primary characteristics of braided channels include highly variable discharge, bed-load abundance, easily erodible banks, steep slopes, and mid-channel bars, shoals, and islands (*char*land) [25]. Generally, these islands are seasonally unstable.

Zaman and Alam [26] estimate that about 20 million people live on *chars* in the floodplains of the major river systems in Bangladesh's coastal regions. These *char*lands are isolated both geographically and socioeconomically, being characterized by a dearth of services and pockets of poverty-stricken communities. The soils of the northern regional and mid-channel island *chars* are generally sandy and silty, with low water-retention capacity and minimal organic matter [15,27]. Thus, crop yields are low on these *chars*. In contrast, the composition of the soil in coastal *chars* tends to feature more clay content. Furthermore, the soil of these *char*lands also tends to have high salinity, which restricts agricultural production to one crop per annum, mainly *aman* paddy during the monsoon season.

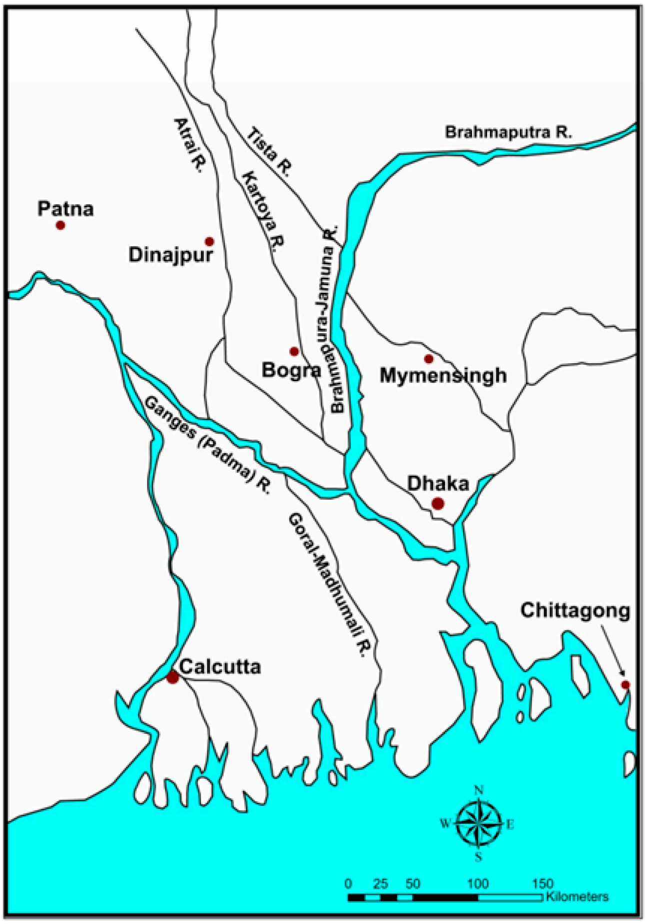

Figure 6. Recent Ganges-Brahmaputra-Meghna river systems.

The large islands of Ramgati, Hatya, Bhola, and Sandwip were created over the last few centuries in Bangladesh's *active* delta region, which occupies the majority of the coastal plains area (Figures 3–6). In the deltaic plains, the erratic nature of the fluvial morphology results in landforms with very dynamic features, which cause them to be highly unstable and unpredictable over time. During the monsoon, the land in this region becomes inundated with water, making the formation of new land (accretion) from deposited sediments a key outcome of delta-formation processes. These features are more noticeable in the Meghna-Tetulia-Shahbazpur distributary systems than in other systems [6].

Hugh Brammer [8,15] has provided some insightful explanations regarding the erratic and intricate features of these estuarine *chars*. For instance, he asserts that the "old land" on the older islands is characteristically different from the land on the newer *char*lands (for example, *Bhasan char*). Brammer observes that the old chars are likely several centuries old and therefore usually have well-developed soil and fresh groundwater available. In contrast, salinity is a major problem in newly accreted *chars*. In addition, the soil in newer *chars* is comparatively undeveloped, thus making these areas very unfavorable for cultivation and settlement. In the Meghna estuary, which covers the Lower Meghna floodplains and the coastal plains, the yearly accretion rate is about 45 sq. km of new *char*land, while 25 km^2 of land, chiefly the settled areas, is lost to erosion. Thus, although there is an annual net addition of 20 sq. km of land in the region, this process results in the critical loss of valuable cultivable and settled lands. Consequently, land and settlement provisions are quite unstable in these estuarine *chars* (also see [28]).

The early maps show that, in the early 19th century, the Brahmaputra-Jamuna River had a *meandering* channel pattern [3,23]. Nonetheless, by 1830 AD, it had become a *braided* river (Figure 6) as a result of the continuous geomorphic process of channel widening. The current reach of the Brahmaputra-Jamuna River in Bangladesh is clearly *braided*, as its numerous channels persistently shift over time due to the erosion of riverbanks and *chars*. These river channels are concurrently engaged in depositing alluvium and forming accreted land. Locally, this new alluvial land, either within or at the channel sides, is called *chars* [28]. The constant erosion and accretion of the Brahmaputra-Jamuna and the formation of unstable *char*lands create a high degree of uncertainty, particularly regarding settlement [3,8]. Both within and alongside a channel, the formation of *char*land begins as sandy shoals created from deposited sediments. In terms of shape, these formations are commonly linear or close to elliptical [8]. In turn, these new formations divert the flow of discharge against the opposite bank of the channel, resulting in continuous undercutting and erosion. Lateral erosion rates along the Brahmaputra-Jamuna River are spatially varied. The extent of yearly lateral erosion is commonly less than 200 m; however, the rate is so variable that, in one single year, it can reach as high as 1 km. In general, the channel-widening processes are ongoing, with a westward shift in the main channel.

3.4. Charland Temporal Cycles

Sarker et al. [3,23] and Brammer's [8] studies offer insightful explanations of how the morphological characteristics of rivers influence the dynamics of *chars*. The findings of these studies revealed that *char*land settlements in the Bengal Basin are impacted by two major factors: (i) the duration of *char*land accretion in years (i.e., the age), and (ii) the legislative and legal status of eroded and accreted land. Some of the old *chars* in the Meghna estuarine region were attached to the mainland prior to Rennell's surveys in the late 18th century. Rennell's surveys illustrated that it was possible for anyone to travel from the Vikrampur area to Dhakshin Shahbazpur (presently Hatiya Island) without interruption by any major river. In the absence of any specific land and settlement records, it is plausible that some of the large old islands were populated as early as the 15th–18th centuries (i.e., the Mughal period).

Nonetheless, the *chars* in the active delta region of the estuary were formed only in recent times. Brammer [8] insists that groundwater quality (i.e., its salinity or lack thereof) is an effective yardstick for determining a *char*'s suitability for relatively permanent human habitation or other temporary socioeconomic activities. Locals are aware of these attributes and adapt themselves according to the dynamism of the *char*land morphology. Focusing on the context of the Brahmaputra-Jamauna and Ganges-Padma Rivers, Sarker et al. [3] argue that it is crucial to differentiate between *island chars,* which are commonly surrounded by water throughout the year, and *attached chars*, which become connected with, and thus are part of, the mainland under normal discharge and flow conditions. However, it has been observed that the abandonment of any outflank river channel can cause an island *char* to become an attached char [28,29].

In a recent ISPAN [29] study of the *char*land formation processes along Bangladesh's major rivers, satellite imagery showed that the Ganges-Padma and Lower Meghna Rivers are characterized by a mix of *meandering* and *braided* channels (i.e., wandering rivers), resulting in more stable *chars* in these basins compared to the Brahmaputra-Jamuna River system (Table 1). In general, the *chars* in the Brahmaputra-Jamuna River are relatively new formations, with more than two-thirds being less than 6 years old and three-fifths (60%) "persisting" between 1 and 6 years. In 2000 AD, *chars* that had persisted for more than 27 years accounted for only 2.2% of the total *char* area within the bank [28,29]. The Meghna River system contains numerous channels that discharge into parallel streams, and any of these streams can function as a single *meandering* river. Consequently, the *chars* in the Upper Meghna region are relatively stable. Notably, most *chars* in this region are island *chars* that have endured for over 70 years.

Table 1. Measurement of changes in landforms and waterbodies in major river systems in Bangladesh, 1984 and 1993.

Item	Total Water Area (ha)		Total Sand Area		Total Vegetated Land (*chars*) (ha)		Total Area within the Banks		Ratio of Attached *Char* Area to Island *Char* Area
Year	1984	1993	1984	1993	1984	1993	1984	1993	1993
Brahmaputra-Jamuna	55,740	61,240 [a]	54,010	70,240 [a]	89,580	98,760 [a]	199,330	230,240	1.00
Change		*+5500*		*+16,230*		*+9180*		*+30,910*	
Ganges	28,620	28,980	36,230	35,660	24,350	35,560	89,200	100,200	1.56
Change		*+360*		*−570*		*+11,210*		*+11,000*	
Lower Meghna	45,610 [b]	57,680 [b]	-	-	11,070	18,070	56,680	75,750	All are island chars
Change		*+12,070*				*+7000*		*+19,070*	

Note(s): [a] Calculated based on 1992 data. [b] figure shows area of water and sand. Sources: [1,24].

Several studies have examined the temporal cycles of *char* formation in the large estuaries of Bangladesh [10,30,31], concluding that the accretion and erosion of *chars* in the Meghna estuary will remain unstable in the foreseeable future. Furthermore, these works found that, while river-dominated forms (i.e., bird-foot planform) of energy prevail in the Mississippi Delta (USA), high tidal energy significantly affects the morphology of the Meghna estuary. The dynamic and erratic nature of the Meghna estuary and the unstable formation of new *chars* are the outcomes of voluminous sediment inputs from upstream and high tidal energy from downstream (also see [28]). This is supported by Akter et al. [2], who observe that the Meghna estuary experiences the erosion and accretion of several thousand sq. km of land each year. As such, it is plausible to expect that instability caused by high tidal energy will continue to characterize the *chars* emerging downstream of the Meghna estuary.

3.5. Channel Shifting and Bank Erosion

In a *braided* river like the Jamuna-Brahmaputra, three types of channel shifting generally take place: (1) the gradual migration of the major flow channel; (2) the rapid shifting of the major flow channel at times of cut-off progression; and (3) the sudden creation of new flow channels [32]. Relying on historical maps, Coleman [11] charted short-term bankline shifts of the Brahmaputra-Jamuna River between 1944 and 1963 (Figure 7A,B), finding that the channel of the river had widened from 7.2 km to 12.1 km at the junction of the Old Brahmaputra during this period. These findings were supported by Tarafdar [33], who observed that, at one reach, the lateral movement of the bankline was as rapid as 13 km over a four-year period. For greater reliability, Coleman [11] further bifurcated the study into two periods: 1944–1952 and 1952–1963. Coleman found that, from 1952 to 1963, the most erosion occurred in Shaghata Upazila (station 7) and the maximum deposition took place at 5700 m near the Porabari of Tangail (station 20). Ultimately, Coleman concluded that "within the [study] period bankline migration was not predictable but, rather it was erratic". Elsewhere, Stene and Haque [12] used Landsat imagery and data for the period spanning 1976–1983 to measure the migration of the west bankline (Figure 7C). Their findings revealed that bankline migration averaged 120 m per year and that nodal points existed along the river at reaches where minimal bankline movement took place. Additionally, they found that a greater number of stations along the right bank experienced erosion compared to the left bank (Figure 7C).

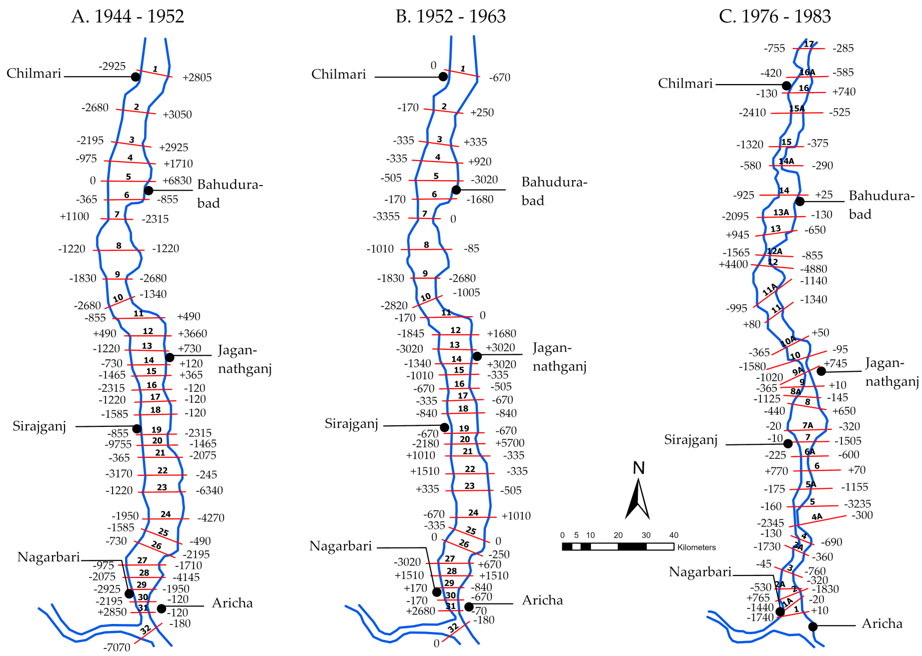

Figure 7. Bankline migration of the Brahmaputra-Jamuna River, 1944–1952, 1952–1963 [11], and 1976–1983 [12].

The ISPAN study of *char*lands [34] examined migration trends from 1830 to 1989, which yielded results that confirmed the overall westward channel migration of the Brahmaputra-Jamuna River. By assessing successively plotted center lines, the ISPAN study determined that, since 1830, the overall center line migration across 20 reaches (each 10 km long) has ranged between 18 and 31 m per annum (Figure 8).

The process of bankline recession in the Brahmaputra-Jamuna River involves the liquification and flowage, or searing away, of the bank material. Thorne [35] explained that flowage failures occur due to variations in pressure between the flood season and the floor recession period. Most shear failures take place due to water pressure that undermines natural levee deposits. Coleman [11] found an average of "five slums per mile over a 30 mile [nearly 50 km] stretch of bankline" on this river and further observed more than 10 bank failures per km in some reaches.

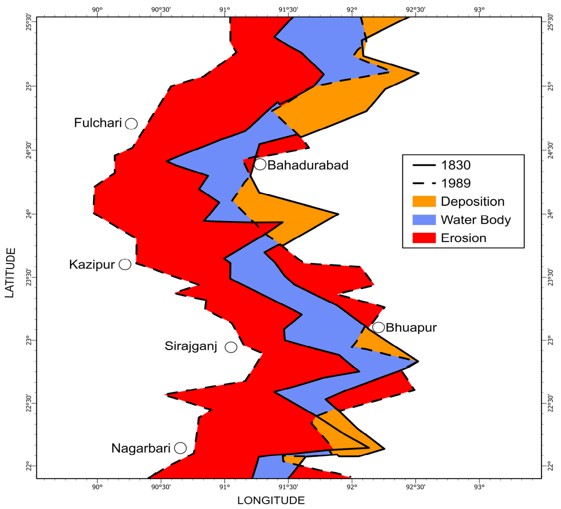

Figure 8. Historical bankline changes of the Brahmaputra-Jamuna River, 1830–1989 (after [36]).

4. The State, the *Permanent Settlement* Scheme, and Administration of Alluvion and Diluvion Regulation

Historically, human habitation of the plains and *chars* of Bengal territory has been influenced by societal and physical factors, including the geomorphological dynamism that drives most aspects of the delta building process, river channel shifts, and the distribution of land and water. With regards to societal factors, state-driven land tenure and legal systems significantly impact social relations and resource entitlements, which have profoundly influenced human occupancy in this region [7,8]. It is critical to note that these factors function interactively. For example, during the 18th century, the sociopolitical spheres of Bengal experienced notable changes, including major alternations in the river systems. Significantly, the takeover of Bengal by the British East India Company in 1757 marked the beginning of major sociopolitical and tenurial changes. Among the various claimants for the settlement of the land, Hindu *zamindars* (landlords) were the Company's preferred class. As such, the *zamindars* were granted land tenure, along with the authority and responsibility to collect revenues and taxes [37]. Notably, it was presumed that the availability of permanent habitable structures and fixed assessments would persuade individuals to reclaim massive areas of potentially arable wasteland, including *char*lands, thereby increasing the tax base. Thus, the Company approached and made agreements with *zamindars*, *talukdars*, and the "actual proprietors" of the land. In 1793 AD, this strategy was implemented all over Bengal by the Company via a proclamation known as the "Permanent Settlement Scheme".

Within three decades, the role and policies of the British Raj (the state) in administering areas of Bengal changed substantially, with several new regulatory provisions and features. For example, in 1825 AD, the Bengal Alluvion and Diluvion Regulation was enacted, which had profound implications for riparian land ownership [7]. Prior to this legislation, claims to ownership of alluvion and diluvian land were regulated by local customs and titles [38]; however, in the cases of established and clearly recognizable matters, the 1825 Regulation made provisions for claims and disputes regarding alluvion land to be decided based on the local use of *payasti* (alluvion) and *sikosty* (diluvion) [39–41]. In fact, the goal of this Regulation was to protect the common interests of the *zamindar* and large landlords, who had formed something of a coalition during the British colonial regime. Consequently, accreted lands from receding rivers were annexed to the tenure of the individual whose estate they adjoined [40]. However, a submerged estate that became attached to an adjoining estate would retain its legal standing upon re-emerging (i.e., the adjoining estate would not assume control) [8].

The Act of 1950, known as the "East Bengal State Acquisition and Tenancy Act" (EBSATA), was introduced following the Partition of the Indian sub-continent in 1947 AD with the aim of abolishing the Permanent Settlement scheme. The Act introduced several constraints on the restoration of lands lost to diluvion to their former owners, of which the two main ones were: (i) the restoration was legal if it occurred within two decades following the diluvion; and (ii) such restoration was legal only if the possession of the land area was held by the rent receivers or cultivating *raiyats* (section 20 of the 1950 EBSTA) and fulfilled the constraint of transfer of holdings up to a maximum of 50 hectares (125 acres; section 90 of the 1950 EBSATA) [7]. The Act stressed the de facto possession of the land and revealed the rise of Muslim landlords as the primary sociopolitical and economic power in the riparian areas of Bengal. The process replaced most of the Hindu *zamindars*, the overwhelming majority of whom had become absentees by then.

Post-Independence (1971) Land Reforms

Understanding the recent (post-independence) land reforms and their implications for riparian land management requires an examination of the historical roots of social differentiation in Bengal. A process of rapid social differentiation started in Bengal in the late 18th century (i.e., the late Mughal period) [42]. During this process, a deeply embedded pattern of revenue demand from the peasant cultivators emerged, undercutting the traditional bonds that had been formed and structured by the Hindu caste system over centuries. The steady rise in the proportion of marginal and landless farmers resulted in new social relations that evolved around land-based power politics. As a result, unequal power structures and relations were gradually established in rural Bengal, with land being controlled within a "patron-client" or "headman-subordinated follower" framework [43]. Zaman [43] has asserted that such asymmetrical power structures were more conspicuous in *char*land areas than in other riparian areas of Bengal.

Recognizing the issues arising from the increase in landless peasants, the post-Independence (1971) national government formulated new policy measures aimed at reclaiming the control of alluvion lands from the *jotedars* (large landlords) and redistributing them among the landless and small landholders (i.e., those owning less than 15% of a hectare of land). To encourage farmers' cooperatives and other forms of collective farming, the Presidential Orders of 1972 (# 72, 35, and 135) were enacted, which called for all newly emergent lands previously lost to diluvion to be reinstated to the government as *khas* (public) land instead of being tenured to the original owners [7,8,44]. Consequently, all *char*lands, irrespective of whether they were formed in situ or via new accretion, were to be considered *khas* land.

There have been several modifications to alluvial land tenure policies in recent decades. For instance, Presidential Order No. 135 of 1972 was amended in 1994 to include provisions for the abatement of rent lost due to diluvion and the maintenance of the right to land re-formed in situ for three decades, which would be subject to a ceiling of 8.09 hectares (20 acres) [8]. As Zaman and Hossain [45] explain, the owner must obtain a certificate from the revenue authority to claim the new land and pay rent to occupy it. If the land re-emerges after three decades, it will be vested in the government as *khas* land. This considerable temporal gap of 30 years gives powerful local individuals and/or groups a distinct advantage in gaining the rights to newly accreted land prior to surveys and settlements.

5. Contemporary Land Management Policies Relevant to *Char*land Inhabitants

5.1. Contemporary Land Laws and Regulations

Among the voluminous documents on contemporary land administration and management directly relating to *char*land ownership, use, and management, Islam et al.'s [9] and Hossain's [46] studies are the most useful for the purposes of the present discussion. In this section, these studies are employed to provide a synthesis of the contemporary land laws and regulations relating to land use, transfers, acquisitions, and resettlement.

In Bangladesh, existing legislation and regulations allow for the ownership of land by individuals, cooperatives, and the state. The security of land interests and rights is associated with agricultural production—and thus, food security—on the one hand, and the social security of vulnerable groups on the other. Presently, the tenancy, rights, and liabilities of agricultural and non-agricultural land are regulated by the 1950 EBSATA and the 1949 Non-Agricultural Tenancy Act, respectively. *Maliks* (owners) or *raiyats* are the only holders of agricultural land, with their rights and liabilities being clearly outlined in section 81(1) of the 1950 EBSATA. However, *maliks* or *raiyats* are not entitled to any interests in the sub-soil, including the rights to minerals [9].

The 1984 Land Reform Ordinance capped future land acquisition at 8.49 hectares (21 acres) and established sharecropping as the only acceptable form of tenancy contract. In 1997, the Agricultural Khas Land and Settlement Policy was enacted to distribute *khas* land to the landless on 99-year leases [47]. An investigation by Tariquzzaman and Rana [48] revealed that, as a political act rather than a legal one, the process determining the acquisition of *khas* land has favored the interests of the prevailing elites. Since a considerable portion of *khas* land has been illegally occupied and "owned" by such elites, government ownership and control over such public lands have been minimal. Notably, numerous studies have observed that such land grabbing has been more acute in the *char*lands compared to other areas [10,44]. As Feldman and Geisler [49] state:

> *State policies and their implementation, particularly in the countryside, continue to be plagued by various forms of corruption and an elite and bureaucratic formation that has been unable to mediate—and in fact, takes advantage of—the costs of neoliberal reforms*

> *that have privatized and decentralized form of rule that were once part of local systems of accountability.*

In the context of *char*land areas, Feldman and Geisler [49] further observe that the poor inhabitants typically remain in flood-prone and *char*land areas, often becoming "displaced in place", as they are among the most likely to gradually lose access to land they once cultivated or lands that emerge after diluvion. Such in situ displacement is characterized by a considerable loss of life support services and the functioning ecosystems upon which the producers' livelihood depends. Critically, displaced families are often forced to move to cities, slums, or designated settlement areas, where they must compete with the existing inhabitants, thus increasing the pressure on urban or fringe area land use as well as other infrastructure and services.

5.2. Regulations on Land Use, Acquisitions and Resettlement

In response to the critical need for regulatory interventions, the Government of Bangladesh introduced the 2001 National Land Use Policy, which provided clear guidelines regarding various forms of land usage, including agriculture, housing, afforestation, commercial and industrial, rail and highways, and tea and rubber farming. The plan's key policy objectives relating to *char*land areas aimed to stem the alarming loss of agricultural land, protect *khas* land, outline distinct land zoning criteria, and establish a data bank for *khas* land, fellow land, acquired land, and *char*land to ensure their effective utilization.

Here, land acquisition by the government for large-scale infrastructure, development projects, and resettlement schemes is particularly relevant to riparian and *char*land areas. At present, the Government of Bangladesh uses the 1982 Land Acquisition and Requisition of Immovable Property Ordinance for such purposes [46,50]. This 1982 Ordinance has its roots in the British Colonial Land Acquisition Act of 1894, which was used to colonize unsettled lands and collect revenue, and the 1989 Act provides the District Collectors with additional authority to acquire property on an emergency basis; however, this power is limited only to projects related to flood and flood control infrastructure [50]. As Hossain [46] observes, there are significant challenges in applying this ordinance due to its exclusive grounding in the "compensation rationale."

Although millions of people are being displaced due to socioeconomic pauperization, periodic natural disasters (e.g., floods, riverbank erosion and *char*land diluvion processes, and cyclones), and large-scale development projects, Bangladesh does not have a national resettlement policy at present [50]. As Zaman [50] notes, the absence of such a national policy has resulted in wide variations in resettlement packages and benefits in current projects, as such outcomes rely heavily upon the negotiation intent and skills of individual task managers. Significantly, the resultant inconsistent compensation and resettlement outcomes have fostered agony and frustration among Bangladesh's displaced populations [46,51].

6. Coping and Adaptations to Environmental Risks in *Char*lands

Empirical studies of how *char*land inhabitants cope with and adapt to environmental risks associated with floods and riverbank erosion have revealed a number of distinct strategies [7,9,43,52–55]. Indeed, based on decades of experiential and social learning, local communities have developed and enhanced their *coping capacities* (i.e., their immediate and direct response to an extreme event) and *adaptive capacities* (i.e., long-term change and transformation strategies to strengthen their ability to respond to adverse effects; see [56]) using both indigenous and modern strategies.

6.1. The Kazipur Charland of the Jamuna-Brahmaputra River System: A Case Study

The first author of the present study conducted a pioneering, collaborative, international research project focusing on river channel shifts and resultant population displacement in Bangladesh's mainland and *char*lands. This research endeavor is known as the Riverbank Erosion Impact Study (REIS) [57]. The field studies presented in the REIS were conducted in three *Upazilas* (sub-districts) between 1983 and 1988: *Kazipur* and *Chilmari*, which are located in the Brahmaputra-Jamuna floodplain, and *Bhola,* which is located in the Meghna deltaic plain. Subsequently, the author [7] re-visited Kazipur Upazila and performed a second field study using the same instrument from 1993 to 1994. As the results of the 1993–1994 surveys are more relevant to the present work, an overview of those findings is provided below.

Kazipur Upazila (Serajganj district) is located on the right bank of the Brahmaputra-Jamuna River, which features numerous *chars* across its western channel. The REIS identified numerous coping and adaptation measures undertaken by local communities and institutions to deal with *char*land erosion and slumping hazards. With respect to coping strategies, the inhabitants in the *char*land area resolutely use easily dismountable and moveable materials (e.g., thatch, bamboo, wood, and corrugated iron sheets) rather than brick, steel, concrete, and other modern (*pucca*) housing materials when constructing their homes [7,8]. An overwhelming majority of the respondents (77%; n = 247) used corrugated iron sheets as their roof materials, while many others used thatch, bamboo, and other materials. House structures made of these local materials were found to be much less susceptible to flood loss and riverbank erosion compared to permanent masonry-based structures.

In addition, the *char*land inhabitants of the Kazipur Upazila have developed a multitude of agricultural measures to minimize potential flood impact and riverbank erosion disaster losses (also see [58–60]). The *char*land soils along the Jamuna-Brahmaputra River are generally composed of calcareous loams [19]. Although these porous sandy soils (i.e., *bali*) do not suit *boro* paddy, they do support pulses and other winter crops; as such, growers in the *char*lands follow a cropping pattern that is distinct from those used on the mainland (Table 2; also see [7]). As can be seen in Table 2, most households in Kazipur's *char*land zone grow *aus* paddies, whereas these crops are much less common in the mainland zones. In addition, the results suggest that the *char*lands may be better suited to the cultivation of pulses compared to other winter crops. The variations in cropping patterns between the *char*land and the mainland zones were found to be statistically significant [χ^2 = 148.4 ($p < 0.001$ level)].

Table 2. Frequency and percentage distribution of cropping patterns, by zone, in Kazipur (%) (n = 247; multiple responses possible).

Type of Crop	Charland Zone (n = 247)		Mainland Zone (n = 73)	
	Frequency	%	Frequency	%
Aus (paddy)	230	93.0	26	35.5
Aman (paddy)	189	76.6	66	90.3
Boro (paddy)	37	15.1	59	80.6
Cane	30	1.2	-	-
Potato	58	23.3	35	48.4
Pulses	149	60.5	19	25.8
Oilseeds	85	34.4	49	67.7
Spices	145	58.7	47	64.5

Note(s): χ^2($p < 0.001$; df = 7) = 148.4 (Significant).

Overall, our examination of the cropping patterns in various zones revealed that settlers in hazardous areas (e.g., the *char*land areas) attempt to mitigate the risk of potential crop loss due to natural hazards by investing less financial capital and cultivating low-cost crops. For instance, *boro* paddy and potatoes require relatively higher investment costs with respect to water, labor, and crop management compared to other crops. Consequently, the two crops are cultivated by a substantially lower percentage of farm households in Kazipur's *char*land zone compared to the mainland zone (also see [8]).

6.2. The Shibchar Upazila of the Ganges-Padma River System: A Case Study

The second case study in this paper focuses on the *char* communities in the Ganges-Padma River system and the coping and adaptation mechanisms detailed in the findings of Islam's study [9]. Islam's [9] investigation of hazard profiles in the *Char*-Janajat Union of Shibchar *Upazila* in Madaripur District, which is located on the left side of the Ganges-Padma River, strongly focused on the interconnected relationship between flooding and riverbank erosion. In 2003, a total of 13,958 people inhabited the *Char*-Janajat Union, which covers an area of 84.1 sq. km. Here, it is common for settlements, standing crops, and infrastructure to be regularly inundated by flooding. Large-scale riverbank slumping and land loss often occur in these riparian communities, particularly during times of flood recession, resulting in catastrophic outcomes such as damage to or the destruction of housing structures, standing crops, cattle, and other capital assets (e.g., infrastructure) (also see [8]).

In *Char*-Janajat, families are frequently displaced due to land loss caused by flooding, riverbank erosion, and slumping. Indeed, it is estimated that, on average, 971 inhabitants in each *mouza* (revenue village) are displaced annually due to the loss of household land. Islam found that, among the displaced families, approximately one-third (28.7%) opted to remain in the area and used a coping strategy characterized by recurrent moves and resettlements (Table 3). In line with Haque's [7] study of Kazipur, Islam [9] found that a considerable proportion of the displaced population in the Ganges-Padma River and *Char*-systems preferred to move shorter distances with the expectation of ultimately moving to newly accreted land.

Table 3. Frequency and percentage distribution of causes of displacement and resettlement in *Char*-Jananat Union, Shibchar.

Reasons	Frequency (n = 101)	Percentage
Floods, riverbank erosion, and bank slumping	29	28.72
Unsafe livelihoods	10	9.90
Attracted by sociocultural amenities	19	18.81
Improvement of socioeconomic status	14	13.86
Entitlement to accreted land	10	9.90
Employment and educational opportunities in different location	9	8.91
Opportunity to move to an urban area	10	9.90

Note(s): Source: Data compiled from Islam [9], based on 2003 and 2008 surveys.

The overwhelming majority of households in *Char*-Janajat, Shibchar, had been forced to deal with being displaced seven times previously (Figure 9). Overall, the coping measures and adaptation behaviors of the settlers in the studied *char*land areas exhibit a high degree of experiential learning, in addition to the settlers' strong desire to reclaim lost land and socioeconomic status. In this regard, Wallace [61] suggested that, by choosing to remain close to their place of origin, displaced families attempt to minimize the magnitude of cognitive restructuring required when adapting to a new environment. Similarly, Oliver-Smith [62] explained this phenomenon within the context of the Peruvian earthquake victims, for whom "conservatism [with respect to geographic movement] is predominantly a defensive stance against the incursion of future stress". For such disaster victims, concern for the continuity of socioeconomic support and cultural identity becomes a top priority.

As Zaman [38] rightly asserts, the "cultural-psychological" explanation is not adequate; therefore, the study of such short-distance movements requires in-depth investigation into other underlying factors. Zaman [38] appropriately asserts that the dream and hope of regaining access to accreted land remain the key factors driving the migration decisions of local inhabitants, not conservatism regarding geographic movement. Uprooted households that do not have their own land to resettle or that cannot hope for any material support from their poor relatives or other local institutions have their choices constrained by these factors [28]. For these households, the choices are either to move and become illegal settlers on *khas* lands or to stay in the *char* areas and be dependent on powerful landowners, not only for land and other necessary supports for resettlement but also for low-paid jobs.

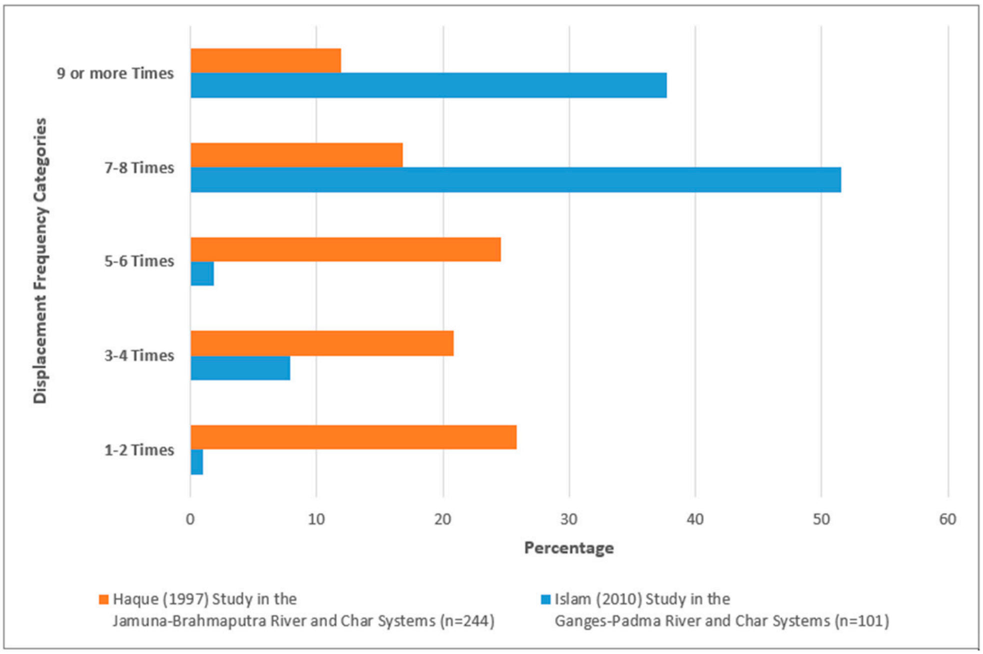

Figure 9. Distribution (%) of the frequency of displacement in the Shibchar area in the Ganges-Padma River and *Char* Systems (n = 101 and Kazipur *char*land of the Jamuna-Brahmaputra River and *Char* Systems (n = 244).

7. Discussion

In this paper, we contend that the Bengal Basin's geomorphological and socioecological systems and associated processes are dynamic and complex, and that, as such, it is critical for mid- and longer-term planning and policy decisions to adopt an adaptive and flexible strategy. The findings of this study reveal considerable variations in the geomorphic and delta-building processes across the major river basins of Bangladesh (see [3,8]). Furthermore, the findings also indicate that the delta-building processes, along with the dynamic nature of river channel shifting, the erosion and accretion of *char*lands, and other depositional features, will continue over the upcoming decades [1,2].

A comprehensive national resettlement strategy is urgently needed (see [50]), as a significant proportion of floodplain and *char*land users are highly vulnerable to displacement due to flooding and *char*land erosion, which in turn results in the serious deterioration of their socioeconomic status [7]. Indeed, Bangladesh currently lacks any effective institutional framework or structure for resettlement planning, implementation, and monitoring. Concerned policymakers should work to improve and effectively implement legislation designed to address these issues and strive to develop a people-oriented institutional framework for assisting families adversely affected by nature-induced disasters and development projects [45,46]. As Zaman [50] observes, resettlement programs in countries with a high population density, such as Bangladesh, should be formulated based on two principles: first, relocation should be based primarily on people's initiative for "self-relocation", and second, the institutions should play a facilitating role by creating conditions that are conducive to geographic movement. Furthermore, democratic institutions should be nurtured in order to ensure effective and responsive legislative frameworks. In this respect, a provision for a neutral national government during the national parliamentary election should be made via a constitutional amendment.

A few recent national policy and planning initiatives relating to land and regional agro-climatic zones are relevant to the present discussion on dynamic, flexible systems-based land and water resource and *char*land planning. The Government of Bangladesh Ministry of Water Resources' 2005 Coastal Zone Policy provided a guideline for working towards achieving sustainable livelihoods, securing access to freshwater, reducing disaster vulnerability, and conserving and enhancing critical ecosystems [63] that considers both socioecological vulnerability and resource potential. The subsequent 2006 Coastal Development Strategy [64] outlines nine strategic priorities, including optimizing the use of coastal land to assist in resettlement and securing the livelihoods of *char*land residents, particularly the most vulnerable displaced people. The primary challenge in this regard is effective implementation, which is largely hindered at present by corruption, nepotism, and the dominance of powerful local elites; only accountable and transparent people-oriented governance with a higher level of adaptive capacity is likely to be able to address these challenges. Unfortunately, Bangladesh ranked 143 out of 180 countries in Transparency International's 2017 Corruption Perceptions Index with a score of 28/100, with 0 denoting the highest level of corruption and 100 the lowest [65]. Empirical investigations have found that, to procure a "work order" for any infrastructure project, it is necessary to allocate 10–20% of the total budget to be paid as bribes to ruling political party leaders, 15–20% to mayors, engineers, and civil managers, and 2–3% to other officials [66]. These barriers can effectively be addressed by ensuring that the judiciary branch exists and functions independently of the legislative and executive branches of government, as well as by involving citizens in the decision-making structure in a participatory manner. Constitutional reform and the strengthening of democratic institutions will be required to ensure the judiciary branch's full autonomy within the governing structure.

Policy and planning approaches to land and water management in the coastal regions of Bangladesh follow a conventional outlook, with sectoral biases. For example, the 1992 Environment Policy called for the jurisdictional authority over newly accreted land to be transferred from the Ministry of Land to the Ministry of Environment and Forests to expedite the stabilization of coastal *chars* via afforestation programs [67]. This policy was followed by the formulation of the 2001 Land Use Policy [68], which tasked the Department of Forestry with planting mangroves as a coastal protection scheme over a 20-year period.

In their 60-year (1962–2022) longitudinal study of Bangladesh's coastal regions based on CORONA satellite imagery, Mahmood et al. [69] found a positive correlation between the increase of mangroves and land stability. Specifically, they observed that approximately 448,011 ha of agricultural land, valued at US $18.8 billion, had been stabilized due to afforestation-related interventions. Furthermore, they found that such programs had enabled the sequestration of 29,756 kt of carbon, thus revealing the multifaceted benefits of Nature-Based Solution (NBS) approaches (also see [70,71]. Although the ultimate objective of stabilizing *char*lands through the planting of mangrove forests is to eventually convert these areas into cultivable land to be distributed among landless displaced families, the successful implementation of this plan remains a major challenge. Involving organizations that represent the landless from the beginning of such afforestation programs could ensure that actual landless families eventually achieve the legal rights required to possess the land.

The recent 2018 Bangladesh Delta Plan 2100 recognizes the dynamic nature of *chars* and, thus, the need for adaptive, flexible planning and management systems [72]. The Delta Plan acknowledges that the complexity and dynamic nature of the "Bangladesh [D]elta necessitates a long terms plan to address challenges and realize the opportunities of Bangladesh Delta" [73] and aims to achieve a "safe, climate resilient and prosperous Delta" by 2100.

Several studies have noted that the results of general circulation models suggest that future warming of the global atmosphere, caused by an enhanced greenhouse effect, will increase monsoon precipitation in South Asia [74]. Recent regional models have projected that, by 2030, temperatures could rise by 1–1.25 °C during the monsoon season (April–September) and by 1.25–1.5 °C in the dry season, resulting in a 10–15% increase in monsoon rainfall and a 14–24 cm increase in sea level [75]. Brammer [8] argues that such changes would affect the interior floodplain areas in the south-central region of the country by creating deeper floods than in normal periods. Therefore, longer-term adaptation policies and actions that account for enhanced flood levels and longer durations are required. The Delta Plan represents a significant milestone in Bangladesh's development planning history, as it is the first plan to consider climate change as an exogenous variable in formulating a macroeconomic framework, and it also adopts an "adaptive delta management" approach [73]. The Delta Plan underscores the significance of accreted land for Bangladesh's development planning and therefore incorporates provisions for assessing and revising laws and regulations regarding alluvion and diluvion. Furthermore, it emphasizes the need for more efficient administration and management of *char*lands and calls for the establishment of a data bank, using the Management Information System, for *khas* land, fellow land, acquired land, and *char*land to ensure appropriate monitoring. The vision and aspirations regarding the management of Bangladesh's dynamic deltas and *char*lands are presently moving in the right direction; however, the evolution of these paths and their effective implementation will remain a critical concern.

8. Conclusions

In this study, we argue that a comprehensive interdisciplinary understanding of dynamic geomorphological, ecological, and human systems is essential to accurately explaining the complex *char*land (mid-channel island) processes. We further assert that dynamic deltaic social-ecological systems like the Bengal Delta demand a flexible planning approach. Furthermore, this study makes a novel contribution to the literature on riparian hazards through two empirical case studies of locations in the Bengal Delta, focusing on the evolution of their geomorphological evolution and fluvial systems and the riparian hazards and risks posed to human occupants by the dynamic fluvial and terrestrial systems. The results of these case studies clearly demonstrate that the interactive processes between hydrogeological and human conditions largely determine the characteristics and outcomes of riparian hazards in Bangladesh, which are by and large very dynamic, fluid, and often erratic. As such, the adoption of an adaptive management approach featuring considerable flexibility, renewability, and self-organizing capacity is urgently needed in Bangladesh's policy, planning, and implementation structures. Considering the current climate change regimes and their embedded uncertainty, it is plausible that the future social-ecological conditions of the Bengal Delta region will be considerably more complex and unpredictable.

The findings of this study also revealed that the alluvial land laws and the sociopolitical norms of *char*land administration during the pre- and post-Independence periods by and large failed to address issues affecting marginalized *char*land residents in Bangladesh. Given the dynamic nature of the Ganges Delta formation and the Brahmaputra-Jamuna and Meghna River systems, along with Bangladesh's rapidly expanding economy and physical infrastructure, it is critical to ensure that policy considers the sensitivity of regional social-ecological systems, adopts an adaptive management approach, and employs Nature-Based Solutions. To achieve the goals of the Bangladesh Delta Plan 2100, a clear Knowledge Development Plan with respect to water and land resources should be established through world-class advanced educational and research institutions. Sustained monitoring and surveillance of geomorphological changes should be implemented with the aim of linking real-world data to water and land resource planning and project development. Furthermore, to realize the UN's Sustainable Development Goals, policy and planning measures are required to address the livelihood insecurity facing the marginalized *char* inhabitants. Nonetheless, it is promising that, in addressing *char*land issues in its Delta Plan 2100, the Government of Bangladesh has shown a clear desire to create a more equitable, flexible, and sustainable approach to planning and implementation.

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