ecologies

MDPI

Article

Constraints and Opportunities of Agricultural Development in *Haor* Ecosystem of Bangladesh

Shaikh Mohammad Bokhtiar [1,†], Md. Jahirul Islam [1,†], Syed Samsuzzaman [2], Mohammad Jahiruddin [3], Golam Mohammad Panaullah [2], Md. Abdus Salam [1,*] and Mohammad Anwar Hossain [4,*]

[1] Bangladesh Agricultural Research Council, Farmgate, Dhaka 1215, Bangladesh; bokhtiarsm@yahoo.com (S.M.B.); jahirulislam213@gmail.com (M.J.I.)
[2] Krishi Gobeshona Foundation, BARC Complex, Farmgate, Dhaka 1215, Bangladesh; dr.samsuzzaman@gmail.com (S.S.); gmpanaullah@gmail.com (G.M.P.)
[3] Department of Soil Science, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh; m_jahiruddin@yahoo.com
[4] Department of Genetics and Plant Breeding, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh
* Correspondence: masalamsso@yahoo.com (M.A.S.); anwargpb@bau.edu.bd (M.A.H.)
† These authors contributed equally to this paper.

Abstract: The *Haors* in Bangladesh are saucer-shaped, low-lying land depressions that form deep basins; they remain submerged for approximately half of the year, typically from June onwards. This fragile ecosystem spans over 2.0 million hectares in the northeastern region of the country, accounting for roughly 14% of the total areas, where approximately 19.4 million people reside. Factors including floods, flash floods, and low winter temperatures constrain agricultural productivity in the *haor* areas. It is a great challenge to change the *haor* areas from less productive to more productive land. This is a comprehensive analysis of the biophysical and socioeconomic characteristics of *haors* which also highlights the constraints and opportunities in agricultural production. It explores strategies for significantly increasing crop, livestock, and fish production within the *haor* ecosystem, in alignment with government policies. Some of the proposed agricultural development strategies for the *haor* areas include the development of short-duration, cold-tolerant crop varieties, such as *Boro* rice, utilizing relatively flood-free elevated lands and homesteads for vegetable production and promoting agricultural mechanization, livestock rearing, fisheries, and agribusiness development. The recommendations presented in this paper focus on enhancing crop yields, increasing cropping intensity, and boosting livestock and fish production; ultimately, they contribute to food security, poverty reduction, and improved livelihoods for the inhabitants of the *haor* areas.

Keywords: *Boro* rice; cold-tolerant; cropping intensity; fisheries; flash flood; fragile ecosystem; livestock; short-duration rice

Citation: Bokhtiar, S.M.; Islam, M.J.; Samsuzzaman, S.; Jahiruddin, M.; Panaullah, G.M.; Salam, M.A.; Hossain, M.A. Constraints and Opportunities of Agricultural Development in *Haor* Ecosystem of Bangladesh. *Ecologies* **2024**, *5*, 256–278. https://doi.org/10.3390/ecologies5020017

Academic Editors: José Ramón Arévalo Sierra and Alan Christian

Received: 14 March 2024
Revised: 29 April 2024
Accepted: 1 May 2024
Published: 7 May 2024

1. Introduction

The *haor* is one of the fragile ecosystem "hotspots" named in the Bangladesh Delta Plan 2100 [1] in Bangladesh; the others are the *barind*, *char*, coastal, and hill ecosystems. The *haor* is a wetland ecosystem in the northeastern part of Bangladesh. Regarding the core *haor* area, it is spread over larger parts of Sunamganj, Habiganj, Moulvibazar, and Sylhet districts, and it also extends to Kishoreganj, Netrokona, and Brahmanbaria districts. The *haor* is a basin-like structure where water remains either stagnant or in a flash flood condition during the months of June to November. Due to its waterlogged conditions, *Boro* rice is predominantly grown in the Rabi season. The cropping intensity and crop productivity in the *haor* area of Bangladesh are notably lower compared to the national average. The average cropping intensity in the *haor* region is 104%, which is significantly lower than the national average of 195% [2].

The *haor* ecosystem, characterized by its unique biophysical and agro-ecological features, represents a notable "hotspot" or fragile ecosystem. While it faces specific challenges, it also holds a significant potential to be made productive with appropriate technological and management interventions. These low-lying river basin areas cover some 2.0 million hectares (about 14% of country's total area), mainly in the northeastern region of Bangladesh, and are home to about 19.4 million people [2,3]. During the monsoon season, *haors* receive surface runoff water from rivers and canals, transforming them into vast stretches of turbulent water. This influx can lead to floods and flash floods in the basin in certain years. Floods, flash floods, and low winter temperatures are among the factors constraining agricultural production in the *haor* areas. The future crop productivity and food security of Bangladesh partly hinge on the effective integration of these ecologically constrained areas into mainstream crop production. Hence, the situation calls for highly innovative research and productive strategies aimed at enhancing crop productivity and cropping intensity in *haor* areas. This is crucial to ensure food security and to improve livelihoods in these regions. This paper provides a review of the biophysical and socioeconomic characteristics of the *haor* ecosystem, along with an exploration of the agricultural production challenges and the opportunities for transforming it into a productive agro-ecosystem.

2. Materials and Methods

Secondary data and information related to crops, livestock, fisheries, and forestry, as well as cross-cutting issues (inputs, marketing, natural resources, and the socioeconomic situation), were gathered from a thorough review of the relevant literature, both online and offline. The data included the extent and distribution of *haor* areas, biophysical characteristics, soil fertility, climate, biodiversity, mineral resources, demographic features, agricultural production systems, status of development in the *haor* areas, *haor* management strategies, and anthropogenic impacts on the *haor* zone. For data and information collection many authentic documents, like books, research or study reports, and policy documents, were consulted through a Google search and also through communications with various organizations, at both the government organization (GO) and non-government organization (NGO) levels. The organizations included institutions of the National Agricultural Research System (NARS), Department of Agricultural Extension (DAE), Department of Livestock Service (DLS), and Department of Fisheries (DOF) and the Bangladesh offices of international organizations, like the Food and Agriculture Organization (FAO), International Rice Research Institute (IRRI), International Maize and Wheat Improvement Center (CYMMIT), International Food Policy Research Institute (IFPRI), WorldFish, NGOs, and private enterprises. The "content analysis" approach was used for analyzing and categorizing textual materials, such as books, papers, oral communications, interviews, and visuals, in order to extract relevant data on various topics. The data collected from various sources are analyzed over time to evaluate agricultural performance and adaptations during different periods, informing adjustments in agricultural management aimed at enhancing future productivity.

3. Results and Discussion

3.1. Extent and Distribution

There are approximately 373 haors that cover a total of 0.68 million hectares (ha) of land in northeastern and eastern Bangladesh [4]. Haors occur in 61 out of the 74 upazilas (sub-districts) of 7 districts of Bangladesh, namely Sylhet, Moulvibazar, Habiganj, and Sunamganj in the northeastern region, Netrakona and Kishoreganj in the north-central region, and Brahmanbaria in the central-eastern region (Figure 1 and Table S1).

All of the 14 upazilas of Sylhet district and 12 upazilas of Sunamganj have *haors*, and the majority of the upazilas (>70%) in the other districts, except Brahmanbaria (44%), also have *haors*. In total, 12.3% of the 495 upazilas of Bangladesh have a *haor* ecosystem (Table 1 and Figure 2).

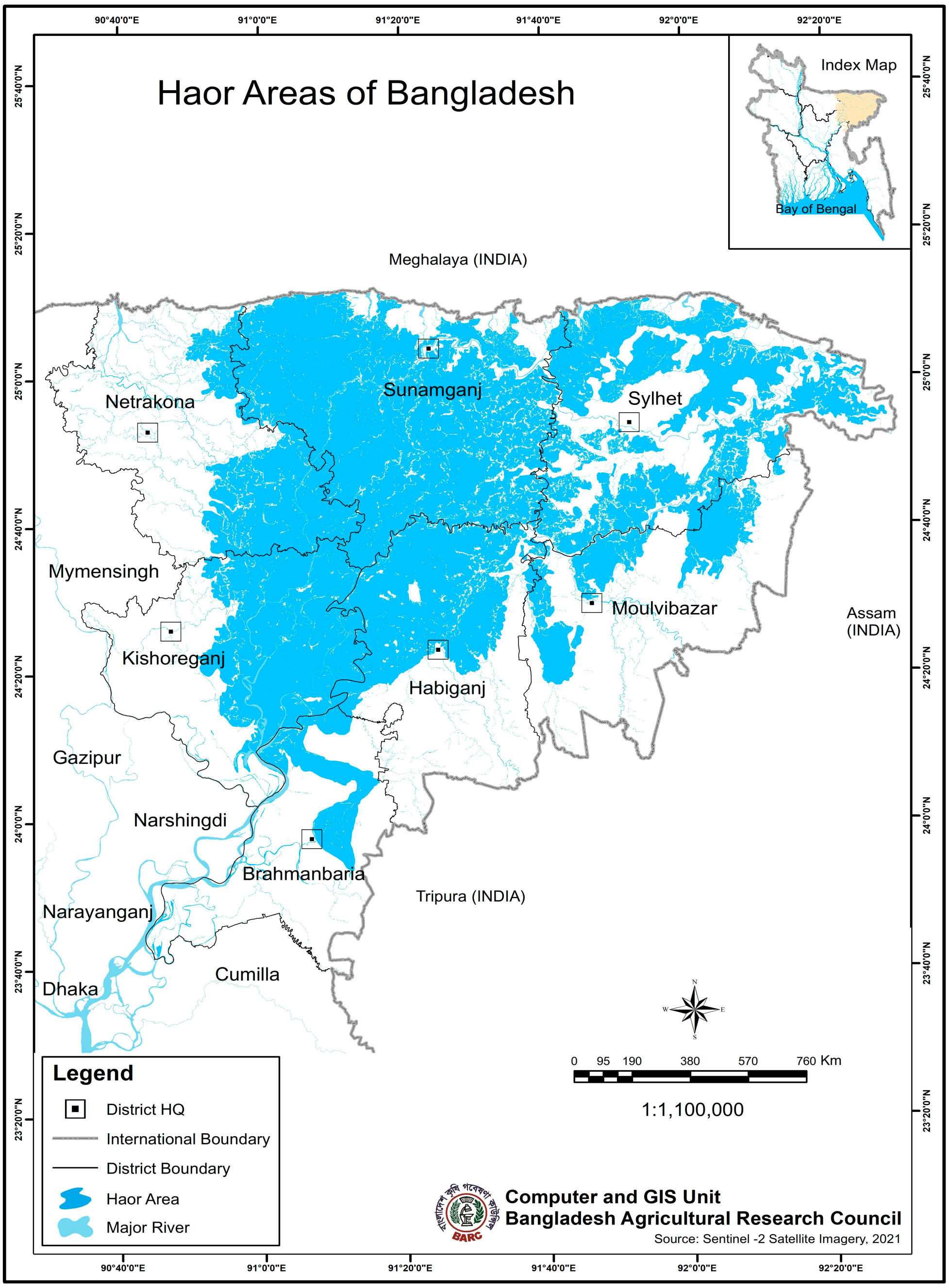


Figure 1. Map of northeastern Bangladesh showing districts (boundaries on map are district boundaries) of the *haor* areas.

The haors of Sunamganj, Sylhet, Habiganj, Moulvibazar, Netrakona, Kishoreganj and Brahmanbaria districts occupy nearly 873,524 ha, which is about 52.9% of the total area of these districts (1,651,992 ha) and 6% of the total area of Bangladesh, i.e., 14,486,269 ha.

Among the seven northeastern districts, *haors* are most prevalent in Sunamganj, where they occupy 290,982 ha out of the total area of 366,558 ha of the district (Figure 3). Sunamganj, Sylhet, Habiganj, and Kishoreganj have 171,098, 113,689, and 98,478 ha of *haor*, respectively. The *haors* in the other three districts, i.e., Netrakona, Moulvibazar, and Brahmanbaria, are less extensive. Importantly, the problems, risks, and vulnerabilities related to agricultural production in the *haor* areas arise from the intrinsic properties of these wetland ecosystems wherever they occur, irrespective of their dimensions [5].

Table 1. Names of upazilas containing *haors* by district.

District	Haor-Based Upazila
Sunamganj	Sunamganj Sadar, Jagannathpur, Dharmapasha, Jamalganj, Chhatak, Derai, Sulla, Tahirkpur, Bishambarpur, Dakkhin Sunamganj, Dowarabazar, Madhyanagar.
Sylhet	Jaintiapur, Beanibazar, Fenchuganj, Balagonj, Biswanath, Sylhet Sadar, Sylhet City Corporation, Companiganj, Golapganj, Gowainghat, Kanaighat, Osmaninagar, Zakiganj, Dakkhin Surma.
Habiganj	Ajmiriganj, Habiganj Sadar, Bahubal, Baniachang, Lakhai, Madhabpur, Nabiganj
Moulvibazar	Moulvibazar Sadar, Kulaura, Rajnagar, Sreemangal, Barlekha, Juri
Netrakona	Atpara, Barhatta, Khaliajuri, Mohanganj, Madan, Kendua, Komlakanda
Kishoreganj	Mithamain, Karimganj, Austragram, Itna, Nikli, Bazitpur, Kuliarchar, Tarail, Bhairab, Katiadi, Kiskoreganj Sadar
Brahmanbaria	Brahmanbaria Sadar, Nasirnagar, Bijoynagar, Sarail

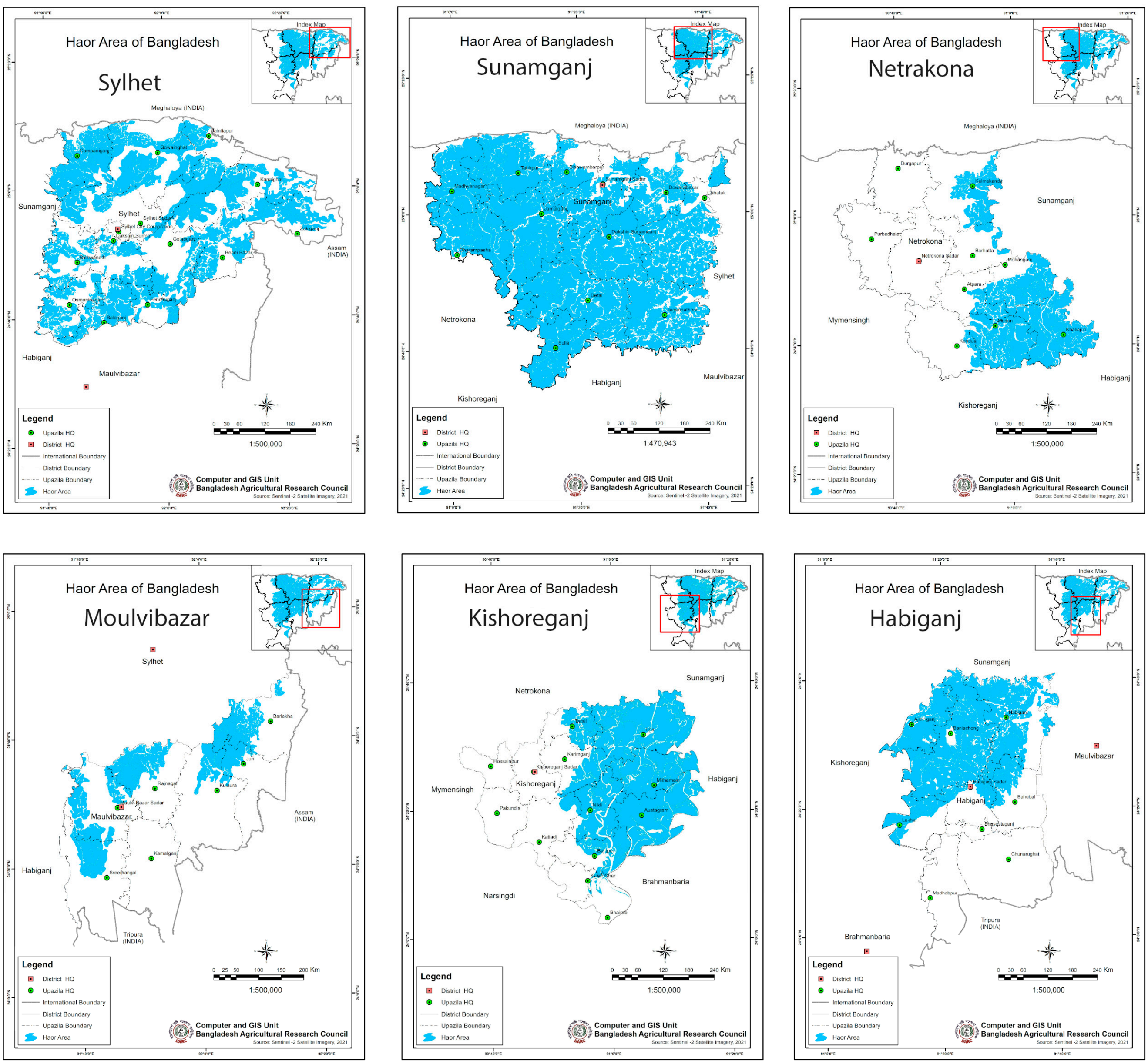


Figure 2. Six northeastern districts of Bangladesh with the largest *haors*.

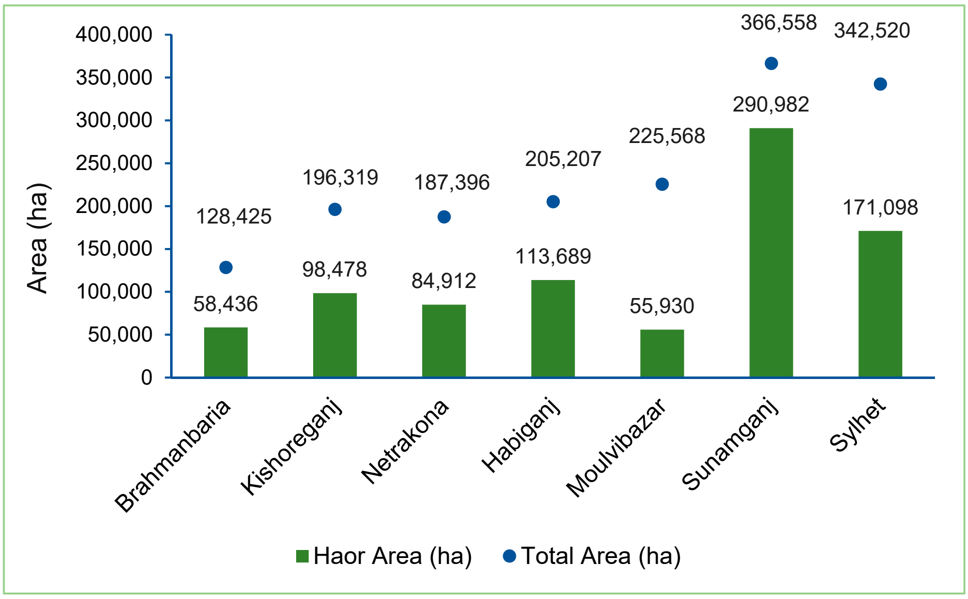


Figure 3. Total areas of haors in seven northeastern districts of Bangladesh in 2022.

3.2. Biophysical Characteristics

3.2.1. Land and Soil

The unique seasonal wetlands of the basin, called *haors*, which cover almost 43% the Surma-Kushiyara sub-basin, are part of the larger Barak-Meghna basin [6]. These basins are filled with water to varying depths during different seasons of the year and are typically interspersed with upland areas of 1–10 ha called haati. The *haor* ecosystem contains approximately 6300 *beels* (relatively deepwater bodies with seasonally varying water depths), of which 3500 are permanent and 2800 are seasonal [3]. The *haor* basin is bordered on three sides by the mountain ranges of India, with Meghalaya to the north, Tripura and Mizoram to the south, and Manipur and Assam to the east. It extends north to the foot of the Garo and Khasia hills and east along the upper Surma Valley to the Indian border [6,7].

The Tippera surface, which is partially low and deltaic and partially higher ground with a piedmont fringe to the east, is directly connected to the south of the *haor* basin [8]. The *haors* are believed to have a tectonic origin and are possibly linked to the Madhupur tract. The original form of the *haor* basin consisted of the floodplains of the Meghna and its tributaries, which contained a diverse array of permanent and seasonal lakes and ponds and abundant aquatic vegetation. In recent years, the basin has become shallower, leading to the gradual sedimentation and formation of reeds and sedges [9].

The *haor* region can be categorized into three distinct zones [10] (Figure 4). The first is the piedmont zone/foothill and near hill zone, which is situated at the highest elevation around the foothills of the Himalayas (Sylhet and Moulvibazar districts). Here, flash floods cause rapid siltation of coarser materials along the levees. The back swamp in this zone acts as a reservoir, storing water and reducing the depth of flooding downstream. The second zone is the flood plain zone, which lies in the middle of the basin and consists of gentle slopes (Netrakona, Kishoreganj, and Brahmanbaria districts). This zone receives sediments that are moderately finer and lower in volume. The back swamps in this area fill and drain several times during each monsoon season, thereby reducing flooding depth downstream. The third zone is the deeply flooded zone, which is the deepest part of the wetlands and is commonly referred to as a *beel* (Sunamganj, Netrakona, and Habiganj districts). During monsoon season, the *beels* become deeply flooded, transforming into a single water reservoir. This phenomenon is particularly pronounced in the Surma-Kushiyara-Meghna basin.

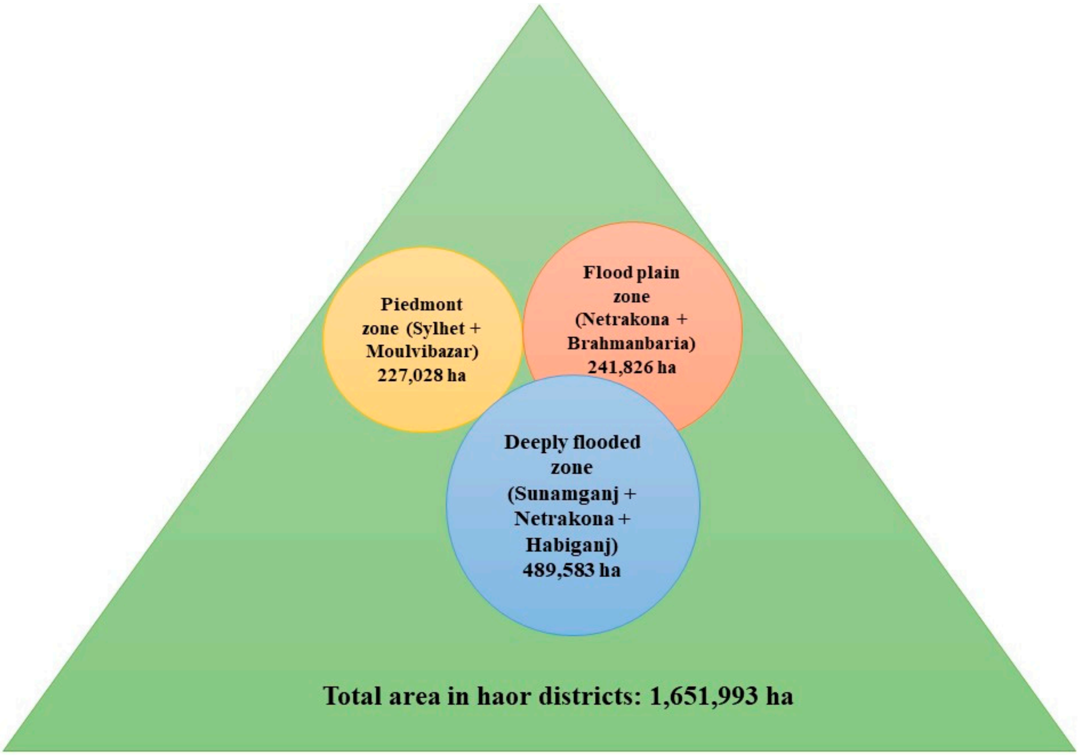


Figure 4. Categories of *haors* and their areas.

The minor hilly streams, like Manu, Khowai, Jadhukata, Piyain, Mogra, and Mahadao, in association with the Surma and Kushiyara rivers form the complex drainage network of the *haors*. The rivers provide rainwater and a sediment load to the plains, including the *haors*. The haor turns into a vast waterbody resembling an inland sea and remains flooded for about 7 to 8 months during the rainy season, within which the villages appear as islands [9].

The *haor* region is characterized by the presence of relatively coarse-textured soils on the ridges and fine-textured soils in the basins or depressions. The Sylhet basin is a vast low-lying area, bordered by high river levees and containing extensive *haor* areas that retain water even during the dry season. Clay soil (fine-textured soils) is the predominant soil type in this region. In certain areas where the percentage of organic matter is high, peat soils can be found. These soils are unconsolidated deposits of semi-carbonized plants, containing about 60% carbon and about 30% oxygen. Peat soils are located near the ground or just a few meters below the ground in Sunamganj, Netrakona, Kishoreganj, and Habiganj districts. They are also found at the fringes of some other lowlands, under a layer of silty or sandy topsoil [11].

The pH of the soils in all the land types, such as high land (HL), medium high land (MHL), medium low land (MLL), low land (LL), and very low land (VLL), varied within the low range of 3.4–3.60 (extremely acidic) to the mid-range of 5.8–6.9 (slightly acidic to neutral) during 2006–2021 (Table S2). In general, the HL and MHL soils tend to be more acidic than the LL, MLL, and VLL soils. It was reported that pH values were from high to nearly neutral and ranged from 6.7 to 7.0, with a mean of 6.9 in the wetlands of the southeastern part of the Sylhet basin [2]. A comparison of the maximum and minimum pH values of the soils in the *haor* areas between the two periods of 2006–2021 and 1999–2002 (Table S3) indicates that there were no significant changes in soil pH. The exception was that the soils of the MLL and VLL tended to lose some acidity during 2006–2021, which may be attributable to the frequent submergence of these lands by flood water with high Ca content.

The average soil organic matter (SOM) content, which is 2.03–3.45% across all the land types, HL, MHL, MLL, LL, and VLL, is above the critical level of 2%, which is good for crops (Figure 5). In general, the *haor* soils are severely phosphorus-deficient, indicating a major soil fertility problem for crop growth [9,12]. The average potassium (K) levels of the soils (exchangeable K) ranged from 0.13 to 0.36 meq/100 g during 1999–2002 and 2006–2021 across the HL, MHL, MLL, LL, and VLL; these levels were below the healthy level of 0.5 meq/100 g for crop production. Over time, the K level in the *haor* soils decreased gradually, which does not bode well for crop agriculture. The average available sulfate-sulfur (S) levels ranged from 16.8 to 68.2 ppm during 1999–2002 and 2006–2021 in the soils in the *haor* region across all the land types, HL, MHL, MLL, LL, and VLL; these levels were much higher than the critical level (12 ppm) and the optimum level (26 ppm), except in the HL (below optimum level). On the other hand, the available zinc (Zn) levels in the soils in the haor region were 1.26–2.77 ppm during 1999–2002 and 2006–2021, across the HL, MHL, MLL, LL, and VLL and were below the optimum level of 4 ppm. The soils of LL and VLL have a higher level of Zn than those of the HL, MHL, and MLL (1.26–2.2 ppm), ranging from 2.24 to 2.77 ppm, which is above the critical level of 2 ppm. Thus, another soil fertility problem could be a general deficiency of the micronutrient, zinc.

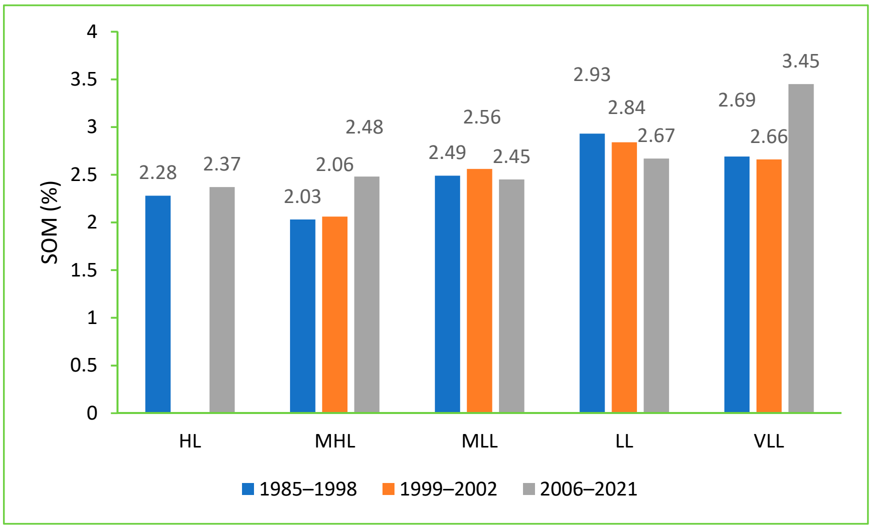


Figure 5. Soil organic matter content in *haor* region (values in %).

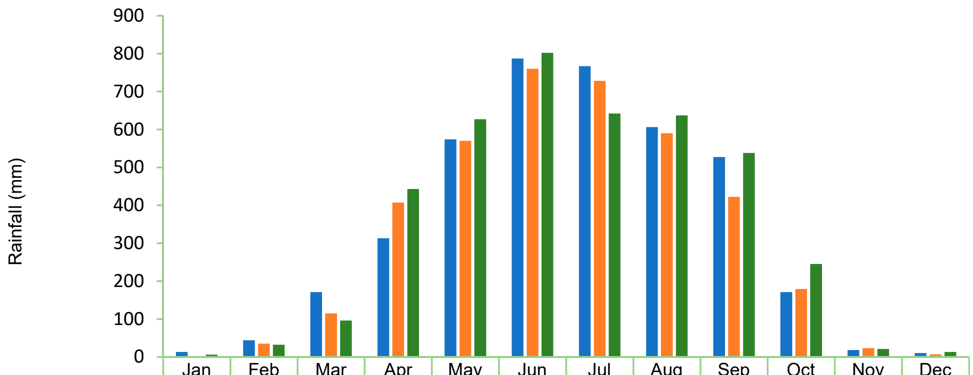
However, this has created a suitable habitat for fish and other aquatic fauna, attracting migratory birds whose excreta contribute to the fertility of the water bodies. Consequently, the enhanced water fertility promotes a rich growth of phytoplankton and macrophytes, which partly contribute to the process of eutrophication [13].

3.2.2. Climate

A sub-tropical monsoonal climate prevails in the *haor* region. The annual average rainfall in the *haor* districts is huge and highly variable across the region. The highest rainfall generally occurs in Sunamganj (383 mm) [14] closest to Cherrapunji in Assam in India (11,371 mm) [15], which receives the highest yearly rainfall in the world. The global climate change which has altered the frequency of some climatic extreme events [16] is impacting the environment and agriculture of Bangladesh, including the *haor* areas.

3.2.3. Rainfall

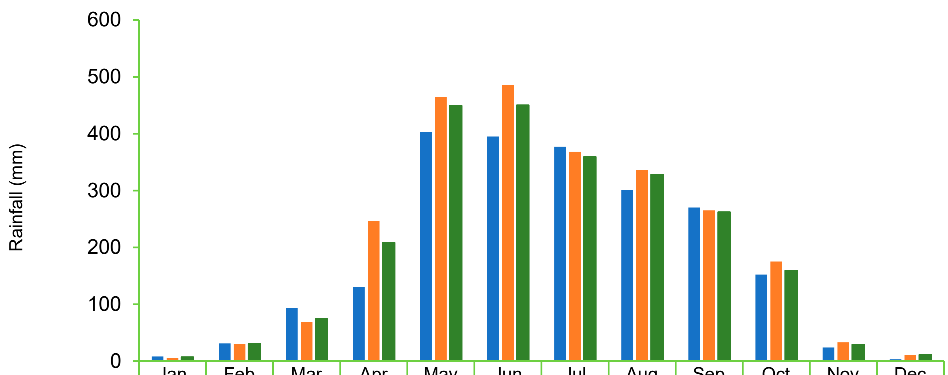
An increasing trend in rainfall was observed with an average monthly rainfall during April (443 mm), May (627 mm), June (802 mm), August (637 mm), September (538 mm), and October (245 mm) during 2011–2020 (Figure 6). This trend indicates that the rainfall increased in Sylhet and Sunamganj districts in these months. In particular, the increasing trend in the months of April, May, and June has been critical for the safe harvest of Boro rice and the planting of Kharif-I vegetables and other crops. The extreme nature of the rivers and high rainfall in April, May, and June caused frequent flash floods in these haor districts. However, the average monthly rainfall decreased severely in January, February, and March during 2011–2020 (6 mm, 32 mm, and 96 mm, respectively) compared with the average rainfall from 1991 to 2000 (13 mm, 44, mm and 171 mm, respectively). This decrease in rainfall has resulted in severe drought in these months, leading to the delayed planting of Boro rice (winter rice) and other winter crops and in the partial damage of these crops if planted in these months.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg Rainfall during 1991–2000	13	44	171	313	574	787	767	606	527	171	18	10
Avg Rainfall during 2001–2010	2	35	115	407	570	760	728	590	422	179	23	7
Avg Rainfall during 2011–2020	6	32	96	443	627	802	642	637	538	245	21	13

Figure 6. Long-term trend of monthly rainfall for Sylhet, Sunamganj, and part of Netrakona, including *haor* areas.

In the other *haor* districts, Moulvibazar and Habiganj and also part of Kishoreganj, the pre-monsoon and monsoon (April-August) rainfall was found to have increased substantially during 2011–2020 compared with the monthly rainfalls in the same months averaged over the period from 1991 to 2000 (Figure 7). The high rainfall in April and May causes frequent flash floods in these *haor* districts. The monthly rainfall was, however, poorly distributed in November, December, and January during all the three 10-year periods and ranged from 3 to 33 mm. This poor distribution in rainfall in these dry months brings about drought, which delays the planting of *Boro* rice and other winter crops, with resultant yield losses.

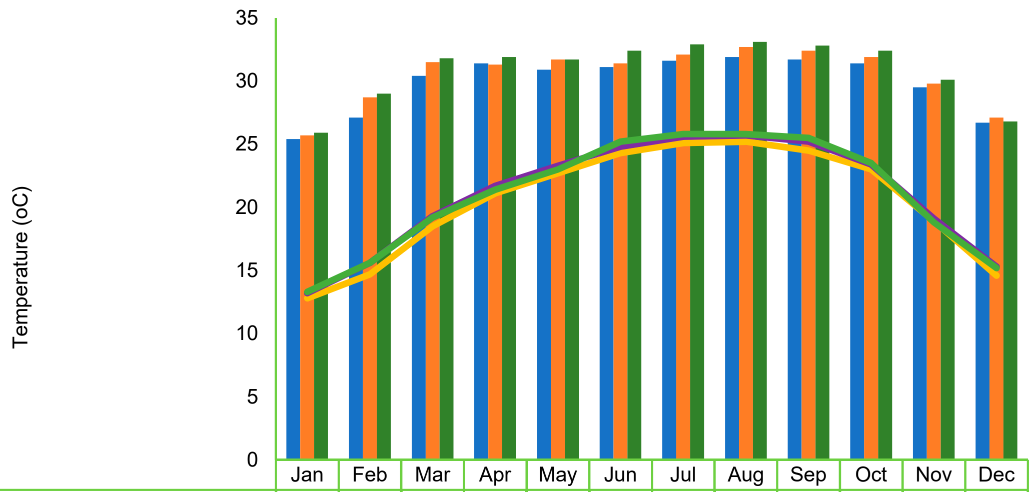


	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg Rainfall during 1991–2000	8	31	93	130	403	395	377	301	270	152	24	3
Avg Rainfall during 2001–2010	5	30	69	246	464	485	368	336	265	175	33	11
Avg Rainfall during 2011–2020	7	30	74	208	449	450	359	328	262	159	29	11

Figure 7. Long-term trend of monthly rainfall for Moulvibazar, Habiganj, and part of Kishoreganj, including *haor* areas.

3.2.4. Temperature

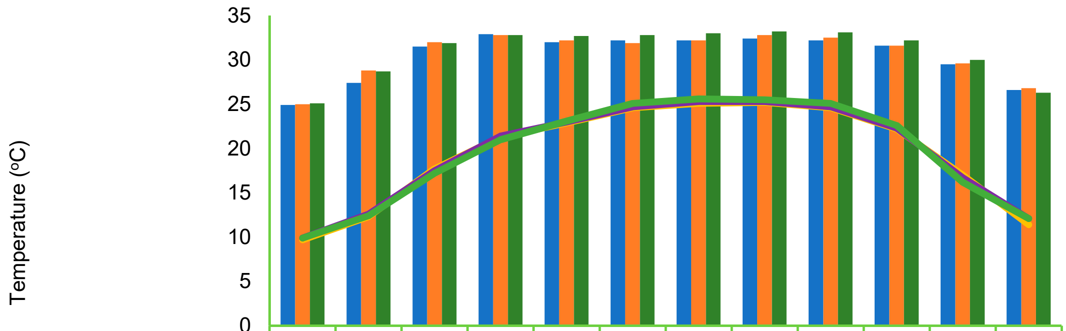
The average monthly maximum temperature increased in all the months during 2011–2020, ranging from 25.9 °C in January to 33.1 °C in August compared with that averaged over the period from 1991 to 2000, which ranged from 25.4 °C in January to 31.9 °C in August. The maximum temperature has increased by 0.50 to 1.20 °C during the last 30 years in Sylhet, Sunamganj, and part of Netrokona, including the *haors* (Figure 8). The monthly minimum temperatures averaged over 10 years (2011–2020) ranged from 12.8 °C in January to 25.8 °C in August. The minimum temperature has also increased by 0.50 to 0.60 °C in all the months of the year except in November, as averaged over the last 10 years (2011–2020), compared to that averaged over the 30 years from 1991 to 2000. Similar increasing trends of temperature were observed in Moulvibazar, Habiganj, and Kishoreganj districts (Figure 9). Such temperature increases are an unmistakable pointer to the adverse impact of climate change on agriculture in the *haor* areas and on the lives and livelihoods of the millions of *haor* inhabitants.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg Max T during 1991–2000	25.4	27.1	30.4	31.4	30.9	31.1	31.6	31.9	31.7	31.4	29.5	26.7
Avg Max T during 2001–2010	25.7	28.7	31.5	31.3	31.7	31.4	32.1	32.7	32.4	31.9	29.8	27.1
Avg Max T during 2011–2020	25.9	29	31.8	31.9	31.7	32.4	32.9	33.1	32.8	32.4	30.1	26.8
Avg Min T during 1991–2000	12.8	14.7	18.5	21.1	22.7	24.3	25.1	25.2	24.5	23	18.9	14.6
Avg Min T during 2001–2010	13.2	15.6	19.3	21.7	23.3	24.8	25.6	25.7	25.2	23.4	19.1	15.3
Avg Min T during 2011–2020	13.3	15.6	19.2	21.4	23	25.2	25.8	25.8	25.5	23.5	18.8	15.2

Figure 8. Long-term trend of monthly maximum and minimum temperatures in Sylhet, Sunamganj, and part of Netrakona, including *haor* areas.

Rising temperatures are projected to increase the severity and frequency of tornadoes and storms in the *haor* region. Almost every year, Bangladesh, particularly the *haor*, coastal, and char (riverine islands) areas, faces natural calamities like floods, cyclones, storms, and tidal surges. A warmer climate will increase the frequency and intensity of the flooding risk [17]. Globally, the *haors*/wetlands are at risk of declining rapidly in terms of both quantity and quality. In a previous report, it was claimed that globally, wetlands are disappearing three times faster than forests, with 35% of the world's wetlands lost since 1970 [18]. This trend is, without any doubt, alarming. Bangladesh is well known as a riverine country with vast areas of low-lying land, including *haors*. These wetlands can help to stabilize emissions of greenhouse gas (GHG) and cope with climate change impacts in a number of ways. Moreover, the wetlands also have economic importance, providing livelihood opportunities to millions of people living in the areas. But, alarmingly, the wetlands of Bangladesh are at risk of disappearing as the ecology of its wetlands is under constant threat. The Bangladesh Delta Plan 2100 identified that wetlands are the only means of livelihood for most of the people living there and an important contributor to food security. In the context of climate change and the increased risk of disaster, conservation of the wetlands is no less important for Bangladesh than achieving the goals of the Paris Agreement and the 2030 Agenda for Sustainable Development.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Avg Max T during 1991–2000	24.9	27.4	31.5	32.9	32	32.2	32.2	32.4	32.2	31.6	29.5	26.6
Avg Max T during 2001–2010	25	28.8	32	32.8	32.2	31.9	32.2	32.8	32.5	31.6	29.6	26.8
Avg Max T during 2011–2020	25.1	28.7	31.9	32.8	32.7	32.8	33	33.2	33.1	32.2	30	26.3
Avg Min T during 1991–2000	9.7	12.3	17.7	21.3	22.9	24.6	25.1	25.2	24.6	22.2	17	11.4
Avg Min T during 2001–2010	9.9	12.6	17.5	21.4	23	24.7	25.3	25.3	24.7	22.3	16.7	12.1
Avg Min T during 2011–2020	9.9	12.4	17.2	21	23.1	25.1	25.6	25.5	25.1	22.6	16.2	12.1

Figure 9. Long-term trend of monthly maximum and minimum temperatures in Moulvibazar, Habiganj, and part of Kishoreganj, including *haor* areas.

3.2.5. Water Regime

The haor region lies in the Meghna basin, which is a part of the Ganges-Brahmaputra-Meghna (GBM) basins. Flow from about 66,640 km^2 of the Meghna basin is ultimately drained into the Bay of Bengal through the Kalni-Kushiyara and Surma-Baulai river systems. Of this area, 35%, or 23,137 km^2, lies in Bangladesh. The estimated outflow of water from this region into the Bay of Bengal amounts on average to 162,619 million m^3/year; 57% of this flow is generated upstream outside of Bangladesh, while 43% is generated within the country [19].

The transboundary flow from India is 70%, 60%, 37%, and 80% of the total flow in the pre-monsoon, monsoon, post-monsoon, and dry seasons, respectively. This inflow (mainly pre-monsoon flow) from India into Bangladesh is the main cause of flash floods in the *haor* areas. As the average ground level in the *haor* areas is very low, the flash floods fill the lowlands and inundate the crop fields of vast areas, inflicting huge damage to the nation almost every year. There is a huge variation in rainfall in the different catchments of the river systems of the upstream area in India. The rainfall patterns on the adjacent Indian side largely affect the flooding in the *haor* areas of Bangladesh.

3.2.6. Flash Floods

Flash floods are a common occurrence in the *haor* areas, occurring first in April and then in June due to water rushing in from India. Off-season flash floods from hilly areas can also hit the *haors* 2–3 times a year, occurring in March and mid-April and massively in May/June. Poor drainage may cause stagnation of the flood water entering from rivers like the Mona, Jhuri, and Kushiara, as well as from the hill slope runoff. Examples of severe flash floods include a prolonged flash flood from March to November 2017 and occurrences in Moulvibazar in May 2011, April 2012, March 2013, April–May 2015, early April 2016, and March 2017 [20,21].

Damage to agriculture/vegetable crops is caused mainly by high rainfall/flash floods. Due to flash floods, siltation with sand changes the soil texture and structure. Erosion of the hills also causes deposition of sands in the rivers and canals, reducing the water area and aggravating drainage problems. Due to inundation, crop planting is delayed and cropping intensity is affected. At least 10–30% crop loss occurs every year due to flash floods. Homestead vegetables and *Boro* rice were fully damaged while 60% of Aus rice (summer rice) and 45% of T. Aman rice (monsoon rice) were damaged due to floods in 2017. Disease and pest attacks were also severe. Low temperature and dense fog in the winter season (mid-December to mid-January) damaged the standing vegetable crops due to chilling injury, increase in disease infestation, and pest attack. Prolonged floods also affect poultry and livestock, causing animal health problems and death due to scarcity of feed and increased incidence of diseases [5,9,22].

Flash floods and water stagnation in *haor* areas are not only affected by climate change; they are also aggravated by human activities. Actions such as altering river flows by narrowing the rivers, erecting bamboo fences for fishing, indiscriminate sand extraction, and obstructing drainage water passage through the unplanned construction of roads and culverts contribute to the increased frequency and intensity of flash floods.

3.3. Demographic and Socioeconomic Features

According to the population census of 2011 [23], the *haor* areas were home to a total of 14.52 million people, constituting some 81% of the total population of the 7 *haor* districts. Overall, the *haor* people represent about 10% of the total population of Bangladesh, indicating that one-tenth of the national population is threatened by risks and vulnerabilities associated with *haor*/wetland conditions.

The challenges arising from the unique topographic and hydrologic features of the *haor* ecosystem are the day-to-day realities of the *haor* people. Flash floods are a major disaster in the haor areas, threatening the lives and livelihoods of the inhabitants. Additionally, the siltation and sedimentation of major rivers, riverbank erosion, impeded navigability, degradation of the ecosystem, etc., adversely affect the *haor* people. Human interventions and failings, like indiscriminate exploitation of natural vegetation and fisheries resources, lack of proper sanitation, scarcity of drinking water, fragile and inadequate road network, illiteracy, poverty, inadequate health facilities, and inadequate operation and maintenance of the existing infrastructure, etc., are critical socioeconomic issues in the *haor* areas [19].

The *haor* region of Bangladesh has generally lagged behind in terms of various key indicators of social and economic development. For example, the overall poverty headcount rates (HCRs) for the Sylhet division, which range from 0.319 to 0.337, are only slightly higher than that of 0.319 for the Dhaka division and are markedly lower than those reported for the western divisions of Khulna, Rajshahi, and Barishal. There are also pronounced variations in the prevalence of poverty and extreme poverty within the *haor* region [24]. Most of the upazilas in the districts of Sunamganj and Habiganj reported HCRs of 0.45–0.55, which were markedly higher than the upazilas in other districts of the *haor* region.

The *haor* region also experiences widespread problems of food insecurity due to a combination of factors, which include crop losses due to early or flash floods and erosion; poor access to markets, especially during the flood season; and isolation from traders and services. The region is characterized by notably lower rates of literacy than the national rate.

3.4. Agricultural Production Systems

3.4.1. Land Use Patterns

The seven *haor* districts have a net agricultural land area of about 780,328 ha, comprising 47% of the total area of the *haor* districts and constituting 8.9% of the total agricultural land area in Bangladesh [25]. The floodplain agricultural lands (89.4%) dominate the land use classes across the seven *haor* districts. Perennial *beels/baors* and herb-dominated areas account for only 3.7 and 2.6%, respectively (Table 2).

Table 2. Land use pattern in haor areas in 2022.

Land Use	Area (ha)	% of Total Area
Floodplain agricultural land	780,328	89.4
Perennial *beels* and *baors*	32,203	3.7
Herb-dominated area	22,764	2.6
Ponds	271	0.03
Fresh water aquaculture	3059	0.4
Swamp reed land	12,910	1.5
Others	21,559	2.5
Total	873,093	-

The crop cover is the maximum in the haor areas during the dry season, when the water bodies shrink. In the wet season, the crop cover decreases when the water bodies swell up. Usually only one field crop, *Boro* rice (winter rice), is grown annually, cultivated during the winter season. The largest agricultural land area (586,012 ha) is under single cropping, followed by the double-cropped area (567,800 ha), out of the net cropped area (1,323,805 ha). Cropping intensity in Sunamganj is the lowest (137%) due to a large single-cropped area. Conversely, the double-cropped area is the highest (the lowest is the triple-cropped area) in Kishoreganj, which led to the highest cropping intensity (187%) among the *haor* districts. Overall, the cropping intensity in the 7 *haor* districts is 169%, which is lower than the national average cropping intensity of 197% (Table S4) [25].

In the Bangladesh context, the *haor* region has the highest proportion of single-cropped areas (44.3%) compared with the national average of 26.1% (Figure 10). In addition, the proportion of double-cropped areas is 42.9% and that of the triple-cropped areas is 12.8% in the *haor* districts. This poor land utilization may be due to the excess water in the floodplains, which does not permit the cultivation of two or three crops a year in this region.

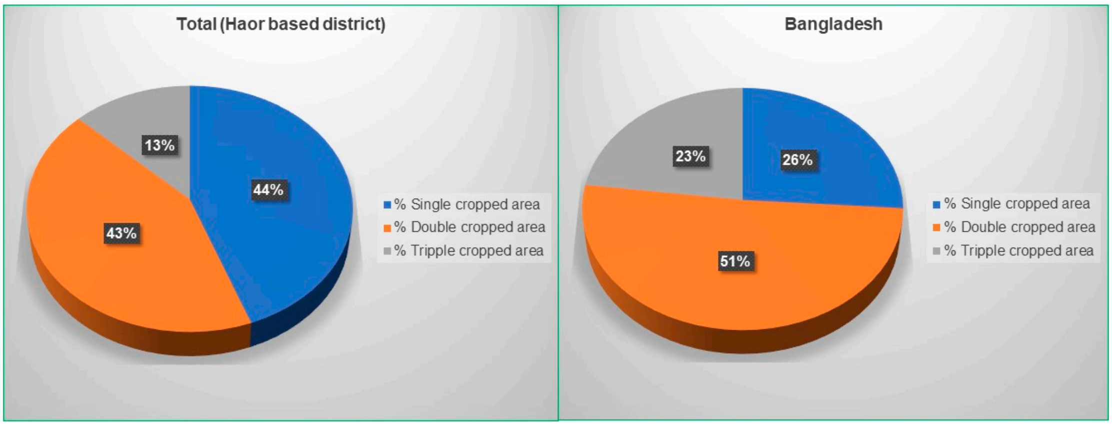


Figure 10. Status of land use for cropping in haor districts and overall in Bangladesh.

The single-cropped area increased from 24% in 2007 to 44% in 2021, as averaged over all the *haor* districts. This increase may be attributed to bringing the wetlands under single cropping by 2021, which remained otherwise uncultivated year-round during 2007. About 88,663 ha of fallow land was brought under cultivation between 2013 and 2020, which eventually resulted in an increase in the single-cropped area in the *haor* region. It also implies that there is enough scope to increase the rice area and thus increase rice-cropping intensity in the *haor* region. These areas usually remain under-utilized with quite low cropping intensity [26].

3.4.2. Crops and Cropping Patterns

Rice-based agriculture is dominant in the *haor* region. Other crops, like potato, groundnut, sweet potato, mustard, and pulses, are grown in the Rabi season to a small extent.

In Sunamganj and Kishoreganj, more than 80% of the total cropped area was under the *Boro*–fallow–fallow cropping pattern in 2007 (Table 3). The other *haor* districts were also dominated by the *Boro*–fallow–fallow cropping pattern in 2007, ranging from 60 to 78% of the total cropped areas. In 2022, *Boro*–fallow–fallow is still the dominant cropping pattern. *Boro*–fallow–T. Aman rice (transplanted Aman rice, i.e., monsoon rice) is the second most prevalent cropping pattern, indicating an improvement of the cropping intensity over a 15-year period from 2007. *Boro*–fallow–fallow is a cropping pattern where crops are grown only in the Rabi season (Nov–April) and land remains uncultivated during the Aus (April–July) and T. Aman (July–Nov) seasons. In the *haor* region, some T. Aus and T. Aman rice are grown on relatively elevated lands by the side of a *haor*. Boro–fallow–fallow is the dominant cropping pattern with the highest coverage (39.64%) in 36 upazilas out of 38 upazilas in the Sylhet region (including *haor* areas), followed by the second most dominant pattern of *Boro*–fallow–T. Aman, which occupies 15.74% of the net cropped area [27]. The rice-based cropping pattern is dominant because in the lowland ecosystem the recession of flood water is usually delayed, which does not allow the timely establishment of non-rice upland crops.

Table 3. Changes in major cropping patterns in the haor areas.

District	Major Cropping Pattern	
	2007	**2022**
Brahmanbaria	*Boro*–Fallow–Fallow (72) * Fallow–B. Aman–Fallow (6) *Boro*–Fallow–T.Aman (5)	*Boro*–Fallow–Fallow *Boro*–Fallow–T. Aman *Boro*–B.Aman–Fallow
Kishoreganj	*Boro*–Fallow–Fallow (82) Wheat–Fallow–Fallow (3) Groundnut–Fallow–Fallow (2)	*Boro*–Fallow–Fallow *Boro*–Fallow–T. Aman *Boro*–Jute–Fallow
Netrokona	*Boro*–Fallow–Fallow (78) Mustard–Fallow–Fallow (6) *Boro*–Fallow–T.Aman (9)	*Boro*–Fallow–Fallow Mustard/*Boro*–Fallow–T. Aman Fallow–Jute–T. Aman
Habiganj	*Boro*–Fallow–Fallow (68) B.Aman–Fallow–Fallow (12) *Boro*–B.Aman–Fallow (8)	*Boro*–Fallow–Fallow *Boro*–Fallow–T. Aman Vegetable–Fallow–T.Aman
Moulvibazar	*Boro*–Fallow–Fallow (64) Fallow–B.Aman–Fallow (18) Fallow–Aus–T.Aman (7)	*Boro*–Fallow–Fallow *Boro*–Fallow–T. Aman Vegetable–Fallow–T.Aman
Sunamganj	*Boro*–Fallow–Fallow (86) Fallow–B.Aman–Fallow (2) Wheat–Fallow–Fallow (2)	*Boro*–Fallow–Fallow *Boro*–Fallow–T. Aman Vegetable–Fallow–T.Aman
Sylhet	*Boro*–Fallow–Fallow (60) Fallow–B.Aman–Fallow (21) Fallow–Fallow–T.Aman (4)	*Boro*–Fallow–Fallow *Boro*–Fallow–T. Aman Vegetable–Fallow–T.Aman

* Figures in the parentheses indicate percent of the total area of the patterns.

In the *haor* areas, homesteads serve as potential sites for growing assorted vegetables during the Rabi (winter crop growing season) and Kharif-1 (pre-monsoon summer) seasons. The major vegetable cropping pattern in the homesteads is the vegetable–vegetable–fallow cropping pattern, covering 5395 ha in the Sylhet region, while the vegetable–vegetable–vegetable pattern is practiced in area of 5890 ha [28].

There are lands which are comparatively high and locally known as *kanda*, comprising 10–40% of the *haor* region and varying from *haor* to *haor*. Usually, the recession of flood water from the raised *kanda* lands is faster, and the lands become ready for agricultural activity 30 to 45 days ahead of the low lands. Again, inundation of the raised *kanda* lands by flash flood water is delayed, and the standing crops can avert damage. Unfortunately, most *kanda* lands are kept fallow throughout the year due to lack of irrigation facilities [29].

3.4.3. Livestock and Poultry

Livestock is an important part of Bangladesh's agricultural economy, contributing to food and nutrition security for the populace, generating incomes for the rural households, supplying manure to enhance soil fertility, etc.; cattle, buffaloes, goats, sheep, chickens, and ducks are the most popular livestock [30,31] in the *haor* region. In 2019, the total livestock and poultry headcounts in the *haor* areas were 37.33 million, accounting for 9.3% of the total counts of livestock and poultry (402.5 million) in Bangladesh [25]. Ducks in the *haor* areas accounted for more than a quarter of the country's total duck population.

In the *haor* areas, between 2010 and 2019, the populations of cattle, buffalo, and goat declined from 5.01 to 3.74 million, 0.3 to 0.127 million, and 1.28 to 0.973 million, respectively. However, the sheep population increased by 67% from 0.19 million in 2010 to 0.318 million in 2019. The cattle population decreased in all the *haor* districts between 2010 and 2019, except in Sylhet, where an increase from 0.86 to 1.04 million occurred. The goat population also decreased in the *haor* districts, except in Habiganj, Moulvibazar, and Sylhet where the goat headcounts increased by 30%, 12%, and 43%, respectively [25,32].

The poultry population has, by and large, increased in all the districts except Netrakona, which showed a 19% decrease from 2.32 million in 2010 to 1.869 million in 2019. The duck population increased in Kishoreganj, Moulvibazar, Sunamganj, and Sylhet while it decreased in Brahmanbaria, Netrakona, and Habiganj. In the *haor* area, poultry farming is limited to females who may also be involved in duck and livestock rearing. The homestead is a livestock production unit [33], contributing income and nutrition to *haor* households. Share-based livestock rearing is a social institution providing an additional extra income source for the poor; those with high social capital can more readily avail themselves of such opportunities.

3.4.4. Fisheries and Aquaculture

The *haor* region of Bangladesh is blessed with great opportunities for fisheries and aquaculture. There are vast floodplains along with some perennial water bodies in the deeper portions of the *haor* basin which provide spawning, nursing, and feeding grounds for a wide variety of finfish, including 143 indigenous and 12 exotic species along with several species of freshwater prawns during the pre-monsoon, monsoon, post-monsoon, and dry periods. The Tanguar *haor*, which is a large *haor*, is home to roughly 141 fish species, including several rare introduced species, accounting for more than half of the country's freshwater fish species, according to different reports [34,35]. Large fish, like major carp, large catfish, *chital*, Gangetic stingray, indigenous species locally known as *gazar* and *shol*, and small fish, such as, *air*, *gang magur*, *baim*, *tarabaim*, *gutum*, *gulsha*, *tengra*, *titna*, *garia*, *betki*, and *kakia*, are some of the notable species of fish.

Among the *haor* districts, Sunamganj accounts for the highest annual fish catch area, comprising 63,956 ha, followed by Netrakona, Moulvibazar, and Brahmanbaria. The open water fish catch area is reported to have increased by 10% from 228,823 ha in 2013 to 251,717 ha in 2020. Conversely, the total floodplain water area of Bangladesh decreased by 1.63% during the same period. This indicates the important role the *haor* region plays in open water fish production in Bangladesh.

3.4.5. Forestry

The *haor* basin is the only region in Bangladesh where remnant patches of freshwater swamps and reed lands still exist [36]. In the past, extensive forests of hijol (Indian oak) in the *haor* area used to be an important source of firewood, but these forests are now almost completely destroyed. In recent times, various herbs and aquatic plants have been collected for use as fuel. On top of that, aquatic plants are also being collected for use as fertilizers [37]. Only a few patches remain of the swamp forests that once dominated the area, featuring flood-tolerant trees, like hijol (*Barringtonia acutangula*) and koroch (*Pongamia pinnata*). The hijol, koroch, bhuidumur (*Ficus heterophylla*), nol (*Arundo donax*), khagra (*Pharagmites karka*), bon golap (*Rosa involucratia*), and barun (*Crataeva nurvala*) are the main plant species found in the swamp forests of the *haor* region. All of them are flood-tolerant species and can survive in the submerged condition for extended periods of time. However, among these, hijol, tomal (*Terminalia myriocarpa*), andkoroch trees are of the greatest value to the people and the environment [36]. Other plant species available in the wetlands include madar (*Erythrina variegata*), gab (*Diospyros peregrina*), makna (*Euryale ferox*), singara (*Trapa bispinosa*), jaldumur (a kind of Ficus), chitki (*Phyllanthus reticulatus*), thankuni (*Centella asiatica*), kalmi (*Ipomoea aquatica*), helencha (*Enhydra flactuans*), hogla (*Typha elephantina*), duckweed, water hyacinth, lotus, and water lily.

Only 4.37% (72,128 ha) of the total area of the 7 haor districts (1,651,992 ha) is covered by forest compared with the overall 17.78% forest area in Bangladesh. Among the haor districts, Moulvibazar has the highest forest cover (12.81%) with 28,900 ha of forest, followed by Habiganj (7.17%) with 14,721 ha, while the lowest forest cover, only 0.43%, is in Netrakona (799 ha). Brahmanbaria and Kishoreganj have virtually no forest cover.

3.5. Cross-Cutting Issues

3.5.1. Agricultural Mechanization

For *Boro* rice, haor farmers prepare their land during mid-October, transplant seedlings during mid-December, and harvest in mid-May. The power tiller is the machine exclusively used for tillage and land preparation. On the other hand, beels are the main source of irrigation water in the *haor* areas, and rivers are the second most important source. The other small-scale irrigation sources are khal (canal), pond, and dubas (small depressions). Low-lift pumps (LLPs) and shallow tube wells (STW) are mostly used to pump water to irrigate the crop fields. About 80% (745,748 ha) of the *Boro* area (931,451 ha) had been brought under irrigation by 2020 (Table 4), while in Bangladesh, overall, almost all the *Boro* areas (97%) are now irrigated. Kishoregonj has the largest (96%) *Boro* irrigation acreage, followed by Brahmanbaria (94%) and Netrakona (93%), while Moulvibazar has the lowest (63%) acreage [25,38]. However, the scarcity of water due to the drying up of the canals at the end of the monsoon season hampers irrigation.

Table 4. Status of irrigation for cultivation of *Boro* rice in the *haor* region.

District	*Boro* Area in 2020 (ha)	Irrigated *Boro* Area in 2020 (ha)	% *Boro* Irrigated Area	Irrigated *Boro* Area in 2014 (ha)	Increase /Decrease in Irrigated *Boro* Area (%)
Brahmanbaria	112,275	106,073	94	96,357	10.1
Kishoreganj	165,114	158,704	96	161,134	−1.5
Netrakona	182,891	170,445	93	162,348	5.0
Habiganj	119,661	83,806	70	85,425	−1.9
Moulvibazar	53,029	33,198	63	34,008	−2.4
Sunamganj	215,991	139,271	64	132,794	4.9
Sylhet	82,490	54,251	66	64,373	−15.7
Haor districts	931,451	745,748	80	736,439	−1.25
Bangladesh	4,762,130	4,638,866	97	4,621,862	0.4

The total number of agricultural laborers now engaged in farming has more than doubled from that in the 1950s; yet, the labor shortage during the sowing/planting and harvesting seasons has become a nagging problem in the *haor* areas. The situation for the farmers has become further complicated due to a sharp increase in labor wages. This has necessitated the use of machinery for *Boro* field operations from transplanting to harvesting. Nowadays, farmers find using machinery, like rice transplanters, reapers, and combine harvesters, cost effective, and thus, the use of such machinery is slowly expanding in the *haor* areas. There has been a substantial increase (55%) in the number of combine harvesters in the *haor* region from 348 in 2019 to 540 in 2020; the use of these machines is on the rise in every *haor* district. The number of reapers also increased by 8%, although not substantially, from 784 in 2019 to 849 in 2020 in the *haor* districts (Table S5).

The Department of Agriculture Extension (DAE) took the necessary initiatives for distributing newly purchased harvesters and reapers and repairing the old machines. However, the average capacity of a combine harvester is in the range of 30–35 ha [39], and thus, a huge number of these machines are required to harvest the *Boro* rice acreage across the *haor* region. The number of available combine harvesters in the *haor* districts is still too inadequate to cover the total *Boro* rice area. Farmers still need to hire migrant laborers for the harvesting of the *Boro* paddies in the *haor* areas almost every year. The situation can be improved through a quick extension of farm mechanization across the *haor* districts.

3.5.2. Agricultural Marketing

In the *haor* region, travel to and from the market is easier in the monsoon season when boats can navigate almost door to market, whereas in the dry season long walks across dried *haor* ridges are often necessary. The volumes of the farmers' produce are very small and far from the market, and the farmers are not organized and prepared for the marketing of their produce; they are not even aware of the market demands and prices. The paikers (brokers) go to the villages, purchasing the farmers' produce and selling it through the arots (a common private selling shed) to the retailers by giving a certain commission to the arotdar (arot owner). The producers, paikers, arotdars, retailers, and consumers are the main actors in the supply and market chain. In this chain, the intermediaries consume a large share of the profit, and the primary producer (farmer) is left with only a marginal profit.

3.6. Advances in Haor Agriculture

3.6.1. Crops

The adaptation of crops to a fragile ecosystem like the *haor* wetlands in the face of climate change adversities requires resilient varieties, suitable cropping patterns, appropriate irrigation techniques, and sustainable land management. Under stressful conditions, plants should possess the capacity to induce morphological, biochemical, and genetic changes [40,41]. Furthermore, certain modern techniques, like the application of biostimulants or hormones, and cultural practices can enhance the ability of plants to adapt to and cope with adverse situations [42,43]. Researchers of institutions of the National Agricultural Research System (NARS) of Bangladesh and related experts of various agricultural extension agencies, e.g., the DAE, are engaged in developing and disseminating climate-smart, stress-tolerant (salinity-, submergence-, drought-, and extreme temperature-tolerant) varieties and improved production technologies for sustainable increases in agricultural production. Some stress-tolerant rice and wheat varieties have already reached famers fields, with the prospect of up to 20% yield increase under varied environmental stresses. For example, the Bangladesh Rice Research Institute (BRRI) has developed and released submergence-tolerant, high-yielding varieties (HYV) of rice, such as BRRI dhan51 and BRRI dhan52, drought-tolerant BRRI dhan42 and BRRI dhan43, and cold-tolerant BRRI dhan56 and BRRI dhan57. The Bangladesh Agricultural Research Institute (BARI) has developed heat-tolerant wheat and tomato varieties. The BRRI scientists have adapted the "Alternate Wetting and Drying (AWD)" irrigation technique to local conditions for irrigation of rice to increase water use efficiency and conserve water resources.

In the *haor* areas, the *Boro*–fallow–fallow is the main cropping pattern, where crops are grown only in the Rabi season (Nov-April), and the land remains uncultivated during the Aus (April-July) and T. Aman (July-Nov) seasons. In some areas, there are small acreages of Aus and T. Aman rice on relatively high land. The most popular *Boro* rice varieties are BRRI dhan29, BRRI dhan28, BR19, BR14, Gochi, Rata, etc. BRRI dhan28 and BRRI dhan29 are grown in 80% of the *haor* rice lands. These two HYV rice varieties require 140 and 160 days to mature, and harvesting is usually conducted in mid-April and mid-May, respectively. But early flash floods occur almost every year, partially or even completely damaging the

Boro rice crop just before harvest. To escape this flash flood, it is essential to plant crops early and harvest by March or by early April at the latest. This requires the development of varieties that are tolerant to cold at both the seedling and reproductive stages. To protect *Boro* rice from cold stress in the *haor* areas, cold-tolerant, short-duration HYVs are necessary. Rice scientists are now working to develop such HYVs; some prospective breeding materials have been identified very recently and may shortly be available as HYV cultivars for growing in the *haor* region [44].

Aroids, locally known as latirajkachu (variety BARI Pani Kachu-1), and quick growing kangkong or gimakalmi (variety BARI Gimakolmi-1,2,3) are examples of varieties that can survive under submergence for several days during flash floods. The BARI-developed country bean is suitable for homestead vegetable gardening. Tomato, potato, cabbage, cauliflower, and carrot, which normally cannot grow due to the late recession of flood water crops, can be adapted to the haor conditions using the zero-tillage cultivation method. The BARI Lau-4 and BARI Shim-7 varieties have been tested and found to be adaptive, particularly to the changing climate of the Sylhet region. The On-Farm Research Division of BARI has developed a year-round homestead gardening model following raised bed systems through on farm testing in its Farming Systems Research Site, Golapganj, Sylhet (called BARI Golapganj, Sylhet model).

3.6.2. Livestock and Poultry

Livestock farming serves as a valuable income source and provides essential nutrients for human consumption, making it a viable livelihood option, especially for small-scale and resource-poor households due to its low investment and technology requirements [45]. The Fayoumi chicken has been found to outperform local chickens in the *haor* areas in terms of weight gain, egg production, and mortality rate. The Jinding duck performs better than the local and the Khaki Campbell in terms of body weight, growth rate, egg quality, and mortality rate. Sheep, especially garole sheep, grow and reproduce very well in *haor* areas, and they are a very good source of protein for the rural people because of their excellent body weight gain and prolific nature. The cattle-fattening program offers hope for the *haor* people and a good source of income [46]. These simple livestock technologies can substantially help the *haor* inhabitants with food and nutrition security, incomes, and poverty alleviation.

3.6.3. Fisheries

In *haor* areas, different culture methods are used for fish production, such as monoculture practices using one species or polyculture practices using more than one species in seasonal or homestead ponds. However, polyculture systems are more beneficial because surface, column, and bottom feeder fish are cultured together, and in this system, feeds are properly utilized. In recent years, the cage culture practice has been tested in *haor* areas. Cage culture is suitable for open water bodies. Growth promoter probiotics are also being used to increase fish production. The NGO, Practical Action, has been working on a proven model for the co-production of fish and vegetable crops, with the potential to protect them from floods. This model is also called an integrated floating cage aqua-geoponic system (IFCAS)—an innovation in fish and vegetable production for shaded ponds in Bangladesh [47].

In Kata fish cultures, one side of the homestead pond is cut to link to cropland to receive mola and other small fish species once in every 15 days. During floods, tree branches are dumped into the flooded pond. Rice bran is provided as feed; then, fish are grown even in floods. Piles of bush are tacked to lure wild fish and to make them flock to the ponds during floods. In addition, some feeds may be applied to attract fish. This technique was tested in Sylhet and proved to be useful. Protein-rich fishes, like shing, koi, mola, tilapia, etc., can be reared starting in April, which would provide two harvests. The fish are not lost during floods as they prefer to stay under the mud in the pond.

3.7. Strategies for Agricultural Development

Several strategic development plans and policies of the Government of Bangladesh (GoB) have emphasized the development of agriculture in the otherwise productive fragile ecosystems or marginal lands, such as the *haor* ecosystem. Some of the more recent GoB policy documents are the Bangladesh Haor and Wetland Development Board (BHWDB) Master Plan (2012–2032); Vision 2041: Perspective Plan of Bangladesh (2021–2041); the Bangladesh Climate Change Strategy and Action Plan 2009; the National Rural Development Policy 2001; the National Agriculture Policy 2018; the 8th Five Years Plan (2020–2025); and the Bangladesh Delta Plan 2100. Similarly, interventions in other ecological settings, like *char*, coastal areas, barind, and hill regions, have showcased the effectiveness of targeted strategies aligned with local contexts, resulting in enhanced resilience and prosperity. Through a blend of innovative approaches and community engagement, these policies have not only uplifted livelihoods but also fostered environmental stewardship, underscoring the potential for sustainable development across Bangladesh's diverse landscapes.

The Bangladesh Haor and Wetland Development Board (BHWDB) has developed a master plan to alleviate the residents of the haor regions from poverty. The master plan framework was developed in 2012, and it is to be implemented until 2032 while incorporating changes as necessary along the way. The project is divided into three categories: short-term (1–5 years), medium-term (6–10 years), and long-term (11–20 years). Currently, there are 154 development projects in the haor region with the top three areas of development being transportation, fisheries, and agriculture. Nevertheless, a significant portion (12%) of the total funding (BDT 2,804,305) is dedicated to power and energy.

In the light of these GoB policies, agricultural development strategies for the haor ecosystem should be emphasized in the following areas (Figure 11):

Figure 11. Proposed agricultural development strategies for *haor* ecosystem.

3.7.1. Spatial Adjustment of Crops

The *kanda*/ridge land (10–40% land) should be used by developing irrigation facilities so that Rabi crops, like pulses, oil seeds, and vegetables, can be grown on these lands.

3.7.2. Temporal Adjustment of Crops

For *Boro* rice, the development of short-duration, cold-tolerant varieties should be expedited to facilitate early harvest to avoid flash floods. Crop diversification with high-value short-duration vegetables, like tomato and cauliflower; pulse crops, like mung bean and lentil; and spices, like onion, garlic, and tuber crops, could be harvested early, averting flood damage.

3.7.3. Up-Scaling of Innovative Technologies

The NARS institutes and local farmers have developed a good number of innovative technologies to adapt to flash flood/flood conditions for successful crop production. These technologies, such as sack gardening, vegetable cultivation on raised beds, tower gardens, floating agriculture, and the sorjan system, should be promoted, where feasible.

3.7.4. Strengthening Agricultural Mechanization

It is essential to intensify and strengthen farm mechanization in the face of acute labor shortage. The agricultural machinery manufacturing sector should be supported to improve its capacity to manufacture competitively priced and high-quality machines and spare parts by providing incentives; they should be encouraged to produce farmer-friendly machinery.

3.7.5. Addressing Soil Degradation

Soil degradation is undermining the long-term capacity of the wetland *haor* agro-ecosystem. Failure to address this problem will erode crop productivity. Although nutrient inputs, new crop varieties, and technologies may work well in the foreseeable future, the challenge of meeting human needs will keep growing. Excessive use of chemical fertilizers and pesticides may soon result in productivity losses. The Land Degradation Neutrality Target Setting Program (LDN-TSP) was implemented in Bangladesh from December 2016 to February 2018 with the support provided by the United Nations Convention to Combat Desertification (UNCCD) (UNCCD 2018). Bangladesh has further committed to the achievement of the LDN leverage plan and to the implementation of the transformative LDN projects to achieve LDN by 2030. According to target 1 of LDN, the Government of Bangladesh will increase soil fertility in 2000 km^2 of cropland area by 2030.

3.7.6. Improvement of Livestock and Poultry

The main challenges facing livestock rearing in *haor* areas are scarcity of grazing fields, insufficient livestock care services, lack of feeds and fodder, and lack of modern technologies. Huge areas of fallow land and water provide the natural resource base for the intensification of livestock production. Land can be used for grass production for forage. Flood-tolerant fodder grasses, like napier and para, can be grown as fodder/silage for livestock. Leaves of floating grasses, e.g., pana (a natural quick growing grass), can be fed to goats. The other good alternative is to grow German grass, which can survive in flood water and also withstand partial shading.

The cattle-fattening program opens up a new hope for local people in *haor* areas and has gained noticeable financial support. Sheep rearing, especially garole sheep, which can withstand drought and eat any grasses available, should be promoted for incomes and protein supplements for the rural people. Locally improved breeds (Sonali/Faomi) may be reared which are disease resistant. Important traditional and recombinant vaccines and biologics against major diseases of ruminants and poultry are being developed using the molecular biotechnological approach.

3.7.7. Improvement of Aquaculture

The following strategies should be adopted to improve the aquaculture: (i) exploration of novel fish feed ingredients from the *haor*-based aquatic plant and animal sources for strengthening fish feed industry; (ii) measurement of siltation in *haor*, *beel*, and river each year to help researchers and policy makers make a proper management plan; (iii) banks of the ponds can be raised above flood level for fish culture; (iv) re-excavation of beels, canals, and rivers in *haor* areas to revive fish breeding grounds and mother fishery; (v) establishment of fish pass or fish-friendly structure to reconnect river water with *haor* and floodplain water for successful fish migration; (vi) identification of breeding season of indigenous fish species; (vii) impact assessment of climate change on fish breeding season and fecundity; (viii) integrated floating cage aqua-geoponic system (IFCAS); and (ix) development of breeding protocol of some important freshwater species (*pabda*, *gulsha*, *tengra*, *balachata*, *angush*, *kakila*, *rani*, *meni*, *piali*, *gutum*, *baim*, *bata*, *tatkini*, *bacha*, *barashi*, etc.). Minimization of the use of pesticides for crops and prevention of fish diseases are also important issues for fisheries and aquaculture development.

3.7.8. Agribusiness Development

In the *haor* areas, the high prices of inputs, like fertilizer, seed, and labor, pose a significant constraint. Additionally, the transportation of harvested produce, such as rice grain, is challenging due to the non-metal dirt roads in most areas. However, there are opportunities for agribusiness development, including fertilizer and pesticide industries, feed mills, and other related businesses, driven by the local and regional demand for quality agricultural inputs. To enhance value chains and relationships among farmers, paikers, arotdars, and retailers, modern digital facilities like mobile phone apps can be utilized. Expanding the government's Union Digital Centers (UDCs) to the *haor* areas would enable the delivery of agricultural extension, marketing, education, health, and social services. These centers should also incorporate an effective early warning system to help farmers prepare for unexpected weather events and to adjust their farming practices accordingly. Furthermore, with the increasing use of computers, mobile phones, and motorized two-wheelers and the expansion of electricity in the *haor* areas, skilled mechanics can thrive in businesses, and women can be engaged in computer- and mobile phone-related ventures.

3.8. Potential Challenges in Implementing Strategies

3.8.1. Policy Challenges

In navigating policy challenges, all the strategies emphasize the need for comprehensive regulatory frameworks and streamlined bureaucratic processes. They identify potential hurdles, such as conflicting interests among stakeholders, regulatory ambiguities, and the lack of coordination between relevant government agencies. By advocating for clear policy directives, stakeholder consultations, and interagency collaboration, it may be possible to overcome these challenges and ensure coherent the implementation of agricultural development strategies.

3.8.2. Financial Constraints

Mobilizing adequate funding and facilitating access to credit for farmers and entrepreneurs is essential in overcoming financial limitations. Strategies such as exploring alternative financing mechanisms, incentivizing private sector investments, and promoting public–private partnerships can optimize funding allocation and resource utilization.

3.8.3. Technological Barriers

Technological barriers, such as limited access to innovative agricultural practices and low technological literacy, present challenges to implementation. The adoption of appropriate technologies tailored to the needs and capacities of *haor* ecosystem stakeholders is crucial to overcome these barriers. This underscores the importance of capacity-building initiatives, technology transfer programs, and investment in research and development. By promoting knowledge exchange and skill development, stakeholders can harness the potential of technology to enhance productivity and resilience in agricultural systems.

3.8.4. Community Engagement Strategies

Meaningful community engagement through participatory approaches, stakeholder consultations, and community-driven decision-making processes is crucial for ensuring the success and sustainability of agricultural development initiatives. Limited community involvement, social barriers, and the need for the inclusive representation of marginalized groups are the main identified challenges in the wetland ecosystems. Capacity-building workshops, awareness campaigns, and the establishment of community-based organizations can empower local communities and foster ownership of development initiatives.

4. Conclusions

In this study, the extent and distribution, biophysical characteristics, biodiversity, demographic features, agricultural production systems, and agricultural development opportunities in the *haor* ecosystem of Bangladesh have been reviewed. Low-lying lands, recurrent floods and flash floods, and prolonged wetness, along with declining soil fertility and misuse of natural resources by the local inhabitants, are the major challenges facing higher and sustainable crop, livestock, and fish production in the *haor* region. With appropriate technological and management interventions, the productivity of the *haor* can be substantially improved. This paper provides suggestions regarding strategies for increasing crop yields and cropping intensity and boosting livestock and fish production, which may contribute to food security, poverty reduction, and the livelihood improvement of the peoples of *haor* areas.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/ecologies5020017/s1, Table S1: Upazila-wise distribution of *haor* areas in different districts of Bangladesh; Table S2: Ranges and classes of soil pH in *haor* region during 2006–2021; Table S3: Range and classes of soil pH in *haor* region during 1999–2002; Table S4: Land use by number of crops grown per year in *haor* districts in 2020; Table S5: Status of combine harvester and reaper in the *haor* region.

Author Contributions: S.M.B. and M.J.I.: conceptualization, methodology, formal analysis, investigation, writing original draft; S.S., M.J. and G.M.P.: visualization, writing, review and editing; M.A.S. and M.A.H.: writing—review and editing and supervision. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data are contained within the article.

Acknowledgments: We are highly grateful to the Computer and GIS unit of Bangladesh Agricultural Research Council (BARC) for providing the maps.

Conflicts of Interest: The authors declare no conflicts of interest.

References

1. Bangladesh-Delta-Plan-2100—Planning Commission-Government of the People's Republic of Bangladesh. Available online: http://www.plancomm.gov.bd/site/files/0adcee77-2db8-41bf-b36b-657b5ee1efb9/Bangladesh-Delta-Plan-2100 (accessed on 22 June 2023).
2. Uddin, M.T.; Hossain, N.; Dhar, A.R. Business Prospects and Challenges in Haor Areas of Bangladesh: Business Prospects and Challenges in Haor Areas. *J. Bangladesh Agric. Univ.* **2019**, *17*, 65–72. [CrossRef]
3. Sarma, P.K. Scenario of Haor Vulnerabilities and Other Obstacles for Sustainable Livelihood Development in Nikli Upazila. *J. Bangladesh Agric. Univ.* **2010**, *8*, 283–290. [CrossRef]
4. Hoq, M.S.; Uddin, M.T.; Raha, S.K.; Hossain, M.I. Welfare Impact of Market Participation: The Case of Rice Farmers from Wetland Ecosystem in Bangladesh. *Environ. Chall.* **2021**, *5*, 100292. [CrossRef]
5. Kamruzzaman, M.; Shaw, R. Flood and Sustainable Agriculture in the Haor Basin of Bangladesh: A Review Paper. *Univ. J. Agric. Res.* **2018**, *6*, 40–49. [CrossRef]

6. Nishat, B.; Chakrabarty, S.K.; Hasan, M.E.; Rahman, A.J.M.Z. *Rivers Beyond Borders: India Bangladesh Trans-Boundary River Atlas*; Drik Publications: Dhaka, Bangladesh, 2014.
7. Thakur, J. *India-Bangladesh Trans-Boundary River Management: Understanding the Tipaimukh Dam Controversy*; ORF Issue Brief No. 334; Observer Research Foundation: New Delhi, India, 2020; p. 18.
8. Akonda, A.W.; Scott, D.A. *A Directory of Asian Wetlands*; IUCN: Gland, Switzerland, 1989; pp. 541–581.
9. Bokhtiar, S.; Samsuzzaman, S.; Jahiruddin, M.; Panaullah, G. *Agricultural Development for Fragile Ecosystems in Bangladesh*, 1st ed.; Bangladesh Agricultural Research Council: Dhaka, Bangladesh, 2023; ISBN 978-984-35-3818-5.
10. Haor Master Plan Volume II. Available online: https://dbhwd.gov.bd/site/publications/e345b982-26a4-4b4a-9f11-1ba389f22509/%E0%A6%B9%E0%A6%BE%E0%A6%93%E0%A6%B0-%E0%A6%AE%E0%A6%BE%E0%A6%B8%E0%A7%8D%E0%A6%9F%E0%A6%BE%E0%A6%B0-%E0%A6%AA%E0%A7%8D%E0%A6%B2%E0%A6%BE%E0%A6%A8-%E0%A6%AD%E0%A6%B2%E0%A6%BF%E0%A6%89%E0%A6%AE-%E0%A7%A8 (accessed on 18 April 2024).
11. Haors and Wetlands—Banglapedia. Available online: https://en.banglapedia.org/index.php/Haors_and_Wetlands (accessed on 14 May 2023).
12. Harris, W.G. Phosphate Minerals. *Soil Mineral. Environ. Appl.* **2002**, *7*, 637–665.
13. Quilliam, R.S.; van Niekerk, M.A.; Chadwick, D.R.; Cross, P.; Hanley, N.; Jones, D.L.; Vinten, A.J.A.; Willby, N.; Oliver, D.M. Can Macrophyte Harvesting from Eutrophic Water Close the Loop on Nutrient Loss from Agricultural Land? *J. Environ. Manag.* **2015**, *152*, 210–217. [CrossRef] [PubMed]
14. Bagchi, R.; Miah, M.A.; Hazra, P.; Hasan, R.; Mondal, H.S.; Paul, S.K. Exploring the Effect of Rainfall Variability and Water Extent in Tanguar Haor, Sunamganj. *Aust. J. Eng. Innov. Technol.* **2020**, *2*, 66–76.
15. Starkel, L.; Singh, S. *Rainfall, Runoff and Soil Erosion in the Globally Extreme Humid Area, Cherrapunji Region, India*; Institute of Geography and Spatial: Warszawa, Poland, 2004; Volume 191, ISBN 8387954322.
16. Parry, M.L.; Canziani, O.; Palutikof, J.; Van der Linden, P.; Hanson, C. *Climate Change 2007-Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Fourth Assessment Report of the IPCC*; Cambridge University Press: Cambridge, UK, 2007; Volume 4, ISBN 0521880106.
17. Hirabayashi, Y.; Mahendran, R.; Koirala, S.; Konoshima, L.; Yamazaki, D.; Watanabe, S.; Kim, H.; Kanae, S. Global Flood Risk under Climate Change. *Nat. Clim. Chang.* **2013**, *3*, 816–821. [CrossRef]
18. Gardner, R.C.; Finlayson, C. Global Wetland Outlook: State of the World's Wetlands and Their Services to People. In Proceedings of the Ramsar Convention Secretariat, Gland, Switzerland, 5 October 2018; pp. 2020–2025.
19. *Master Plan of Haor Areas: Volume 1, Summary Report*; Ministry of Water Resources, Government of the People's Republic of Bangladesh: Dhaka, Bangladesh, 2012.
20. Rahman, M.R. *Technological Fixes for Disaster Management in Bangladesh*; People at Risk: Disaster and Despair, Disaster Research Training and Management Centre (DRTMC); University of Dhaka: Dhaka, Bangladesh, 2019; pp. 71–95.
21. Abedin, J.; Khatun, H. Impacts of Flash Flood on Livelihood and Adaptation Strategies of the Haor Inhabitants: A Study in Tanguar Haor of Sunamganj, Bangladesh. *Dhaka Univ. J. Earth Environ. Sci.* **2019**, *8*, 41–51. [CrossRef]
22. Ministry of Disaster Management and Relief-Government of the People's Republic of Bangladesh. Available online: http://203.76.123.197/egls/documents/357/search-detail (accessed on 22 April 2024).
23. Population-and-Housing-Census-Bangladesh Bureau of Statistics-Government of the People's Republic of Bangladesh. 2022. Available online: http://www.bbs.gov.bd/site/page/47856ad0-7e1c-4aab-bd78-892733bc06eb/Population-and-Housing-Census. (accessed on 12 April 2023).
24. Gillingham, S. CARE Bangladesh Programme Strategy: Haor Region 2015–2020. 2016. Available online: https://www.carebangladesh.org/publication/Publication_5340141.pdf. (accessed on 13 April 2023).
25. *Yearbook of Agricultural Statistics*; Bangladesh Bureau of Statistics (BBS), Statistics Division, Ministry of Planning, Government of the People Republic of Bangladesh: Dhaka, Bangladesh, 2020; ISBN 9789844750470. Available online: https://bbs.gov.bd/site/page/3e838eb6-30a2-4709-be85-40484b0c16c6/Yearbook-of-Agricultural-Statistics (accessed on 13 April 2023).
26. Jabbar, M.A.; Alam, M.S. Adoption of Modern Rice Varieties in Bangladesh. *Bangladesh J. Agric. Econ.* **1993**, *16*, 1–19.
27. Muttaleb, M.A.; Shahidullah, S.M.; Nasim, M.; Saha, A. Cropping Systems and Land Use in Sylhet Region. *Bangladesh Rice J.* **2017**, *21*, 273–288. [CrossRef]
28. Rashid, M.H.A.; Islam, A.; Shirazy, B.J.; Shahidullah, S.M. Cropping Systems and Land Use Pattern in Rajshahi Region. *Bangladesh Rice J.* **2017**, *21*, 237–254. [CrossRef]
29. Cell, C.C. Adaptive Crop Agriculture Including Innovative Farming Practices in Haor Basin. 2009. Available online: http://203.76.123.197/egls/documents/19/search-detail (accessed on 27 April 2023).
30. Alam, M.S.; Quayum, M.A.; Islam, M.A. Crop Production in the Haor Areas of Bangladesh: Insights from Farm Level Survey. *Agriculturists* **2010**, *8*, 88–97. [CrossRef]
31. Aziz, M.S.B.; Hasan, N.A.; Mondol, M.M.R.; Alam, M.M.; Haque, M.M. Decline in Fish Species Diversity Due to Climatic and Anthropogenic Factors in Hakaluki Haor, an Ecologically Critical Wetland in Northeast Bangladesh. *Heliyon* **2021**, *7*, e05861. [CrossRef]
32. *Yearbook of Agricultural Statistics*; Bangladesh Bureau of Statistics, Ministry of Planning, Government of the People's Republic of Bangladesh: Dhaka, Bangladesh, 2012.

33. Alam, M.S.; Masum, K.M.; Campus, B.; Sholashahor, B. Status of Homestead Biodiversity in the Offshore Island of Bangladesh. *Res. J. Agric. Biol. Sci.* **2005**, *1*, 246–253.
34. Liong, S.; Lim, W.; Kojiri, T.; Hori, T. Advance Flood Forecasting for Flood Stricken Bangladesh with a Fuzzy Reasoning Method. *Hydrol. Process.* **2000**, *14*, 431–448. [CrossRef]
35. Miah, M.R. Enhancing Food Security through Acclimatized Species Domestication in the Haor Region. *ABC J. Adv. Res.* **2013**, *2*, 49–65. [CrossRef]
36. Bennett, D.S.; Scott, D.D.; Karim, A.; Sobhan, I.; Khan, A.; Rashid, S.M.A. Interpretive Description of the Region's Wetlands; Wetland Resources Specialist Study, Northeast Regional Water Management Plan, Bangladesh Flood Action Plan 6. 1995. Available online: http://www.bicn.com/wei/resources/nerp/wrs/index.htm (accessed on 5 August 2023).
37. Alam, M.S.; Hossain, M.S. *Banglapedia: National Encyclopedia of Bangladesh*, 2nd ed.; Asiatic Society of Bangladesh: Dhaka, Bangladesh, 2012.
38. *Yearbook of Agricultural Statistics*; Bangladesh Bureau of Statistics, Ministry of Planning, Government of the People's Republic of Bangladesh: Dhaka, Bangladesh, 2015.
39. Islam, A.S. *Rice Mechanization in Bangladesh*, 1st ed.; Kashem, M., Ed.; Bangladesh Rice Research Institute: Gazipur, Bangladesh, 2018.
40. Islam, M.J.; Kim, J.W.; Begum, M.K.; Sohel, M.A.T.; Lim, Y.-S. Physiological and Biochemical Changes in Sugar Beet Seedlings to Confer Stress Adaptability under Drought Condition. *Plants* **2020**, *9*, 1511. [CrossRef]
41. Islam, M.J.; Ryu, B.R.; Rahman, M.H.; Rana, M.S.; Cheong, E.J.; Wang, M.-H.; Lim, J.-D.; Hossain, M.A.; Lim, Y.-S. Cannabinoid Accumulation in Hemp Depends on ROS Generation and Interlinked with Morpho-Physiological Acclimation and Plasticity under Indoor LED Environment. *Front. Plant Sci.* **2022**, *13*, 984410. [CrossRef]
42. Islam, M.J.; Mou, M.A.; Razzak, M.A.; Lim, Y.-S. Exogenous Putrescine-Mediated Modulation of Drought Stress Tolerance in Sugar Beet: Possible Mechanisms. In *Sugar Beet Cultivation, Management and Processing*; Springer: Berlin, Germany, 2022; pp. 441–457.
43. Islam, M.J.; Uddin, M.J.; Hossain, M.A.; Henry, R.; Begum, M.K.; Sohel, M.A.T.; Mou, M.A.; Ahn, J.; Cheong, E.J.; Lim, Y.-S. Exogenous Putrescine Attenuates the Negative Impact of Drought Stress by Modulating Physio-Biochemical Traits and Gene Expression in Sugar Beet (*Beta vulgaris* L.). *PLoS ONE* **2022**, *17*, e0262099. [CrossRef]
44. Bangladesh | International Rice Research Institute. Available online: https://www.irri.org/where-we-work/countries/bangladesh (accessed on 28 May 2023).
45. Rabby, T.G.; Fredericks, L.J.; Alam, G.M. Livestock Husbandry Strategy in Alleviating Poverty in the Haor Area of Bangladesh. *Asian J. Anim. Vet. Adv.* **2013**, *8*, 41–52. [CrossRef]
46. Ali, S.; Kashem, M.A.; Aziz, M.A. A Scenario of Agricultural Technologies Practiced in Haor Area of Sunamganj District in Bangladesh. *Seedling* **2018**, *5*, 7–69.
47. Haque, M.M.; Alam, M.R.; Alam, M.M.; Basak, B.; Sumi, K.R.; Belton, B.; Murshed-E-Jahan, K. Integrated Floating Cage Aquageoponics System (IFCAS): An Innovation in Fish and Vegetable Production for Shaded Ponds in Bangladesh. *Aquac. Rep.* **2015**, *2*, 1–9. [CrossRef]