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Factors responsible for community transmission of COVID-19: Case study of Dhaka, Narayanganj and Gazipur districts in Bangladesh

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ABSTRACT

Coronavirus is a highly communicable disease that transmits within a community. The present study is an endeavor to identify the responsible factors of community transmission of the coronavirus (COVID-19) disease in Dhaka, Narayanganj and Gazipur districts of Bangladesh. The study follows qualitative approach for identifying and analyzing the factors. The study reveals that the three districts covering more than one-third of the total confirmed cases (i.e. about 39.31%) by March 7, 2023 from the first outbreak in Bangladesh. The study identified some important causes (i.e. Returnees' apathy, hiding of information and lack of awareness, concentration of economic activities, large number of commuter, place of first outbreak, relative location, concentration of slums, breaking of law, and urbanization) responsible for rapid community transmission of the virus in these districts. Based on the expert opinion maintaining self-home quarantine, social distancing and operative surveillance might be useful for reducing community transmission of coronavirus in the study area.

Keywords: Community transmission; COVID-19; Large number of commuters; Urbanization; Returnees' apathy

1. Introduction

Recently emerged COVID-19 is a highly contagious disease (WHO, 2020a) that has spread globally from Wuhan, China and identified as a pandemic (Eschner, 2020*).* A novel coronavirus was first identified in persons exposed to a seafood or wet market of China (Perlman, 2020) in December 2019. Until February 11, 2020, the COVID-19 was known as "2019 novel coronavirus".

The International Committee on Taxonomy of Viruses (ICTV) named the novel virus in the form of a bioRxiv preprint as SARS CoV-2 (severe acute respiratory syndrome coronavirus 2) (Hu et al., 2021). WHO announced “COVID-19” (Corona Virus Disease - 2019) as the name of this new disease on 11 February, 2020. Coronavirus is characterized as a respiratory disease of human that is severe in most cases and about 75 to 80% similar to severe acute respiratory syndrome coronavirus (SARS-CoV) (Zhu et al., 2020). Besides, it is more closely related to several bat coronaviruses (Zhou et al., 2020b). As of 7 March 2023, there have been 6.8 million (i.e. 6,866,434) confirmed fatalities and more than 750 million (i.e.759, 408,703) confirmed cases identified all over the world (WHO, 2023).

The existence of COVID-19 disease in human body depends on the transmission from one person to another (WHO, 2020b). There are four transmission stages of novel coronavirus disease that include (1) no cases, (2) sporadic cases, (3) cases of clusters and (4) community transmission. In first stage, there are no confirmed cases of COVID-19. During the second stage, there is one or more confirmed cases of coronavirus that are either imported or locally acquired is often called sporadic case of transmission. On the third stage, maximum cases of coronavirus transmit both locally and chain-wise that is referred as cluster transmission. On final stage, outbreak of the virus infects huge number of people through chain transmission and it is referred as community transmission (WHO, 2020d). However, novel coronavirus can be transmitted through different ways including close contact with infected person (i.e. within 1metre); droplet from infected people when he coughs, sneezes, talks or sings (Liu et al., 2020). Moreover, touching surfaces and objects by the infected person including touching mouth, eyes and nose or respiratory secretions expelled by infected individuals on surfaces and objects (i.e. fomites or contaminated surfaces) might be responsible for transmitting the virus from one person to another (Van et al., 2020). Furthermore, urine and stools from infected person (i.e. fecal-oral) might spread the virus to human body (Guan et al., 2020). Virus can replicate in blood cell (i.e. blood-borne transmission) (Chang et al., 2020). However, medical wastage suspended in the air (i.e. air borne transmission) and mammals (e.g. dog, cat) might be the infectious agents of the virus to transmit from one person to another (WHO, 2014; Sit et al., 2020).

The distributional pattern of the virus in China carries essence in studying spatial epidemiology (Miquel, 2014; Novel, 2020). The epidemic has spread very quickly and took only 30 days to expand from Hubei province to the rest of mainland China. Within 14 days, it spread outside China and started to invade the world. Outside China, Thailand confirmed the first case of novel coronavirus on 13 January 2020 (WHO, 2020c). The first confirmed case of COVID-19 in Bangladesh was identified in early March 2020 in the patient returned from Italy. By 7 March 2023, there have been 2, 037, 871 confirmed cases and 29, 445 deaths reported in Bangladesh (WHO, 2023; DGHS, 2023a). In terms of confirmed cases and fatalities, Bangladesh is the 46th worst affected country in the world and 2nd in the South Asian countries by the mentioned date (WHO, 2023). Coronavirus spread across the country within a very short time (i.e. two months) (IEDCR, 2020b). Meanwhile, community transmission started in the country following some rapidly growing clusters in Dhaka, Narayanganj and Gazipur districts. According to Basak et al. (2022), about 80% COVID-19 cases are concentrated in the cluster of Dhaka and Narayanganj within a month from the first outbreak. There are a number of biological factors of human being associated with the spread of novel coronavirus such as age, sex, life expectancy, diet and nutrition (Grant et al., 2020; Lau et al., 2020; Rate, 2020; Zhou et al., 2020a). Besides, a number of socio-demographic and geographical factors that are responsible for rapid transmission of the disease such as social connectivity, religion, education, governance, household size, population size, population density, rural and urban population, migration, and tourism (Stojkoski et al., 2020; Basak et al., 2022). However, there was a gap in research on the identification of possible responsible factors of COVID-19 for community transmission in Bangladesh. Therefore, present study tries to reveal the responsible factors of the disease for community transmission in and around Dhaka district.

The study would be helpful to identify the possible responsible factors of a contagious disease transmission. Government of a country would be capable to curb the contagious disease by knowing the potential factors of virus transmission within the community. On the other hand, the study would also be helpful for knowing how cluster area of a country becomes more vulnerable for the transmission of a contagious disease.

2. Study area

Based on the nature of available secondary data from the mentioned sources (mentioned in the research method and materials section) on confirmed cases, the study identified Dhaka, Narayanganj and Gazipur districts to analyze the responsible factors of community transmission of the virus (Fig. 1). The area of Dhaka district is 1,463.60 square kilometers and the density of population is 10, 067 per square kilometer (Population and Housing Census, 2022). On the other hand, Narayanganj district covers 683.14 square kilometers and the density of population is 5, 712 per square kilometer (Population and Housing Census, 2022). However, Gazipur district is covered by 1,770.54 square kilometers and 2, 914 people live in per square kilometer (Population and Housing Census, 2022). The three districts are predominantly urbanized areas that are the economic (e.g. garment factories, shopping mall, markets, restaurants), political and cultural hub of Bangladesh. Moreover, there are 75 universities, 23 medical colleges, 25 technical training colleges, 20 government teachers training college are located in these districts. Besides, one metropolitan area and two city corporations (i.e. Dhaka Metropolitan Area, Narayanganj City Corporation and Gazipur City Corporation) are located in these three districts in which the density of population is comparatively higher than in the sub-district areas.

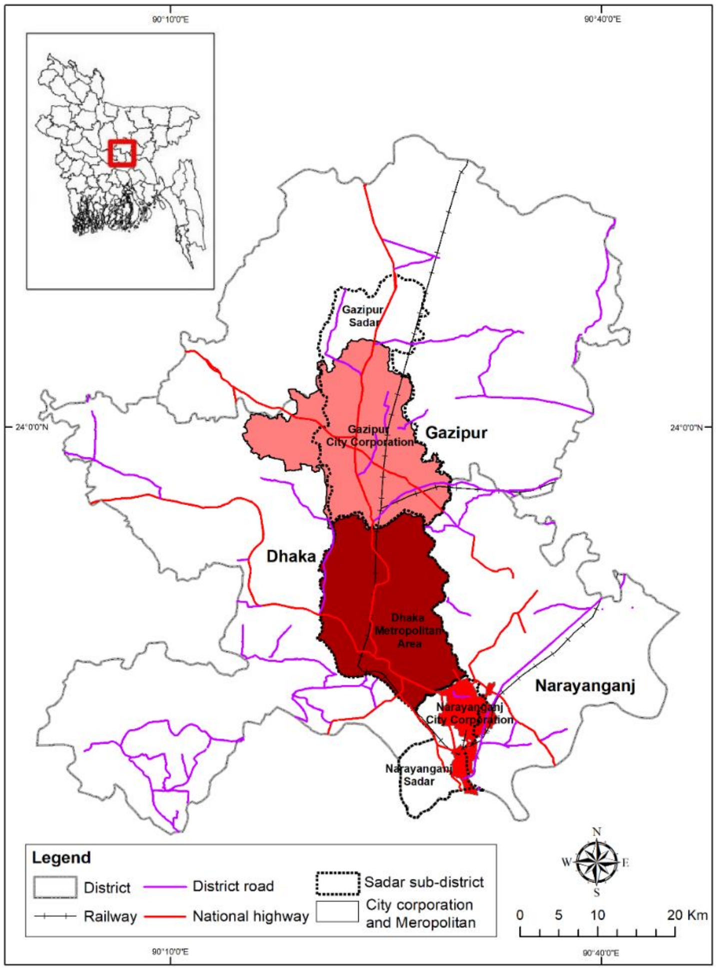

Fig. 1. The location of the three study districts.

As of 7 March 2023, total the COVID-19 patients in Bangladesh are 2, 037,871 in Bangladesh. Of these, Dhaka, Narayanganj, and Gazipur districts account for 801, 151 COVID-19 cases. The three districts covered more than one-third of the total confirmed cases (i.e. about 39.31%) from the first outbreak to March 7, 2023. Dhaka continues to remain the worst-affected district in terms of the number of cases caused by the deadly virus. As of 7 March 2023, a total of 728, 887 (about 35. 77 percent of all cases) of COVID-19 confirmed cases are detected in Dhaka district alone and stood first in rank in cases of confirmed cases. Narayanganj have seen the fifth highest cases of COVID-19 confirmed patients in the country (i.e. 36, 835 which is about 1.81% of the confirmed cases in Bangladesh). Moreover, Gazipur district is the sixth hotspot where, confirmed cases of COVID-19 patients stood as 35, 429 (about 1.74% of the confirmed cases in Bangladesh) (DGHS, 2023a). Therefore, this cluster area is the perfect ground for the present study.

3. Research method and materials

The present study adopts qualitative approach of collecting and analyzing data and information. To identify the factors of community transmission in and around Dhaka district, primary data were collected through interview of relevant persons purposively selected from the study area by using a semi-structured questionnaire. Fifteen Key Informant Interviews (KIIs) were conducted that includes academicians (n=3), health workers (n=4), administrative officers (n=5) and returnees (n=3). The interviews of the relevant persons were conducted in-person. The KIIs were conducted to identify the responsible factors of COVID-19 for community transmission and these factors were validated by the field observations and secondary data. Therefore, 15 KIIs are supportive for the present study.

The identification of the responsible factors was followed a three-step process. Firstly, the respondents were asked to identify the most important factors of community transmission from social, economic and geographical point of view. The respondents were free to identify as many factors as they wish for the first phase of the interview. Additionally, the respondents were asked to identify the relevant causes and issues of the identified factors. In the second step, the respondents were provided with the common factors and associated issues that were previously identified by all the respondents (i.e. 15 respondents). The respondents were then asked to rank the common factors by distributing full marks (i.e. 100) to all the factors. The respondents were then asked to give weights to the individual issues of the identified factors in a 10-points rating scale from 0 to 10. In the third step, the final factors (with their averaged individual ranks) and associated issues (with their individual weights) were provided for validation. The identified factors and associated issues were then visualized by using the software Gephi (version 0.9.2). In addition to the respondents' interviews, a number of field visits in the three districts were undertaken to observe the real-ground situation of the factors identified by the respondents. The secondary data used in this study has been collected through reviewing of existing literature including article, book chapter and other relevant documents. The study has taken verbal consent from the respondents before the interviews.

4. Results of the Study

4.1. Socio-demographic characteristics of the people of the study area

Socio-demographic characteristics including gender, religion, and literacy rate of the people of study area are more or less similar (Table 1). Therefore, people of the clusters have similar practices during the pandemic. Thus, community transmission of COVID-19 in these three districts got the momentum from the very beginning.

Table 1: Socio-demographic characteristics of the people of the study area

Name of the District	Gender (%)		Religion (%)		Literacy Rate (%)
	Male	Female	Muslim	Non-muslim	
Dhaka	53.51	46.49	94.82	5.18	84.68
Narayanganj	51.57	48.43	95.17	4.83	79.09
Gazipur	51.94	48.06	94.40	5.6	81.25

Source: Population and Housing Census, 2022

4.2. Factors responsible for community transmission

The respondents were identified a total number of nine factors that are highly responsible for community transmission within and between the most affected areas of the three districts. According to the aggregated ranks given by the respondents, the nine responsible factors from highest to lowest rank are: returnees' apathy, hiding of information and lack of awareness, concentration of economic activities, large number of commuter, place of first outbreak, relative location, concentration of slums, breaking of law and urbanization (Fig. 3). Moreover, a total number of 22 associated issues of the nine factors were identified by the respondents. The respondents identified that roaming outside without any valid reason (weight: 2.71) and overlooking of the rule for self-quarantine (weight: 2.21) were the two most relevant issues of the factor- returnees' apathy. Economic activities (weight: 2.26) and the existence of garment industries (weight: 1.59) were identified as the major issues of the factor-economic zone. Likewise, connectivity (weight: 7.0) and neighboring districts/locations (weight: 6.0) were the two mostly relevant issues of the relative location factor (Fig. 2).

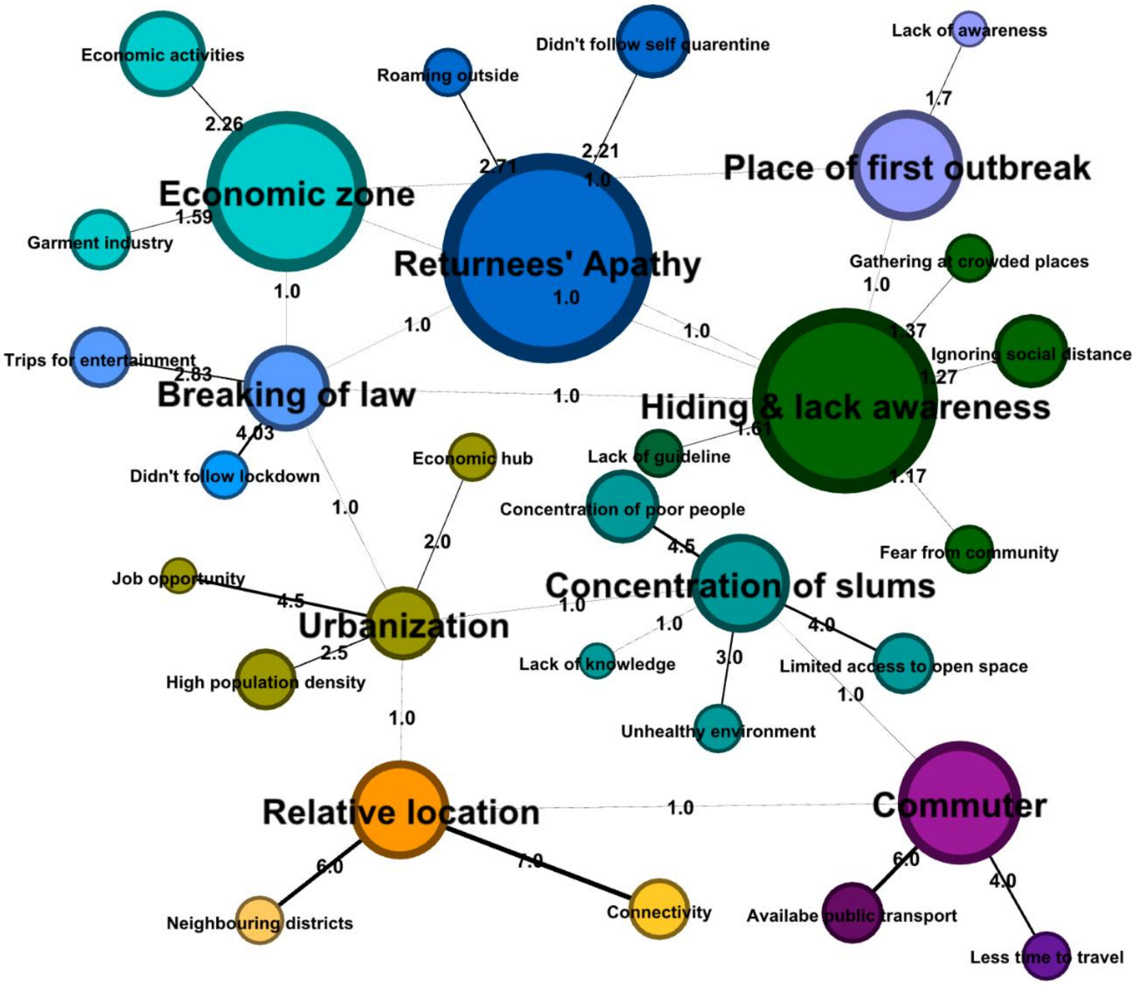

Fig. 2. Ranking of the identified factors of community transmission of the COVID-19 and their associated issues. (Note: The circles named by dark bold letters are the major factors and the non-bold letters are the associated issues of those factors. The sizes of the circles show the rank whereas, the width of the connecting lines indicate the weights of the associated issues of the influencing factors).

5. Discussion

The identified factors and associated issues by the respondents carry essence in explaining the reasons behind the transmission of the virus in and around Dhaka district. This section of the study justifies the validity and relevance of the responsible factors supported by available secondary data and literature.

5.1. Returnees' apathy

Since January 2020, a total number of 61, 74, 734 passengers came to Bangladesh from different countries (DGHS, 2023b). The majority of them were from the countries severely affected by COVID-19 (e.g. China, Italy, Germany and France). The general guideline for the returnees from abroad is to stay at home for 14 days period and stay away from other members of their families or outsiders as much as possible to prevent the spread of the coronavirus (IEDCR, 2020a). However, the indifference of returnees from abroad over following self-quarantine rules put their family members and relatives at risk of contracting novel coronavirus residing in the clusters. Consequently, the disease got the momentum of community transmission in the study area from the very beginning of COVID-19. For instance, Dhaka district and its surroundings account for more than two-thirds of the COVID-19 cases (Basak et al., 2022).

5.2. Hiding of information and lack of awareness

According to Communicable Disease Act-CDA (2018) hiding of information about coronavirus is a punishable offence. However, hiding information while affected by coronavirus disease is very common in Bangladesh. Patients fear that local community and health workers including doctors and nurses would avoid them and their family members if they got to know that the disease affects them. Moreover, it is observed during the field visits that people in the study area do not wear mask, do not disinfect house regularly, and do not wash hands frequently, ignore social distance, gather at the crowded place and roam outside. Furthermore, they do not maintain sneezing and coughing etiquette. Consequently, the hiding of information in parallel to the lack of awareness could be the important factor of rapid transmission of the virus in the most affected areas of the three districts.

5.3. Concentration of economic activities

By any means, Dhaka, Narayanganj and Gazipur districts are the industrial (e.g. garments industry) hub of Bangladesh (Sabur et al., 2012). There are more than 4,000 garment industries in

Bangladesh. However, about 80% of garment factories are located in Dhaka, Narayanganj and Gazipur districts (BGMEA, 2015). Therefore, concentration of economic activities is thought to be one of the important factors responsible for community transmission in Dhaka, Narayanganj and Gazipur districts. Despite the risk of contracting the deadly virus, thousands of garment workers had to return to their workplaces in Dhaka, Narayanganj and Gazipur districts amid the shutdown. Garments and factory workers and owners did not follow the instructions that are given by the government. Consequently, these three districts are highly affected by the novel coronavirus and infected about 801, 151people by 7 March 2023 in which most of the affected people are the residents of the three clusters (DGHS, 2023a).

5.4. Large number of commuter

Historically, authorities of three districts have given emphasis on the importance of public transit predominantly for the commuters. Likely, Narayanganj is well connected with Dhaka by railway and regional highways (i.e. R110, R111 and R801) (Fig. 1). Ten pairs of commuter trains run per day between Dhaka City and Narayanganj City. It is the most popular route that is presently caring more than 12,000 passengers per day (Wang et al., 2014). On an average about 1,500 large, 2,000 medium and 2,500 microbuses are plying daily on three regional roads and caring about 158,500 passengers daily. Moreover, two pair of commuter trains is operating per day between Gazipur and Dhaka which presently caring more than 2,000 passengers per day. Gazipur is also connected with Dhaka by two regional roads (i.e. R311 and R310), linking to national highway N3 and thereafter by R803 (Fig. 1). On an average, about 274 large, 393 medium and 345 minibuses are moving on the road R311 every day. The traffic on road R310 is about 770 large, 2,088 medium and 1,772 minibuses per day. Daily passenger traffic on the road R310 by busses alone stands 123,000 (DHUTS, 2010). Although the commuter trains between the city corporations were stopped immediately after the first outbreak of coronavirus in the country, but a large number of people commutes every day within the city corporations by using public buses that led to the community transmission of coronavirus among the most affected areas of the three districts.

5.5. Relative location

The identified administrative areas in Dhaka, Narayanganj and Gazipur districts are very close to each other (Fig. 1). Narayanganj City Corporation and Sadar area is at the southern side and Gazipur City Corporation and Sadar is at the eastern side of Dhaka Metropolitan Area.

Narayanganj City center is only about16 km far away and Gazipur City center is about 31 km far away from Dhaka Metropolitan Area. Besides, Gazipur City Corporation is not very far away (i.e. 57.5 km) from Narayanganj City Corporation. These three districts are situated within very short distance that leads to the rapid transmission of COVID-19 in and around Dhaka district.

5.6. Concentration of slums

The process of rapid urbanization in Bangladesh creates a large numbers of slums in the country. A total number of 8, 41, 822 slum dwellers (i.e. 35%) are identified in Dhaka (i.e. about 6, 92, 628), Narayanganj (i.e. about 31, 800) and Gazipur districts (i.e. about 1, 17, 394) out of 18, 00, 486 slum dwellers in the country (Population and Housing Census, 2022). Besides, about 47.2% urban populations are living in the slum area of Bangladesh (Statista, 2018). Slums are characterized by densely populated area, unhealthy environment, absent of basic services including safe drinking water, education, treatment etc. Moreover, most of the slum dwellers are socio-economically poor and engaged in informal activities (e.g. house keeper, rickshaw puller). They have no enough knowledge about newly emerged coronavirus. A gradual influx of marginalized people to the slums in the three clusters posed a challenge to health system. Limited access to open space in the slums is resulting rapid spread of coronavirus. Maintaining of social distance and self-quarantine is virtually impossible for the slum dwellers in the urban areas of the districts.

5.7. Breaking of law

On 23 March 2020, the government of Bangladesh has declared to follow public holiday and lockdown all over the country except pharmacies, hospitals, restaurants, shops of essential commodities (e.g. fresh produce markets and grocery shops), urgent industries, retail banks in limited capacity and other emergency services (CDA, 2018). The holiday has been declared with the sole objective of social distancing to prevent spreading of the virus. All the residents were requested to stay at their homes during holiday and to avoid going out in public places except for urgent tasks such as obtaining ready-to-go meals, groceries, medicines and for taking medical treatment by wearing protective equipment such as masks and gloves (DGHS, 2023c). However, field observations show that people at community level of Dhaka, Narayanganj and Gazipur districts did not follow the government orders in regulating the situation.

5.8. Urbanization

The three districts (i.e. Dhaka, Narayanganj and Gazipur Districts) are located almost in the central part of Bangladesh. Moreover, Narayanganj and Gazipur districts are considered as suburban areas of Dhaka. Dhaka attracts a large number of people from its outskirts. These areas have been experienced high rate of urbanization (JICA, 2010) that initiates industry-based economic growth. Moreover, Dhaka, Narayanganj and Gazipur City Corporations are densely populated areas. As a result, the Metropolitan area and the two city corporation areas of the three districts contain more coronavirus patients than non-urban areas.

6. Conclusion

The study identified the factors including returnees' apathy, hiding of information and lack of awareness, concentration of economic activities, large number of commuter, place of first outbreak, relative location, concentration of slums, breaking of law, urbanization and associated issues of community transmission that reflect the characteristics of rapid urban growth in the studied districts. In case of contagious diseases like COVID-19, it might be very difficult to stop spreading of the virus. However, proper regulation of the means of transportation among the most affected areas, impose of strict procedures for the returnees and controlling of economic activities from the government side would be useful for controlling the rapid community transmission of the virus. Moreover, awareness among the residents, following social distancing and obeying rules and regulations are vital to prevent the spread of the virus in the study area. The factors responsible for rapid community transmission identified in the present study would be useful for the policymakers and responsible authorities to prevent further spread of the virus in the study area.

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Flood management in Bangladesh: A review

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ABSTRACT

This study aims to provide a comprehensive overview of the current understanding of Bangladesh's flood types, causes, and impacts. The research is intended to minimize flood-related losses and harness the benefits of flooding through effective management strategies. The study identifies various causes of flooding, encompassing short-term and long-term factors and physical or natural and human-induced causes. The frequency of floods in Bangladesh has noticeably increased in recent years, posing severe threats to life, property, and the environment. The country primarily faces four types of floods: regular monsoon floods, flash floods, floods resulting from excessive rainfall, and tidal floods. Floods have adverse impacts, including environmental and socio-economic consequences, both in the short and long term. Therefore, implementing an appropriate flood management system is imperative to safeguard people's livelihoods and the environment from further deterioration.

Keywords: Flood, types, causes, impacts, management, Bangladesh.

1. Introduction

Floods have a recurring impact on Bangladesh, affecting the country nearly every year with varying magnitudes and types depending on its geographical location. The consequences of these floods are adverse, impacting both the environment and people's livelihoods. According to Milliman et al. (1989), Bangladesh is primarily characterized by a flat landscape with some hilly regions. Most of the rivers in Bangladesh flow in a mature stage, as the country has been formed through the sedimentation of a vast river system. As a result, during the wet monsoon, approximately 30 to 35 percent of the total land becomes flooded annually.

Because of Bangladesh's flat topography and the characteristics of delta formation, between one-fifth and one-third of the country experiences annual flooding caused by overflowing rivers during the monsoon season (ESCAP, 2003). Khalequzzaman (1994) describes a flood as an abnormal or above-normal surface-water flow that usually submerges dry land. Additionally, Khalequzzaman (2000) highlighted that floods are water-related environmental issues, and their severity greatly relies on land use practices within the watersheds of each river or stream.

When water overflows onto land that is usually dry, that situation is called a flood (lll, 2003**)**. According to Rumana (2020), a flood occurs when the water flow of a river or other channel exceeds a particular stage, causing it to spread over the bank area or adjoining highland and resulting in damage to the environment and man-made structures.

Because of its geographical location, Bangladesh has a rich history of facing yearly floods, some of which can be catastrophic. While certain floods have brought benefits, others have caused adverse effects on both infrastructure and human lives (Saleh et al., 1998). Khalequzzaman (2000) observed that, when considering historical data, floods' frequency, magnitude, and duration have substantially increased over the past few decades. On the contrary, Ahmad and Ahmed (2003) reported that in Bangladesh, recent flood history indicates a shorter interval between catastrophic floods, accompanied by an escalation in their intensity and duration.

Bangladesh is endowed with numerous rivers and experiences intense monsoon rains. As a result of drainage congestion, rainfall, runoff, and storm tidal surges, the country is susceptible to inundation from overflowing water. During the wet season, approximately 30 to 35 percent of the total land gets flooded throughout the country (Milliman et al., 1989).

The year and flood-affected areas of Bangladesh (1954-2020) are shown in the table-1.

Table 1: Year-wise flood-affected area in Bangladesh from 1954-2020

	Flood affected areas			Flood affected area			Flood affected area	
Year	Sq. km.	%	Year	Sq. km.	%	Year	Sq. km.	%
1954	36,800	25	1978	10,800	7	2002	15,000	10
1955	50,500	34	1980	33,000	22	2003	21,500	14
1956	35,400	24	1982	3,140	2	2004	55,000	38
1960	28,400	19	1983	11,100	7.5	2005	17,850	12
1961	28,800	20	1984	28,200	19	2006	16,175	11
1962	37,200	25	1985	11,400	8	2007	62,300	42
1963	43,100	29	1986	6,600	4	2008	33,655	23
1964	31,000	21	1987	57,300	39	2009	28,593	19
1965	28,400	19	1988	89,970	61	2010	26,530	18
1966	33,400	23	1989	6,100	4	2011	29,800	20
1967	75,700	17	1990	3,500	2.4	2012	17,700	12
1968	37,200	25	1991	28,600	19	2013	15,650	10.6
1969	41,400	28	1992	2,000	1.4	2014	36,895	25
1970	42,400	29	1093	28,742	20	2015	47,200	32
1971	36,300	25	1994	419	0.2	2016	48,675	33
1972	20,800	14	1995	32,000	22	2017	61,979	42
1973	29,800	20	1996	35,800	24	2018	33,941	23
1974	52,600	36	1998	1,00,250	68	2019	45747	31
1975	16,600	11	1999	32,000	22	2020	59028	40
1976	28,300	19	2000	35,700	24			
1977	12,500	8	2001	4,000	2.8			

Source: FFWC, 2020

2. Methodology

The current research has been conducted based on secondary sources and a thorough literature review. All secondary sources, such as articles, books, and various reports, were obtained from online searches. The search keywords included terms related to floods, causes, types of floods, impacts, and flood management strategies. Numerous articles, books, and reports were discovered, mainly focusing on floods in Bangladesh, and a relevant selection of these materials was utilized in this study.

3. Result and discussion

The review has investigated various aspects of floods in Bangladesh, including their types, causes, impacts, and flood management strategies. Being one of the lowest-lying countries globally, Bangladesh encounters flood hazards annually, especially in low-lying areas, riverbank regions, and coastal zones. The significance and necessity of different flood management strategies are crucial in mitigating the impact of floods in Bangladesh.

3.1 Types and causes of floods in Bangladesh

According to Hossain et al., 1987; Miah, 1988; Ahmad, 1989 and Brammer et al., 1993 basically four types of floods occur in Bangladesh. These are mentioned below:

- Normal monsoon flood
- Flash flood
- Floods owing to excessive rainfall
- Tidal flood

Types of floods	Month											
	1	2	3	4	5	6	7	8	9	10	11	12
Normal monsoon flood						━	━	━	━			
Flash flood				━	━				━	━	━	
Floods owing to excessive rainfall					━	━	━	━	━	━		
Tidal flood						━	━	━	━			

Fig. 1. Flood calendar of Bangladesh (Source: Rumana, 2019)

On the other hand, BWDB classified floods in Bangladesh based on the water level of the river as follows: (Yeasmin, 2009).

- Normal flood (River water level remaining within 50 cm. below the danger level)
- Moderate flood (River water level remaining up to 50 cm. above the danger level)
- Severe flood (River water level above 50 cm. of the danger level)

Various authors have presented different types of flood causes in Bangladesh. Khalequzzaman (1994) identified two types of causes responsible for floods, while Nishat (2004) identified additional causes. The figure below (Fig. 2) illustrates the causes of floods identified by Khalequzzaman (1994) and Nishat (2004).

Rumana (2019) discusses various causes of floods, encompassing both physical/natural and man-made factors (Fig. 3). Both types of causes contribute to flooding in Bangladesh. However, in urban areas, floods primarily occur due to man-made factors.

According to Khalequzzaman		According to Nishat
1. Short-term causes • Monsoon downpour • Synchronization of flood peaks	2. Long-term causes • Local relative sea level rise • Inadequate sediment accumulation • Subsidence and compaction of sediments • Riverbed aggradation • Deforestation in the upstream region • Damming of rivers • Soil erosion due to tilling • Excessive Development • Seismic (earthquake) and neotectonic activities • Greenhouse effect	• Runoff in excess of conveyance capacity • Deterioration of drainage channels • Drainage congestion • Deforestation • Rise in sea level due to wind • Tidal waves/tidal effect • Global climate change • Impact of embankments constructed elsewhere

Fig. 2. Causes of flood in Bangladesh (Source: Khalequzzaman, 1994; Nishat, 2004)

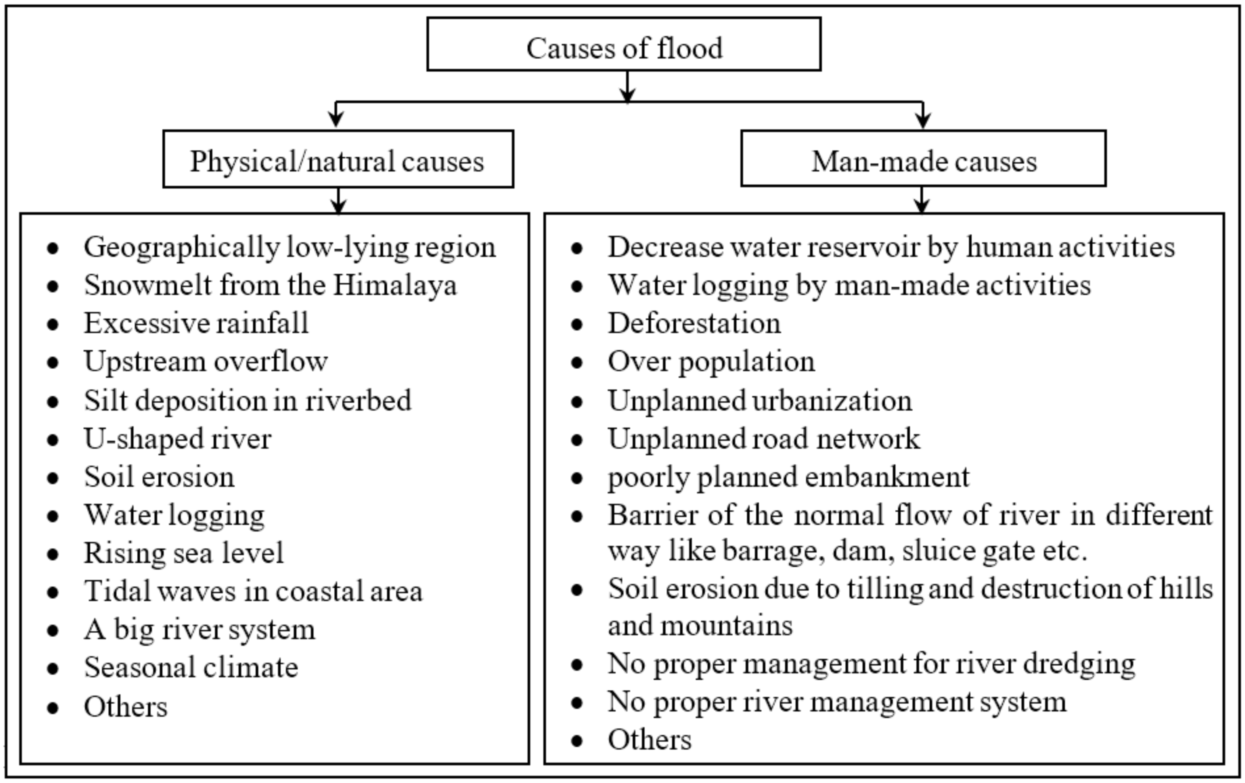

Fig. 3. Causes of flood in Bangladesh (Source: Rumana, 2019)

3.2. Impacts of flood in Bangladesh

As stated by Maskrey (1999), Alcantara-Ayala (2002), Few (2003), and Hutton and Haque (2004), vulnerability to floods is influenced by various factors, including flood characteristics, physical infrastructure, geographic location, geomorphological setting, and the socio-economic, cultural, and political conditions of the affected population. Floods have significant adverse impacts on the environment and human life, and various flood impacts are elaborated upon below.

Environmental impacts:

- Surface and groundwater pollution by toxic materials and dissolved chemicals (Alam, 1995; lll, 2003)
- Soil erosion (Elahi, 1991a)
- Silt deposition (UNEP, 2001)
- Riverbank erosion (Elahi, 1991a and 1992; Halli, 1991; Ahmed and 1991)

Socio-economic impacts:

- Loss of human life (Ahmed, 2001; Chadwick et al., 2001; Nishat, 2008)
- Scarcity of pure drinking water (lll, 2003; Brouwer et al., 2007)
- Scarcity of flood (del Ninno et al., 2001; Younus, 2012)
- Sanitation problem (Rashid, 2000)
- People homeless (Elahi, 1991a; BWDB, 2007 and Alauddin, 2010)
- Loss of properties (Elahi, 1991b; Islam and Sado, 2000; and del Ninno et al., 2001)
- Loss of livestock (DMIC, 2007; Nishat, 2008)
- Attack different types of diseases (diarrhea, respiratory, infections, skin lesions etc.) (Islam, 1998)
- Loss of agricultural lands and crops (Elahi, 1991a; Paul and Rasid, 1993; Saleh et al., 1998; del Ninno et al., 2001; and Brouwer et al., 2007)
- Disruption economic activities (Paul, 2005)
- Damage of roads, railways, bridges, culverts, embankments, institutions and infrastructures (Miah, 1988 and Mohanty, 1993)
- Harm to big engineering projects (Alam,1995)
- Population displacement due to flood and riverbank erosion (Ahmed, 1991; Amin, 1991; Elahi, 1991b; 1991 and Saleheen, 1991)

Short-term impacts

- Scarcity of drinking water (lll, 2003; Brouwer et al., 2007)
- Scarcity of food (del Ninno et al., 2001; Younus, 2012)
- Sanitation problem (Rashid, 2000)
- Damage of house (Mohanty, 1993)
- Damage of communication system (Elahi, 1991b)
- Diseases (Islam, 1998)

Long-term impacts

- Damage of country's economy (Miah, 1988; Ahmed, 2001; Chadwick et al., 2001 and Nishat, 2008)
- Permanent migration (Elahi, 1991b and Ahmed, 1991)
- Increase poverty (Sen, 2003)

Table 2: Impacts of serious floods in Bangladesh

Flooding year	Impacts
1984	Over 50,000 sq. km. was inundated, estimated damage was US$ 378 million.
1987	Over 50,000 sq. km. was inundated, the estimated damage was US$ 1 million and 2,055 people died.
1988	61% of the country was inundated, estimated damage was US$ 1.2 billion, more than 45 million people were homeless and between 2,000-6,500 people died.
1998	Nearly 100,000 sq. km. was inundated, rendered 30 million people were homeless, 500,000 homes were damaged, infrastructures were lost in huge amounts, estimated damage was US$ 2.8 billion and 1,100 people died.

Flooding year	Impacts
2004	38% of the country was inundated, the estimated damage was US$ 6.6 billion, nearly 3.8 million people were affected and 700 people died.
2007	An area of 32,000 sq. km was flooded, destroying more than 85,000 houses and damaging nearly 1 million houses. Additionally, around 1.2 million acres of crops were destroyed or partially damaged, leading to an estimated total damage cost of over $1 billion. Tragically, 649 people lost their lives as a consequence of the flood.
2010	49 districts of the country were inundated and 10 million people were affected.
2017	In the country, 31 districts experienced flooding, affecting 238,843 people severely and 6,536,509 people partially. The flood caused complete damage to 71,628 houses and partial damage to 548,175 houses. Additionally, 15,529 hectares of agricultural land were fully inundated, and 562,594 hectares were partially submerged. The disaster also resulted in the complete destruction of 34 educational institutions and partial damage to 3,134 institutions. Furthermore, 403 km of roads were fully damaged, and 4,432.38 km of roads were partially damaged. The flood disaster also led to the damage of 268 bridges and 96 km of embankments.

Source: MoEF, 2009, Gunter et al., 2010, FFWC, 2017

3.3. Flood management in Bangladesh

In Bangladesh, floods have occurred almost every year due to its geographical setting since ancient times. Some data have been discovered regarding flood management from ancient to colonial periods. However, after 1947, various types of flood management policies and strategies were implemented in diverse ways to mitigate flood damage. The following section outlines different government initiatives for flood management in Bangladesh at various time periods.

Table 3: Flood management history

Established year	Government policies
1957	Report of United Nations Technical Assistance Mission (Krug Mission Report)
1964	EPWAPDA-East Pakistan Water and Power Authority
1966	IBRD-International Bank for Reconstruction and Development (Review of EPWAPDA, 1964)
1971	BMD-Bangladesh Meteorological Department
1972	BWDB-Bangladesh Water Development Board
	JRC-Joint River Commission
	FFWC-Flood Forecasting Warning Center
	IBRD Report on Land and Water Resources, Bangladesh
1983	MPO-Master Plan Organization
1986	NWP-National Water Plan, Phase-1
1989	FAP-Flood Action Plan
1991	NWD-National Water Plan, Phase-11
1992	WARPO-Water Resources Planning Organization (Rename of MPO)
	LGED-Local Government Engineering Department
1993	Ministry of Disaster Management and Relief (Disaster Management Bureau)

Established year	Government policies
1995	Bangladesh Water and Flood Management Strategy (Follow up to FAP)
1999	NWP-National Water Policy
2001	NWMP-National Water Management Plan
2012	DDM-Department of Disaster Management under the Ministry of Disaster Management and Relief following enactment of the Disaster Management Act, 2012
2015	DMP-Disaster Management Policy
2020	NPDM-National Plan for Disaster Management (2021-2025) under the Ministry of Disaster Management and Relief

Source: Author

Elahi, 1991a; Ahmad et al., 1994, 2001; Paul, 1995; Tingsanchali, 1996; Ahmad and Ahmed, 2003; Nishat, 2004; besides them the reports made by WMO/GWP, 2003; and DDM, 2014 all of authors and reports present the two types of flood mitigation measures. These are:

3.3.1. Structural measures

Structural solutions involve the implementation of engineering structures such as embankments along river sides, dams, drains, reservoirs, and other structures to manage the natural flow of rivers. These solutions typically address specific problem areas within the river basin in isolation. In Bangladesh, structural solutions are practised on a limited scale and are often incorporated as part of flood control projects (Rasid and Paul, 1987).

Structural mitigation measures can encompass both engineered and non-engineered structures. Before determining the appropriate flood measures, assessing the advantages and disadvantages of each individual structural or non-structural approach in terms of environmental, economic, social, engineering, and other relevant aspects (World Water Forum, 2000).

3.3.2. Non-structural measures

Non-structural measures aim to mitigate losses or damages through administrative actions. Social scientists and conservationists favour them as they do not directly control or alter the inundation process and do not promote economic growth. It is essential to link non-structural measures with structural measures and vice versa to ensure comprehensive flood management (Nishat, 2004).

As per the WMO/GWP (2003) guidelines, non-structural measures hold great significance. Early flood warning systems are crucial in saving lives and protecting property. 1972 the Flood Forecasting and Warning Centre (FFWC) was established with only 10 flood monitoring stations along the major river systems. It covers the entire country with 85 flood monitoring stations, providing real-time flood information and early warnings with 24 and 48 hours lead times. FFWC greatly assists the Government of Bangladesh, disaster managers, and flood-affected communities residing in flood-prone areas. This enhanced system facilitates flood preparedness, emergency mitigation planning, agricultural strategies, and rehabilitation efforts by FFWC.

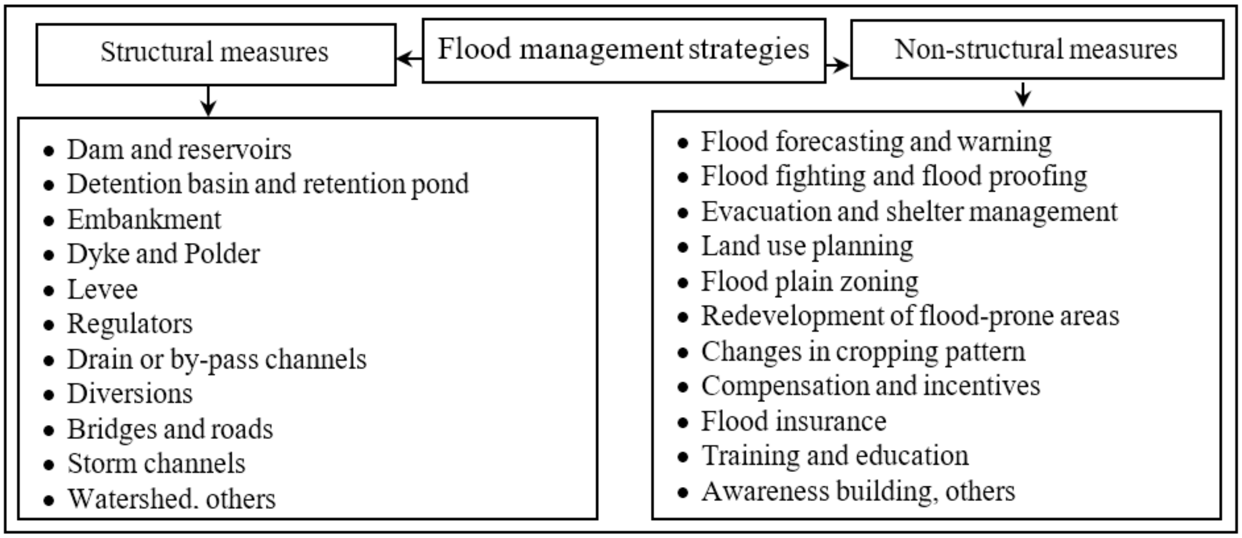

Fig. 4. Flood management strategies (Source: Rumana, 2019)

Bangladesh's national disaster management institutional framework comprises a network of interconnected institutions at both the national and local levels. Its primary aim is to facilitate effective planning and coordination for disaster risk mitigation and emergency response management.

The chain of disaster management framework of Bangladesh is given below:

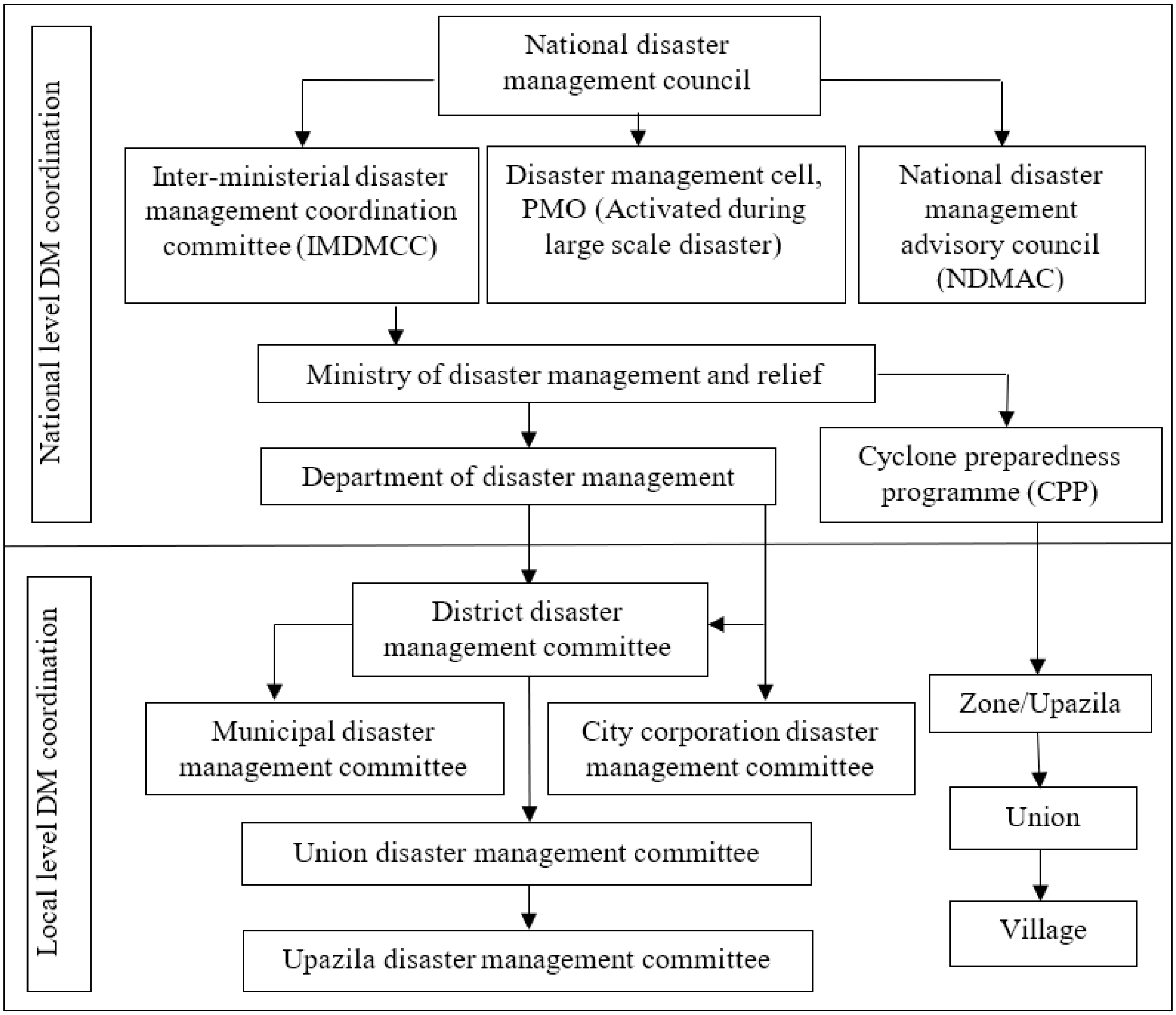

Fig. 5. Disaster management framework in Bangladesh (Source: DDM, 2014)

4. Conclusion and recommendations

To reduce flood damage in Bangladesh, both governmental organizations (GOs) and non-governmental organizations (NGOs) must play crucial and active roles. The first step is establishing appropriate policies and planning to decrease flood damage. Subsequently, modern and technologically advanced strategies should be implemented. Concurrently, GOs should seek support from international agencies to exchange knowledge, policies, and technology to mitigate flood damage effectively. Additionally, the involvement of the local community is essential in devising strategies to minimize flood impact. By fostering better collaboration between GOs, NGOs, and international agencies, the damage caused by floods can be significantly reduced, leading to an improved quality of life for the people of Bangladesh. The following are some recommendations for achieving sustainable flood management in Bangladesh.

- Early warning can help people to make early preparation for impending floods.
- People should plant more trees around their homestead, pond bank, fallow land etc. Tree plantation alongside the road, embankment, bare land etc., by GOs and NGOs under the social forestry program is another adaptation practice.
- During floods, people should drink pure water to protect them from waterborne diseases.
- Many flood shelter centres need to be established and pure drinking water, proper sanitation, emergency treatment etc. need to be maintained in those shelters.
- A proper plan has been established for proper land use, water and power development.
- Different government organizations are engaged in flood management in our country, as mentioned in Table no-3. At the same time, many NGOs are actively mitigating flood hazards at different stages. These organizations must take proper policies and apply these policies strictly to mitigate and adapt to the flood disaster.

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Assessing the impacts of Teesta riverbank erosion on livelihood pattern: A case study of Tepa Kharibari union of Dimla upazila, Nilphamari in Bangladesh

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ABSTRACT

River bank erosion is a typical natural disaster that is one of the critical public concerns in Bangladesh. This disaster has long-term consequences on human life. The erosion victims are compelled to displace for their survival issues. Therefore, this paper aims to assess the impacts of Teesta Riverbank erosion on the inhabitants those are living beside bank and erosion prone areas. This study is followed by inductive method, and analyzing the effects of bank line erosion and shifting as well on the human life. Basically, primary data are emphasized to construct the study focusing Teesta River channel shifting regarding erosion, effects of the catastrophic disaster on livelihood and mitigation process of the effects resulting from the disaster. The major findings of the study are that the people of this area are too much vulnerable to cope with erosion with their own capacity and resources. Thus, they are very much in need of relief and other structural rehabilitations. In addition, there are not enough measures with a view to such disaster management at Tepa Kharibari Union, Nilphamari District.

Key Words: Bank erosion, Teesta River, livelihood, structural rehabilitation, disaster management

1. Introduction

Erosion and accretion are common and continuous phenomena of rivers in Bangladesh. Morphologically, Bangladesh is a deltaic floodplain, consists of the sedimentation deposited by the major and minor rivers. Basically, the major rivers of Bangladesh are dynamic, highly responsible for extreme bank erosion, and whereas, 94 Upazilas of Bangladesh face riverbank erosion each year (BWDB and ADB, 2006). It is experienced that the magnitude and rate of bank erosion vary from river to river regarding prevailing heterogeneous characteristics of bank materials and erosive materials, and varying hydrological characteristics. In addition, the nature of river (meandering, braided) directly affects the erosion process of bank line (CEGIS, 2009). Literature suggests that riverbank erosion is getting high due to channel shifting and recurrently hits in Bangladesh (Elahi et al., 1991) and this disaster gets more active in Teesta as result of lateral channel shifting with various environmental challenges. (Akhter et al., 2019).

The mighty Teesta River is a transboundary river of Bangladesh and also a blessing to the Teesta adjacent people, especially for agricultural purposes. The waterway channel regularly contains a solitary stream of water, yet a few streams stream as a few interconnecting surges of water, delivering a plaited stream (Walther, 2013). Conversely, Teesta River becomes curse having flood and bank erosion; these two environmental disasters are causes of human sufferings (Elahi et al., 1991). These disasters are more affecting on the people of Bangladesh due to geographical characteristics (e.g. location, physical setting, huge population, displacement) and climate change effects (Ghosh and Sarker, 2021; Ghosh, 2022). The erosion rate of Teesta River along Lalmonirhat District is much higher than other districts of Teesta Basin areas (Sultana, 2022). This unwanted situation (e. g. erosion) goes peak at monsoon period in Bangladesh with devastation on homestead land, barren land, agricultural land with crops, schools, roads and embankments (Ghosh and Mahbub, 2014; Ghosh and Mahbub, 2017 & 2018). Every year, both banks of the Teesta experience erosion attacks depending variability of upstream rainfall, flood, channel shifting, bar formation (Sultana, 2022; Akhter et al., 2019). As a result, the victim landowners beside the Teesta River shift their residences and changed their livelihood options (Elahi and Rogge, 1990). Previous study revealed that almost one-third of erosion victims affected by mighty Padma River changed their occupation pattern (Ghosh, 2016). The bank erosion directly effects on the livelihood of the agrarian society of the Teesta floodplain. Factors affecting the marginalization of the rural peasants are bank erosion, channel migration, and flood (Elahi and Rogge, 1990). The hydrological conditions and irrigation projects both in India and Bangladesh are highly controlled by the dry flow of Teesta River (Haque et al., 1998). To cope with riverbank erosion, the victims take different adaptive measures through indigenous practices (Ghosh and Mahbub, 2014; Ghosh, 2016).

Most of the impacts by riverbank erosion have long-term effects on the victims (Haque, 1998). Long-term socio-economic impacts have direct (living condition) and indirect effects (human health) on the victim people (Das et al., 2014). The displaced people caused by riverbank erosion seek their better residence very immediately to protect their older members, women and children. These victim households experienced some new knowledge regarding the disaster (e.g. erosion) to resilience themselves (Rahman, 2010). Every year, almost one million people of Bangladesh are directly affected by riverbank erosion (RMMRU, 2007) and affected people migrated nearby town and megacity, especially Dhaka City (RMMRU, 2007; Ghosh and Mahbub, 2014).

Riverbank erosion is considering catastrophic natural disasters that cause the displacement of inhabitants who lived near and nearby river banks (Ghosh and Mahbub, 2014). A stream bank comprises the sides of the channel with the territory close by the bed of a stream, between which the stream is bound (Leopold et al., 1995). In most cases, erosion-distressed people lose not only their means of livelihood, homes and assets but also become low-grade rather than their previous identity, and they, therefore, always try to hard working to come back regarding recognition as per previous identity (Das et al, 2014). Therefore, Riverbank erosion, is a silent and very serious hazard in Bangladesh with disastrous socio-economic consequences (Ghosh and Mahbub, 2014 and Miah, 2004).

2. Aim and objectives of the study

The main focus of this study is to investigate the impacts of Teesta Riverbank erosion on the socio-economic conditions of the people of Tepa Kharibari Union of Dimla Upazila. To achieve the aim of the research, the following objectives are considered to be continued of the study.

a. To identify the changes in the bank erosion of the Teesta River in the study area since 2004 to 2022;
b. To explore the effect of Teesta Riverbank erosion on livelihood pattern in the study area; and finally
c. To assess the mitigation process of victim people regarding the social and economic losses caused by erosion.

3. Methods and data sources

3.1. Selection of the study area

Literature reveals that the river Teesta has over 100 years of history of bank erosion. The increased discharge in lower Teesta between Kharibari and Teesta Barrage has led to channel shifting and instability with the formation of large channel meanders which are still mobile. In addition, the Teesta River flow is attacking towards the bank directly at Purba Chhatnai, Tepa Kharibari, Khoga Kharibari, and Khalisa Chapnai. 5 unions (Purba Chhatnai, Paschim Chhatnai, Tepa Kharibari, Khoga Kharibari, and Khalisa Chapnai) of Dimla Upazila located at right bank of Teestsa River are affected by massive erosion. Tepa Kharibari Union under Dimla Upazila, Nilphamri District is geographically located on a bank of the Teesta River shown in Fig. 1. This union is selected to conduct this study regarding Teesta Riverbank community livelihood management due to impacts of erosion. The total area and households of this union are 7836 acres and 3879, respectively (BBS, 2013). Tepa Kharibari Union divided into 4 villages or mouzas, these are Char Kharibari, Dakshin Kharibari, Purba Kharibari, and Uttar Kharibari (BBS, 2013).

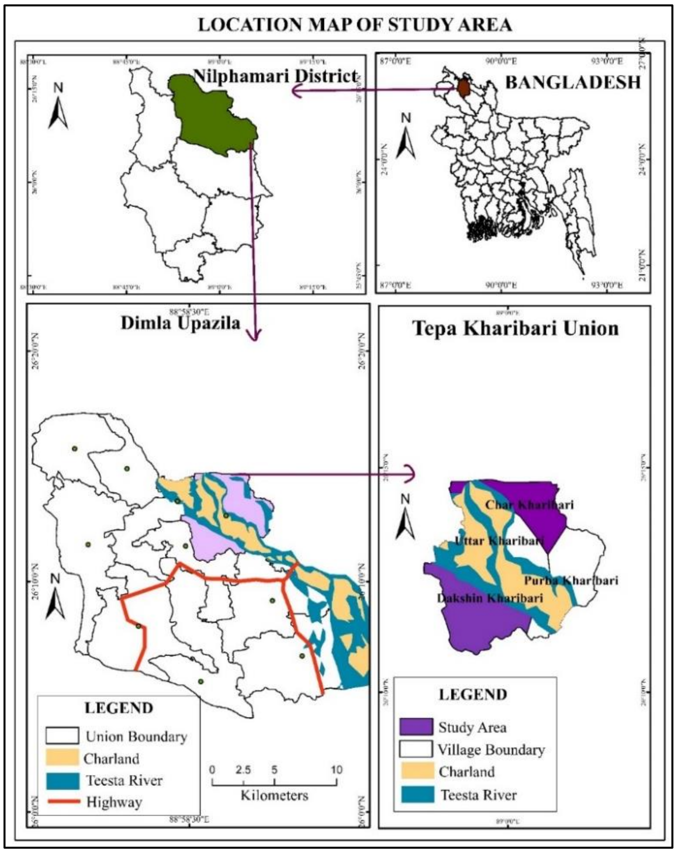

Fig. 1. Study area

3.2. Data Collection method

This study is comprised of quantitative and qualitative data. These data are collected from primary and secondary sources. In regards of primary data collection, reconnaissance survey, questionnaire survey at household level, field observation are conducted. Before designing the questionnaire for sample survey and sample size determination a reconnaissance survey was driven to conceptualize the real scenario of the erosion victim community.

The collected information through this survey are used to design questionnaire regarding face to face survey. With a view to demonstrate actual facts, sample survey questionnaire is designed into five segments involving 36 questions (open-ended and close-ended). A semi-structure questionnaire is prepared to conduct survey at household level of Teesta Riverbank community at Tepa Kharibari Union. Two mouzas of this union are selected by cluster sampling method. The data collected through face to face field survey includes empirical field observation.

The secondary data of this study are collected from different authorized institutions of local and national level. Tepa Kharibari Union Parishad Office, Bangladesh Bureau of Statistics, Daily News Paper, Published and unpublished research are the main sources of secondary data.

3.3. Sample size and technique determination

The sample size of the study is determined by Yamene’s formula (1967). The calculated sample size of Char Kharibari and Dakshin Kharibari mouza is following formula:

In the case of Char Kharibari Mouza

$$n = \frac{N}{1+N(e^2)}$$

$$= \frac{771}{1+771(.10^2)}$$

$$=88$$

Where;

N = 771

e = 10% = 0.01

In the case of Dakshin Kharibari Mouza

$$n = \frac{N}{1+N(e^2)}$$

Where;

N = 1737

e = 10% = 0.01

$$= \frac{1737}{1+1737(.10^2)}$$

$$=95$$

Total Sample Size = 88 (Sample Size of Char Kharibari) + 95 (Sample Size of Dakshin Kharibari)

= 183 households

The 183 households from two mouzas are selected by simple random sampling.

3.4. Data processing and analysis

Descriptive statistical method is applied for data presentation and analysis as well. With a view to following this method, the collected data are sorted properly in order to eliminate the unnecessary and irrelevant information through checking and verification before the coding process and then, MS Excel Software is used to graphical presentations. Arc view GIS software is also exercised to prepare the map for fulfilling the purposes by following various steps of the software. Base map is collected from Banglapedia and produced final map is completed by coordinating the base map, creating shape file for certain geographic feature, digitizing and editing the; setting other elements for layout the final map.

In addition, satellite images are analyzed through unsupervised classification by ArcGIS 10.5 and these required satellite images collected from United State Geological Survey (USGS). The time frame of collected images is dry season, especially in the month of February in order to obtain cloud free images.

4. Results and discussion

4.1. Changes of bank erosion

The Teesta River, one of the most dynamic rivers in Bangladesh, supports livelihood patterns of local riparian people. In order to investigate bank line changes, channel shifting and land accretion of the Teesta River within Tepa Kharibari Union, Nilphamari District, four satellite images have been analyzed using the morphometric technique. The satellite images (e.g. 2004, 2010, 2016, and 2022) have been selected on the basis of 6 years interval to identify the changes of the Teesta River.

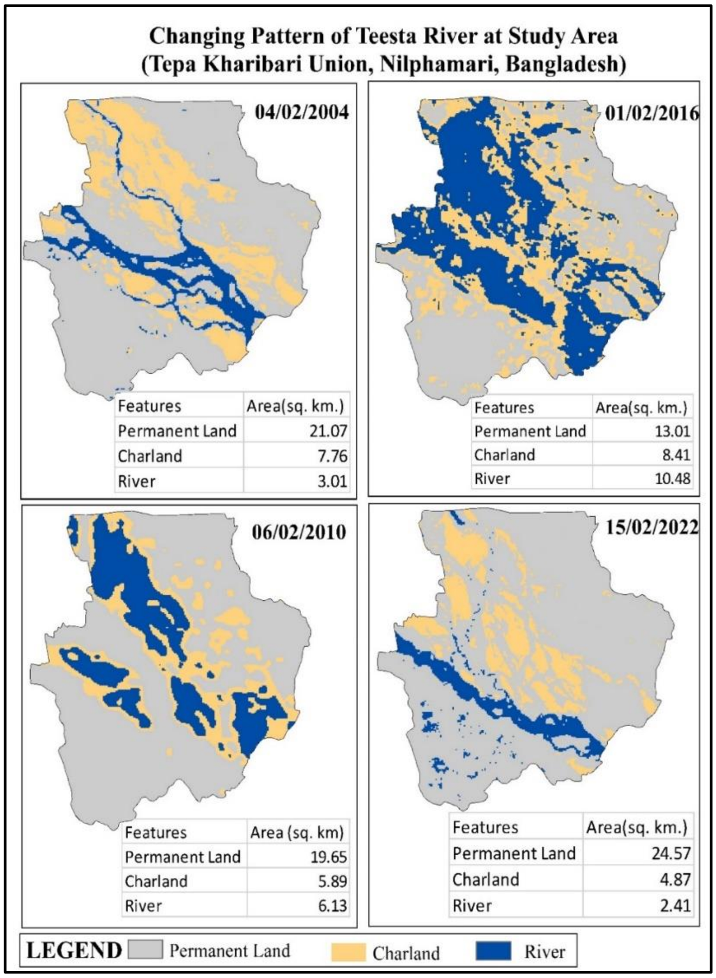

Fig. 2. Changing pattern of Teesta River channel at study area *(Source: USGS Landsat Images)*

Table 1: Changes in the river, char land, and permanent area in Tepa Kharibari Union

Year	Total Area (sq. km)			Total Area (%)		
	Permanent Land	Char land	River	Permanent Land (%)	Char land (%)	River (%)
2004	21.07	7.76	3.01	66.2%	24.4%	9.5%
2010	19.65	5.89	6.13	62.0%	18.6%	19.4%
2016	13.01	8.41	10.48	40.8%	26.4%	32.9%
2022	24.57	4.87	2.41	77.1%	15.3%	7.6%

Source: USGS (Landsat Images)

The area of permanent land, char land and river has been changed from the period 2004-2022 (Fig. 2 and Table 1) as a result of variability of erosion. Table 1 shows the changes of erosion and accretion in the study area due to Teesta Riverbank erosion. Massive bank erosion was at Teesta River along the study area in 2016. This study shows that the Teesta River channel is becoming narrow gradually.

4.2. Housing structure

Fig. 3 shows the housing structure of the households those are living in erosion prone areas in Tepa Kharibari Union, Nilphamari District. A very common sight prevails that an overwhelming portion of house floor is muddy. There is no building house in the area as a result of poverty that caused by riverbank erosion.

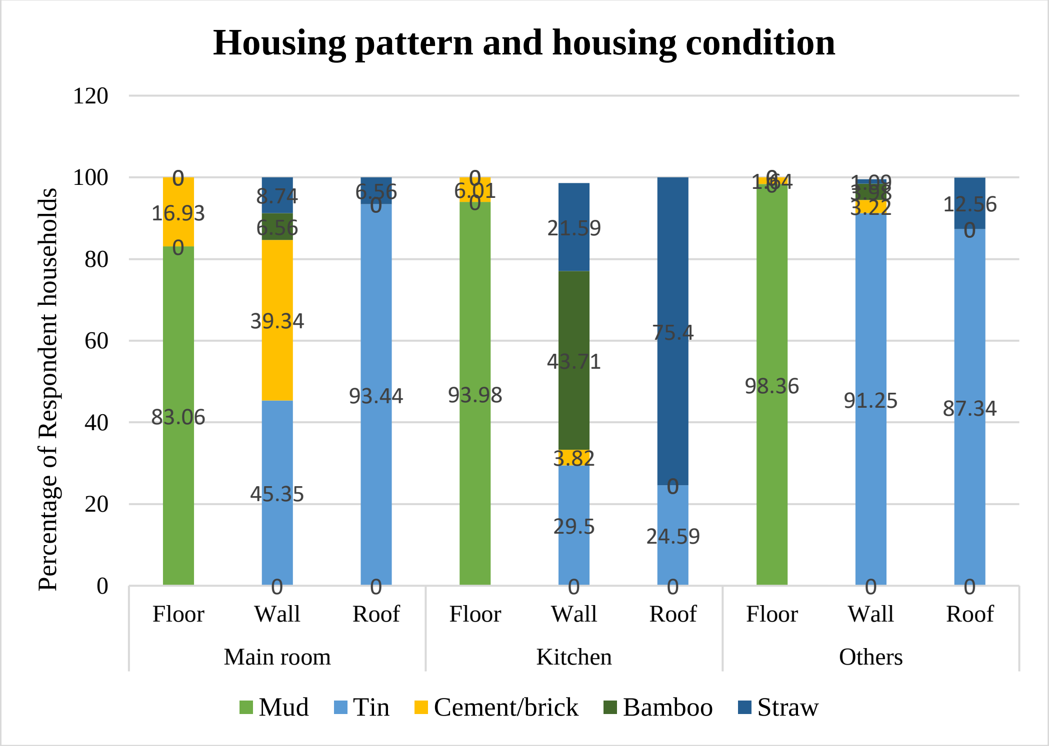

Fig. 3. Housing pattern and housing condition *(Source: Field Survey, 2022)*

4.3. Residence distance from river bank

About 6.6% and 37.2 % of respondent households are very close (10m) and distance at 30 metre (m) to Teesta River bank, respectively. In this regard, these households are located in such a vulnerable distance to erosion. On the contrary, 26.8% of households at Dakshin Kharibari reside more than 40 m from the Teesta River. Regarding 11.5% respondents' household distance are 50 m and rest of households' (27.3%) distance are more than 50m. Bank erosion begets great miseries to tens of thousands of people at every year, those live along with the riverbanks (Keya and Harun, 2007). To build residences at very close to the riverbank and living that places are more vulnerable to erosion.

4.4. Occurrences of victims by riverbank erosion

Almost half of the victimized households experienced bank erosion from 4 to 6 times and remaining half of them faced this disaster less than 3 times in the last 21 years. Most of the respondents faced riverbank erosion with an average 5 years interval. Only 1 family from the surveyed households faces more than 10 times erosion regarding location of residence very close to the river. Most of cases, erosion victim households change their residence more than one time due to bank erosion (Ghosh and Mahbub, 2017 and 2018).

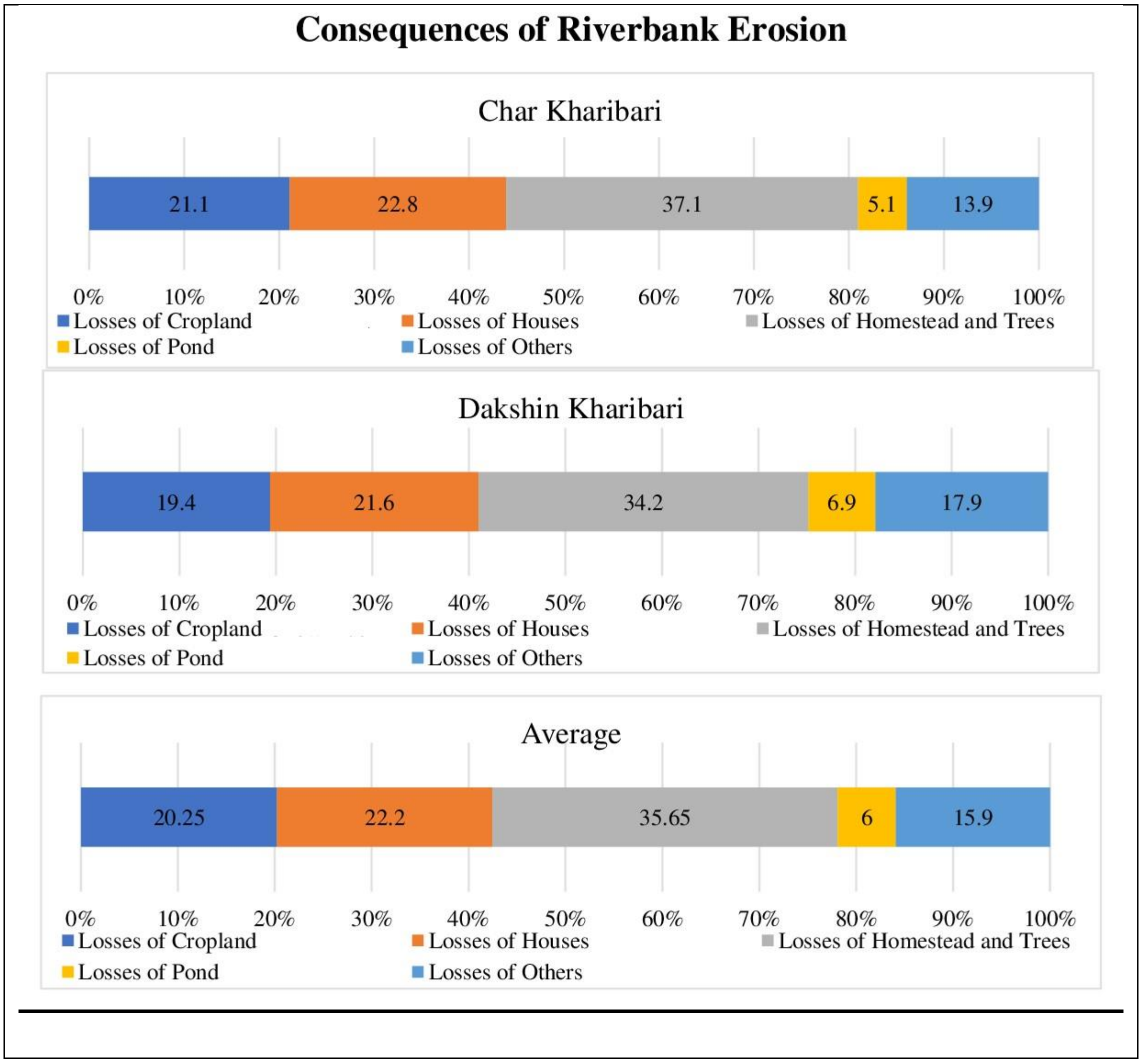

Fig. 4. Consequences of riverbank erosion in study area *(Source: Field Survey, 2022)*

4.5. Consequences of riverbank erosion

Fig. 4 shows the consequences of riverbank erosion among the people who live in the Tepa Kharibari Union, Nilphamari District. Almost one- third people claimed that they lost their homestead lands. Land is the basic resource, and homestead land is the main habitat of people (Ghosh, 2016). River bank erosion is the cause of losses of land (homestead, agricultural, forest), property (tree, fish, and domestic material), livestock and poultry, etc.

4.6. Vulnerabilities generated by riverbank erosion

Different types of vulnerabilities and risk factors are generated on the people due to erosion. Social instability and insecure environment are happed that cannot be reduced easily. Table 2 presents the generated vulnerabilities by bank erosion in the Tepa Kharibari Union. Different social crisis like divorce, child marriage, schooling drop, income erosion, unemployment are the common issues as a result of bank erosion. Bank erosion affected people migrated from erosion prone areas to another whereas, safe from erosion and also migrate to urban areas for their employment (Ghosh and Mahbub, 2014). On the other way, this disaster affects greatly on physical environment.

Table 2: Vulnerabilities generated by riverbank erosion

Vulnerabilities generated by riverbank erosion	Percentage of respondent households		
	Char Kharibari	Dakshin Kharibari	Average
Homeless	9.8	8.8	9.3
Land loss	13.8	12.4	13.1
Migration	3.8	3.4	3.6
Unemployment	6.6	5.6	5.9
Indebted	10.6	11.3	11.2
Divorce	2.1	2.2	2.1
Children drop from school	14.5	15.3	15.0
Illness	1.6	1.8	1.7
Child marriage	10.9	12.1	11.5
Others	6.2	5.8	5.5
Multiple vulnerabilities	20.1	21.3	21.1
Total	100	100	100

Source: Field Survey, 2022

4.7. Social destructions caused by bank erosion

Some sorts of social destructions are caused by riverbank erosion in the study area. These recorded destructions are social instability, lack of social and family bondage, changing occupation, migration to elsewhere, lack of access to social service, broken the social network, sub-standard social status, pull down integrity and affection among people, generated oppressions for women by men, and poor by rich.

Regarding 15 % respondents are compelled in changing occupation. Changing occupation pattern is very common phenomenon of river bank erosion households in Bangladesh (Ghosh, 2016). Other social destructions caused by this disaster are presented by Table 3.

Table 3: Social destructions are caused by riverbank erosion

Social destructions are caused by riverbank erosion	Percentage of respondent households		
	Char Kharibari	Dakshin Kharibari	Average
Broken social bondage	10.9	9.9	10.4
Broken family relation	7.9	7.1	7.5
Compelled in changing occupation	15.4	14.5	14.7
Migration to city	7.1	6.5	6.8
Closed access to social service	3.4	3.8	3.6
Broken the social network	1.5	1.7	1.6
Lowered social status	9.6	10.1	10.1
Pull down integrity and affection	17.5	19.1	18.2
Oppressions generated by strong for weak (women by men and poor by rich)	12.1	13.3	12.7
Others	14.6	14.0	14.4
Total	100	100	100

Source: Field Survey, 2022

4.8. Number of displacements to the inhabitants

Basically, number of displacements are linked with the number of facing erosion by households. Fig. 5 depicts the number of displacements of the households affected by bank erosion of Teesta River. This disaster compelled to displace forcefully. This study demonstrates that 60% sample households displaced their residence as involuntary way.

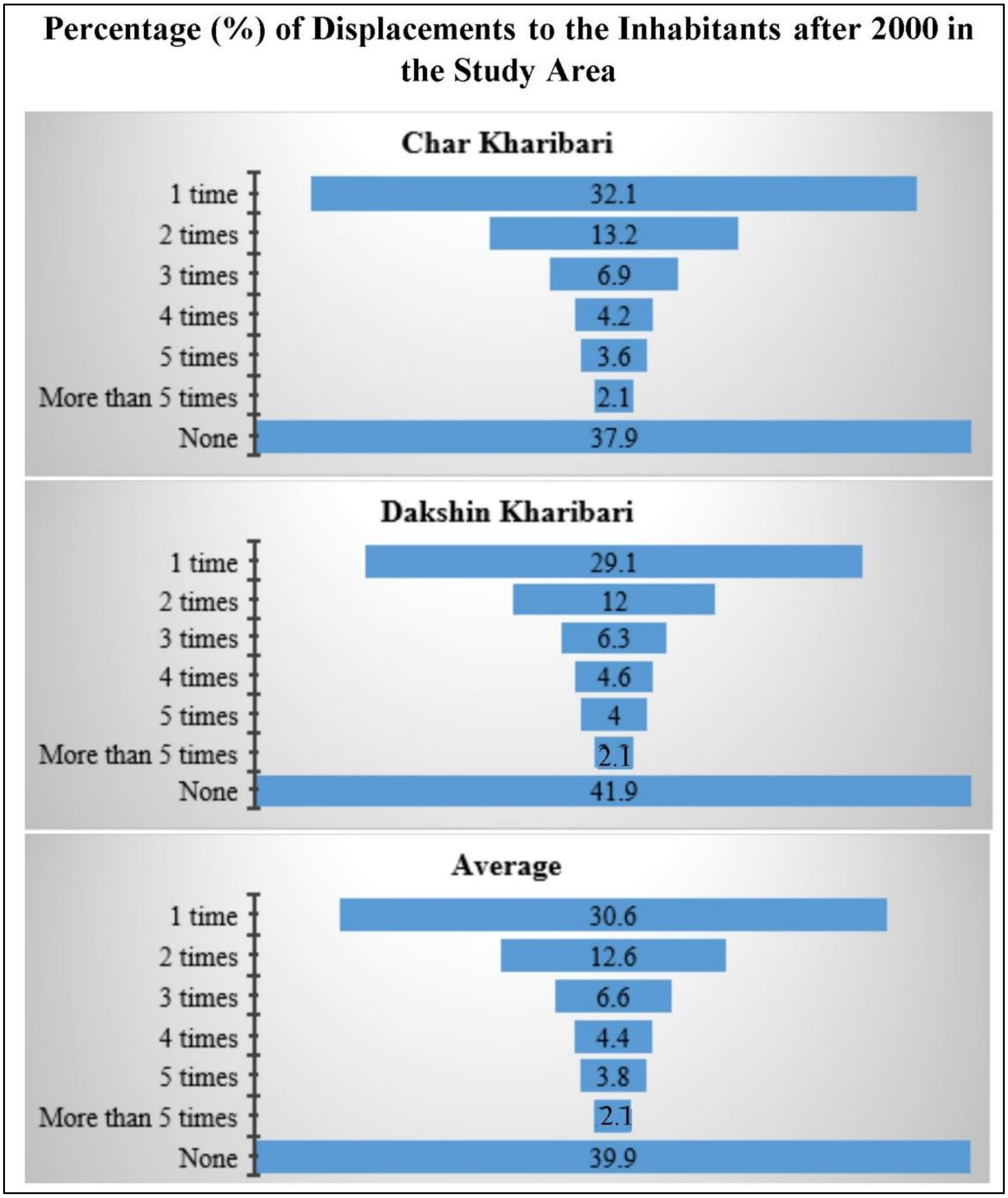

Fig. 5. Number of displacements to the inhabitants (*Source: Field Survey, 2022)*

4.9. Copping strategies of erosion victim households

Bank erosion victim households become pauperization due to income erosion and limited opportunities provided from different sources. Riverbank erosion is considered as one of the major causes of national poverty (Rahman, 2010). Victim people cope with the loss of cultivable land and households by the help of neighborhood, relative, Government and NGOs. Fig. 6 illustrates the victim households' assistance from different sorts of funds. Table 4 also shows the types of assistances getting from different levels to survive.

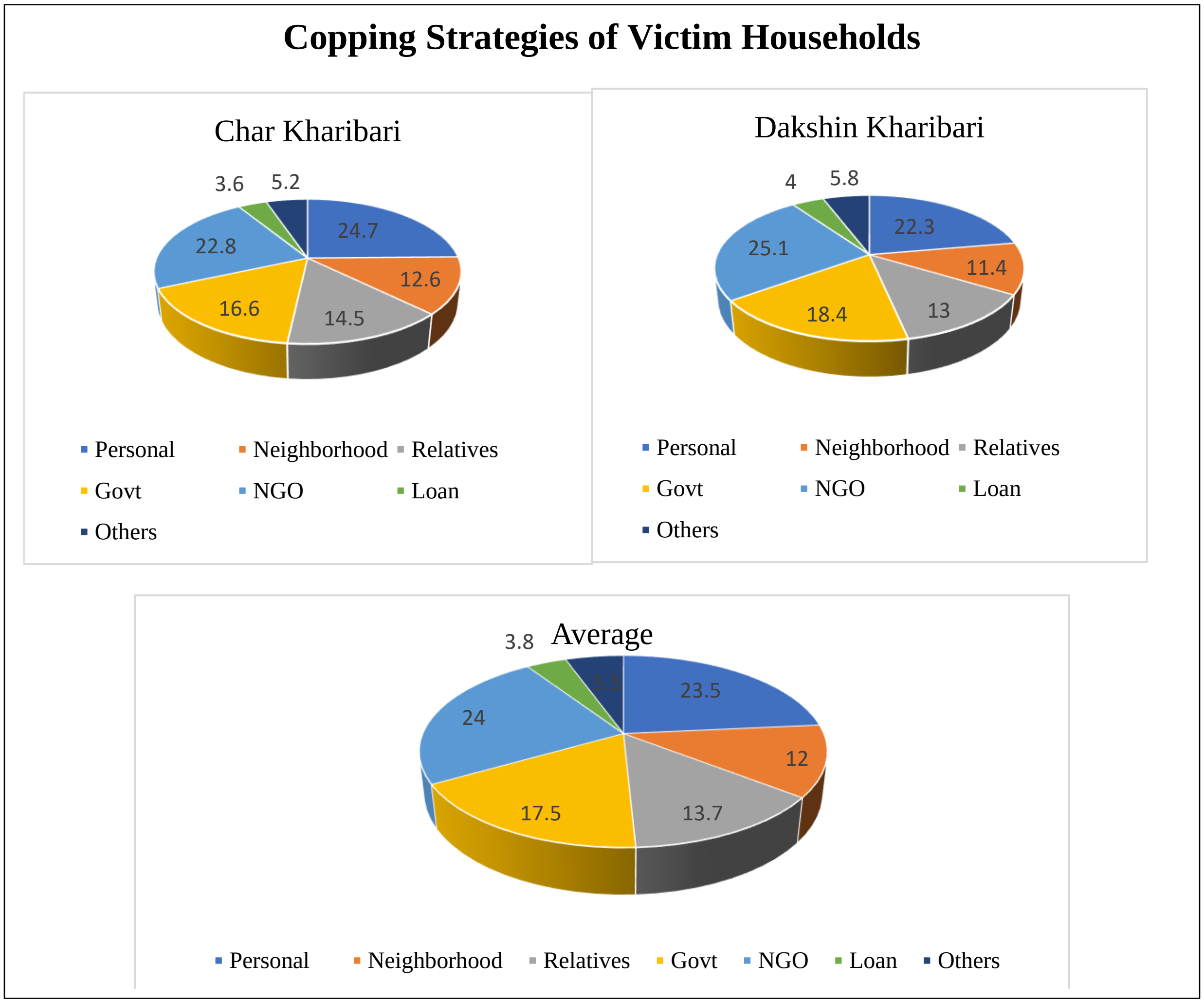

Fig. 6. Copping strategies of victim households (*Source: Field Survey, 2022)*

Table 4: Types of assistance received by the riverbank erosion

Types of Assistance	Percentage of Respondent Households		
	Char Kharibari	Dakshin Kharibari	Average
Received relief services (Rice, lentil, oil and vegetable)	18.4	16.6	17.5
Received relief services (Dry food and mineral water, kerosene)	26.3	23.1	24.7
Received rehabilitation services: houses, buildings, agricultural inputs, loans, etc.	4.0	3.6	3.8
Land from accredited chars	5.7	6.3	6
Shelter on the embankment	17.1	18.9	18
Development services from NGOs	22.8	25.2	24
Others	5.7	6.3	6
Total	100	100	100

Source: Field Survey, 2022

5. Recommendations and conclusion

Every year, riverbank erosion has made a great impact on our life and economy. Here, we put some recommendations to reduce the possible risk or impact of riverbank erosion. As a result of riverbank erosion, a long-term impact on livelihood pattern of people are observed. Some specific suggestions are recommended to reduce the effects of riverbank erosion and also protect bank line erosion.

- The long course of Teesta River has to be managed by a guideline and erosion prone areas of this river need to be pointed by details survey and analyzing satellite images.
- Teesta River floodplain has to be managed by involving different stakeholders.
- Some sorts of engineering measures (e.g. block embankment, river training, sand filling bag falling) and also others measures (tree planting, displacement at save place from erosion, creating employment opportunities, provide relief among real victim households) are needed to be incorporated immediately.

Bank erosion of the Teesta River at Tepa Kharibari and Dakshin Kharibari affects deadly on the people regarding socio-economic conditions. Moreover, the erosion is more aggressive at Dakshin Kharibari than at Tepa Kharibari Char as a result of the bend is yet in the mature stage. As a consequence, the different categories of lands near the bend are under threat of erosion for the next few years. Thus, the local people, who lost their lands, are being deprived of their livelihood security and in terms of effects they are getting pauperized gradually. They are losing access to all sorts of capital they need to maintain their livelihood. The study focuses on assessing the nature of exposure regarding riverbank erosion and its associated impacts on livelihood at local level. It is shown in this study that the people of this area are too much vulnerable to cope with riverbank erosion on their capacity and resource. The area is badly in need of support from the government so, they can mitigate and get prepared for riverbank erosion which occurs almost every year.

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Variations of aerosol optical depth during COVID-19 lockdown in Bangladesh

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ABSTRACT

The outbreak of COVID-19 pandemic has created an acute crisis across the world to both human health and world economy. Bangladesh imposed nationwide lockdown to control the spread of the pandemic, providing an opportunity to study the impact of global emissions reductions on Aerosol Optical Depth (AOD) levels, an index of air pollution in Bangladesh. The objective of this study is to examine the variations of AOD induced by the COVID-19 lockdown period by contrasting its value between strict lockdown period and partial lockdown period in Bangladesh. Spatial and temporal variations of AOD were analyzed over Bangladesh during both lockdown periods using Moderate Resolution Imaging Spectroradiometer (MODIS) data. The key findings of this study showed that AOD reduced due to lockdown in Bangladesh which is more significant for strict lockdown than partial lockdown. Investigation of other air pollutants such as nitrogen dioxide (NO_2), sulfur dioxide (SO_2), ozone (O_3), carbon monoxide (CO) and particle matter (PM2.5 and PM10) also revealed similar results as AOD. In addition different meteorological variables during the same time periods were also determined to observe the variations. This study can help the policy makers to develop a guideline for reducing and controlling air pollutions in Bangladesh.

Keywords: Aerosol optical depth, COVID-19, lockdown, Bangladesh

1. Introduction

The Severe Acute Respiratory Syndrome-COrona VIrus Diseases 2019 (SARS-COVID-19) has extremely wounded the world through comprehensive human to human transmission and gave rise to the human death rate and authentic economic losses over the globe (Bukhari and Jameel, 2020; Ranjan et al., 2020). According to the World Health Organization it has recognized that the

COVID-19 as the sixth public health exigence on a global scale on 30 January 2020. WHO also reported that the COVID-19 pandemic is making global influences like as AIDS (1980s), Bird Flu (2005), H1N1 Swine Flu (2009), Ebola in West Africa (2014), Zika (2016), and Ebola in Congo (2019). The COVID-19 pandemic has rapidly been spreading in the world after the first case detected at 31 December 2019 in the Wuhan city of China with a total confirmed cases of 534,299,912, total deaths about 6,317,884 and the total recovered about 505,204,999 till 20 May 2020 where the world's top five affected countries were United States of America, Russia, Brazil, the United Kingdom and Spain (Shi et al., 2020; Li et al., 2020). These data was collected from WHO's COVID-19 dashboard which provides the details of global COVID-19 cases.

Bangladesh indicated the first verified cases of coronavirus disease (COVID-19) in the country on Saturday, 7 March 2020 (Shammi et al., 2021). Two of the infected individuals were returned from Italy, and a third patient is a family member of one of the travelers. The COVID-19 pandemic in Bangladesh is a segment of the global COVID-19 pandemic spreading due to severe acute respiratory syndrome coronavirus 2 (SARS-CoV-2). This COVID-19 pandemic in Bangladesh has traced day by day over the total nation and the number of suspected people has been increasing. In order to prevent the population, the government of Bangladesh declared strict lockdown throughout the nation from April 2020 to December 2020 and later a partial lockdown from January 2021 to December 2021 and took some necessary steps to spread conversance to keep this symptom away from them (Shammi et al., 2021). During lockdowns all mass gatherings were prohibited, except emergency transportation both intra-district and inter-district transportation were banned, industrial activities were also limited along with other measures. These measures during lockdowns has altered pollution concentrations and improved air quality by decreasing various emission sources (Kumar et al., 2020; Haque et al., 2022).

Numerical studies have started in this heading and oppressing on how global lockdown activity has improved the state of the Earth's Atmosphere due to COVID-19 (Sanap, 2021). The studies focusing the association between air quality, meteorological conditions and COVID-19 cases across Bangladesh during COVID-19 lockdowns are limited. Some studies were carried out on different aspects of environmental conditions associated with COVID-19 pandemics. Rana et al., (2022) observed the variations of a particular air pollutant, Rana et al., (2022) analyzed the impact on air quality and Roy et al., (2020) investigated relation between health hazards and air quality during CODID-19 pandemic. However merging different factors such as changes of different air pollutant concentrations, meteorological and environmental impacts on air pollutants and the relationship between COVID-19 cases and air pollutants in Bangladesh like developing country is very important. Because air pollution in Bangladesh is extremely high along with higher population density and inappropriate managerial activities.

Atmospheric aerosols are the most important particles in atmosphere. Earth's atmosphere is changing because the variations of atmospheric aerosol load, greenhouse gases, solar radiation, and land surface properties (Mamun et al., 2014). To determine the conditions of lower atmosphere and earth's surface atmospheric aerosols play a vital role (Mamun et al., 2015). Aerosols (minute particles suspended in the atmosphere and represented by aerosol optical depth simply called AOD) are indicators of pollutants levels and may provide required information related to the air pollutants and pollution driven problems those are having potential to affect both human and environment (Singh and Nanda, 2020). Temperature fluctuations, rainfall pattern changes, intensive tropical cyclone, radiative forcing and desertification are integrated by aerosol studies (Mamun et al., 2014). Satellite remote sensing as like Moderate resolution Imaging Spectro radiometer (MODIS) is an effective way to observe aerosol optical properties. MODIS gives global aerosol optical data both land and ocean. MODIS satellite data has been shown to have tremendous skillful for mapping the ordination and properties of aerosols. Aerosol intentness are regularly developing especially in Asia due to growing populations, perfunctory urbanization with consequent land use changes, increasing industrializations and increasing motorized traffic (Islam et al., 2014). In this study MODIS aerosol datasets are used to investigate the variability of aerosol optical properties.

Air pollution, civic and medical waste creation, noise quality and other elements are all impinged by this pandemic (Mostafa et al., 2021). Air contamination is a big global factor right now and there is no exception in Bangladesh. Excessive air pollution causes a variety of lung illnesses. According to a survey conducted by Mahmood in 2011, 15,000 people die in Bangladesh each year as a result of lung ailments induced by high air pollution. The principal substance of the atmosphere that are harmful to human health include particulate matter (PM), sulfur dioxide (SO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), and ozone (O_3). Under the influence of sunlight, NO_2 performs a critical series of reactions with essential fleshly compounds to produce O_3

(Manisalidis et al., 2020). Several studies have shown that NO_2 has opposed impacts on human body, particularly the lungs (Huangfu, P., & Atkinson, R., 2020). CO is also emitted into the circumstance as a result of incomplete affliction. Because it substitutes oxygen in hemoglobin, it is exceedingly damaging to one's health. Apart from pulmonary disorders, CO has a significant impact on the human heart (Forifa et al., 2013). Asthma, bronchitis, and other lung illnesses are caused by SO_2 (Reno et al., 2015). The intense of high sulfur quantity fuels is the primary source of SO_2 emissions in the environment.

Previous work did not provide any comparisons of air quality along with meteorological conditions linked to COVID-19 pandemic between two different lockdown time periods. In this paper the monthly averaged variations of AOD over Bangladesh was observed by dividing the study into two sceneries, i.e., first lockdown (April 2020- December 2020) and second lockdown (January 2021- December 2021). Other important air quality indicators such as $PM_{2.5}$, PM_{10}, NO_2, SO_2, O_3 and CO were also analyzed during the time periods.

2. Methodology

2.1. Study area

Fig.1 shows the map of Bangladesh as study area. Bangladesh is the most densely populated and extremely polluted country in South Asia. It is one of the most vulnerable countries for climate change impacts in the world. It has the largest border with India such as west, north and east and also the southeast border with Myanmar. Bangladesh is the largest delta which formed by Ganges, Brahmaputra and Meghna river system (Mamun et al., 2014). High temperatures, extreme coldness and fairly marked seasonal variations of precipitation are the main climatic characteristics of Bangladesh (Islam et al., 2014). There are four distinct seasons which are considered in the study area from climatic point as like (1) winter season which belong December to February (2) the pre-monsoon hot summer season from March to May (3) rainy season belong June to September and (4) the post-monsoon season which lasts from October to November. The mean temperature of the country is 25°C. Maximum temperature is 40°C from March to June. November to March is the coolest part of the with temperatures range from 8°C to 15°C. Maximum rainfall occurs during rainy season in Bangladesh. With recurrent floods, cyclones, droughts, tornadoes, and storm surges is one of the most pervious to global climate change due to its unique geographic location and complicated hydrogeologic setting. Vehicle and industry emissions are two primary drivers of air pollution in Bangladesh (Mahmood, 2011). Industrial expansion, on the other hand, is a major driver of economic growth in Bangladesh, accounting for more than 35% of GDP (Ahaduzzaman et al., 2017). Apart from these, brick kilns are an outgoing and significant origin of air pollution in Bangladesh, particularly during the dry season. It is one of the world's most polluted countries in recent decades. Deep-province carried contaminate from cities within Bangladesh, including Dhaka, Narayanganj, Gazipur, Rajshahi, Chattogram, and Khulna, were reported as some of the significant drivers of air quality deterioration in Bangladesh (Mamun et al., 2014).

Fig.1. Map showing the study area.

2.2. Dataset and analyses

Aerosol optical depth (AOD) can be measured by both in situ and remote sensing Measurement systems and the satellite remote sensing measurement is used. To research the large spatial and temporal heterogeneities of aerosol distributions satellite remote sensing is necessary. The

MODerate resolution Imaging Imaging Spectroradiometer (MODIS) AOD datasets are used. MODIS has a unique collaboration of features such as, a wide spectral range of electromagnetic energy; calculations at three spatial resolutions of all day and every day; and it has a wide domain of view. There are 36 spectral channels under MODIS sensor onboard NASA's Terra and Aqua satellites (Islam et al., 2015). By observing, all the spectral channels provide atmospheric, oceanic, and terrestrial information (Ali et al., 2017). An AOD at 550 nm reclaimed using MODIS has been surveyed used to address various climate and air quality. The combination of Dark Target (DT) and Deep Blue (DB) algorithms assess the aerosol optical depth (AOD) at 550 nm over land and ocean with a spatial resolution using MODIS-measured reflectance based on visible to shortwave infrared. Cloud mask, gas, and Rayleigh adjustments, as well as surface reflectance computations, are used to update MODIS aerosol products on a regular basis (Ali et al., 2019). MODIS collects data in real time, which is critical for understanding long- and short-term changes in the global environment. Aerosol retrieval differs between land and oceans. Using diverse parts of the electromagnetic spectrum, the MODIS delivers measurements at moderate geographical and temporal resolutions (Mamun et al., 2014).

2.3. Changes of aerosol subtypes

The current study used the aerosol subtypes profile to research the aerosol types over the Bangladesh because the aerosol optical properties from the ground-located aerosol robotic network are not available for classifying aerosol types. In addition, the study examined the variation in particular during the shutdown in Bangladesh's using spatial distribution of aerosol subtype profiles.

Significantly decreased levels of air particles were also noted in Bangladesh's during strict lockdown, similar to what was discovered for NO_2, O_3, CO, SO_2, $PM_{2.5}$ and PM_{10} along with AOD.

2.4. Air dignity and meteorological volatile during lockdown periods

A number of air contaminants and air quality parameters have been considered in the comparison of air quality. MODIS satellite data was used in this study. Satellite data has been made to be quite dependable in recent years due to its consistency and the fact that its observation area is not limited to specific places. As a result, satellite data may be used to properly monitor NO_2 and other gases in the atmosphere. Comparison of air quality between distinct timelines or between two different locales can be readily done using time-averaged map created from satellite data. NASA's

GIOVANNI platform has produced time-averaged map of various contaminants in the atmosphere. Table 1 shows the summary of the air contaminants observed during lockdown based on satellite data. Various air quality criterions in Bangladesh are showing in Table 2. The ministry of Environment, Forests and Climate Changes (MEFC) Bangladesh monitor the air pollutants regularly using in situ measurements CAMS which are located throughout the country (Ministry of Environment, 20200.

Various meteorological particles such as average daily temperature, average daily dew point temperature, daily precipitation, and daily average wind speed, were estimated from April 2020 to 2021.

Table 1: Summary of the air contaminants observed during lockdown based on satellite data (GIOVANNI 2021)

Time-averaged maps	Unit	Description
NO_2	1/cm^2	Clouds are screened in 30% of the time.
$PM_{2.5}$ density	kg/m^2	monthly 0.5 0.625 degree
O_3	DU	Daytime/ascending, daily 1 degree
CO	ppbv	Monthly 0.5 × 0.625 degree
SO_2 density	kg/m^2	Monthly 0.5 × 0.625 degree,

Table 2: Criterions of air quality of Bangladesh (MEFC 2020)

Pollutant	Average value	Average
SO_2	80 µg/m^3 (0.03 ppm)	Annual
	365 µg/m^3 (0.14 ppm)	24 h
CO	10 mg/m^3 (9 ppm)	8 h
	40 mg/m^3 (35 ppm)	1 h
O_3	235 µg/m^3 (0.12 ppm)	1 h
	157 µg/m^3 (0.08 ppm)	8 h
NO_2	100 µg/m^3 (0.053 ppm)	Annual
$PM_{2.5}$	15 µg/m^3	Annual
	65 µg/m^3	24 h
PM_{10}	50 µg/m^3	Annual
	150 µg/m^3	24 h

3. Results and Discussion

3.1. Spatial and temporal variation of AOD during Apr 2020 - Dec 2020 and Jan 2020 - Dec 2021 over Bangladesh

Fig. 2 and Fig. 3 show the spatial scenarios of MODIS monthly mean AOD over Bangladesh during the periods of COVID-19 first and second lockdowns respectively. During the first lockdown period and second lockdown period, a spatial contrast in AOD was detected across Bangladesh. First lockdown reported lower aerosol loading than second lockdown. Noted that first lockdown across Bangladesh was more rigorous than second lockdown. Qiu et al., (2021) also reported a significant reduction in AOD ranging from 1% to 47% in big cities across Bangladesh.

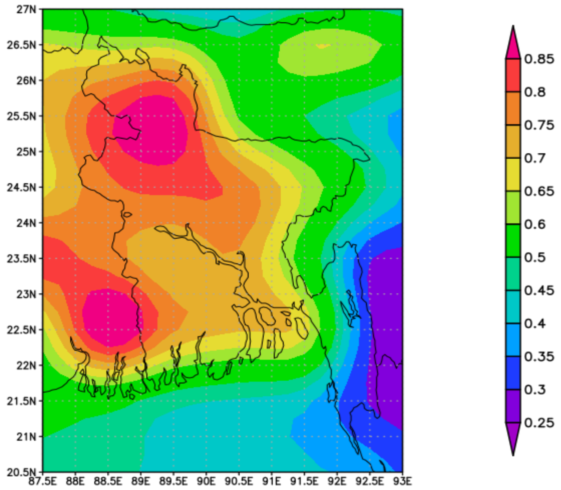

Fig. 2. Spatial distribution of AOD over Bangladesh during first lockdown (Apr 2020 - Dec 2020).

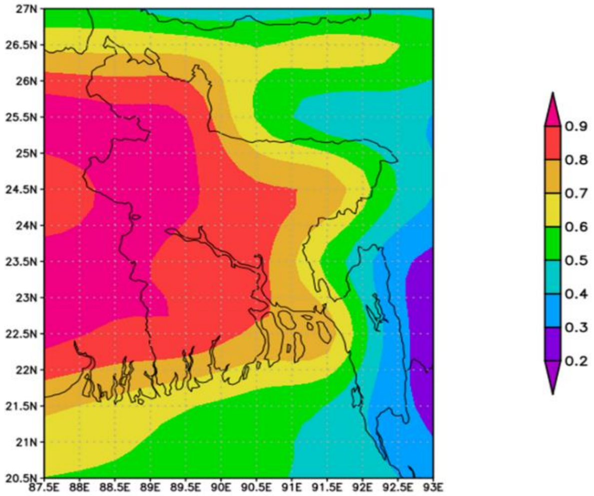

Fig. 3. Spatial distribution of AOD during second lockdown (Jan 2021 - Dec 2021)

Fig. 4 and Fig. 5 shows the area averaged time series of AOD across Bangladesh during first lockdown period and second lockdown period respectively. Almost similar patterns of time series were observed during the both lockdown periods. High AOD values were rapidly decreasing after starting the lockdowns and reached its lowest values towards the closing of lockdowns. At the ending months of the lockdowns the values of AOD again started to increase. Therefore measures taken during lockdown periods helped to decline AOD sources.

Nitrogen oxides (NOx) are mostly emitted as NO from industry, power plants, household heating, and vehicle exhausts, and they are then oxidized to generate NO_2. NO_2 is a precursor of nitrate aerosols and ozone, as well as a tracer of anthropogenic combustion activity. NO_2 can cause respiratory disorders including asthma, as well as harming the ecosystem by causing acid rain. NO_2 can cause respiratory disorders including asthma, as well as harming the ecosystem by causing acid rain. As expected, during the rigorous lockdown (March–May) and partial lockdown (June) in 2020, a significant geographical differential in NO_2 and O_3 (1015 molec/cm^2) was recorded in all of Bangladesh's main cities compared.

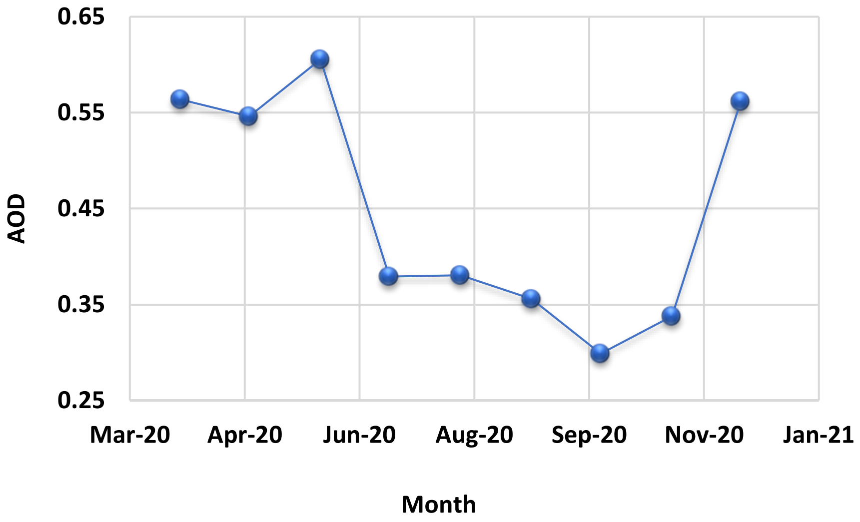

Fig. 4. Time series of area averaged AOD over Bangladesh during first lockdown (Apr 2020 - Dec 2020).

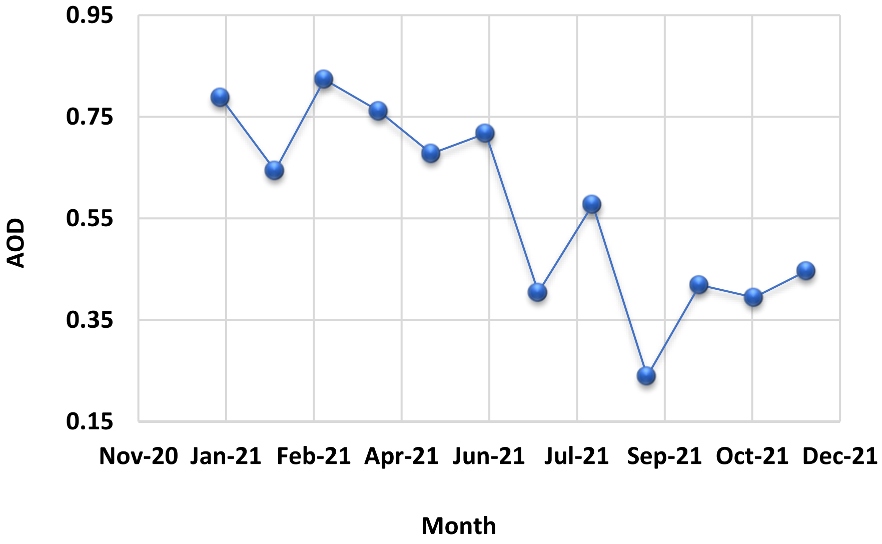

Fig. 5. Time series of area averaged AOD over Bangladesh during second lockdown (Jan 2021 - Dec 2021).

3.2. Statistical evaluation

To evaluate the features of the data collected during the lock-down and partial lockdown periods statistical analyses were conducted. For the air pollutants and climatic variables during the first lockdown and second lockdown periods, the mean, standard deviation, minimum value, maximum value, range, and median were determined. Tables 3 and 4, respectively is the statistical data analysis for the air quality parameters and meteorological parameters. In this study, the null hypothesis argues that the pretext of the data collected at various period can be regarded as same. In light of these nonparametric tests, an argument was made regarding whether to accept or reject the null hypothesis.

Table 3: The statistical data of the air pollutants during the lockdown periods

Observed period	Statistical parameters	NO_2 (ppb)	O_3 (ppb)	CO (ppm)	SO_2 (ppb)	$PM_{2.5}$ (µg/m^3)	PM_{10} (µg/m^3)
1st Lockdown period (Apr 2020–Dec 2020)	Mean	36.72	6.39	3.87	11.80	30.22	75.06
	Standard deviation	5.00	2.00	0.17	1.39	5.03	20.71
	Min value	9.2	2.38	0.78	10.52	35.2	87.07
	Max value	70.78	5.1	2.36	46.36	40.52	104.12
2nd lockdown period (Jan 2021–Dec 2021)	Mean	45.35	24.47	3.95	13.27	90.56	278.99
	Standard deviation	6.00	3.00	1.2	2.56	8.25	25.05
	Min value	11.2	20.25	2.21	12.51	55.62	221.06
	Max value	121.63	28.9	3.69	113.86	150.09	280.45

Higher air pollution would be a reason of higher daily COVID-19 case rate as the human lung is affected directly by COVID-19 (Islam et al., 2021). During first lockdown the amount of all the air pollutants (NO_2, O_3, CO, SO_2, $PM_{2.5}$ and PM_{10}) were lower than second lockdown. Ahmed et al., (2022) also found similar results. First lockdown period was stricter than second lockdown period in Bangladesh. Due to strict lockdown air pollutions from various manmade sources were limited which results a cleaner air during first lockdown period than second lockdown period. All the meteorological parameters (average temperature, average wind speed and precipitation) also showed lower values during first lockdown period than second lockdown period in Bangladesh. Further studies are needed to analysis the relationship between lockdown conditions and meteorological conditions in order to link the meteorological conditions with COVID-19 cases.

Table 4: Summary of the statistical data of the meteorological properties during the observed periods.

Observed period	Statistical parameters	Average temperature (°F)
1st Lockdown period (April 2020–Dec 2020)	Temperature at 2 Meters	24.92
	Temperature at 2 Meters Max	38.32
	Temperature at 2 Meters Min	8
	Temperature at 2 Meters range	30.34
		Average wind speed (m/s)
	Wind speed at 10 Meters	2.64
	Wind speed at 10 Meters max	14.27
	Wind speed at 10 Meters min	0.05
	Wind speed at 50 Meters	3.87
	Wind speed at 50 Meters min	0.05
		Precipitation (cm)
	Precipitation corrected(mm/day)	8.53
	Precipitation corrected sum (mm)	3142.97
2nd lockdown period (Jan 2021–Dec 2021)		Average temperature (°F)
	Temperature at 2 Meters	25.48
	Temperature at 2 Meters Max	40
	Temperature at 2 Meters Min	7.01
	Temperature at 2 Meters range	32.99
		Average wind speed (m/s)
	Wind speed at 10 Meters	2.63
	Wind speed at 10 Meters max	11.55
	Wind speed at 10 Meters min	0.03
	Wind speed at 50 Meters	3.88
	Wind speed at 50 Meters min	0.03
		Precipitation (cm)
	Precipitation corrected(mm/day)	6.56
	Precipitation corrected sum (mm)	2394.66s

3.3. COVID-19's impact on several factors in Bangladesh

The economy is the most significant industry that has been adversely impacted by the pandemic. During the epidemic, all nations have encountered serious economic challenges (Mostafa et al., 2021). The primary causes of the global economic crisis include reductions in the functioning of industries, transportation of people and goods (Fernandes, 2020). Bangladesh, like other nations, has been dealing with a number of issues as a result of the decline in economic activity during the shutdown (Ahmed et al., 2022). The lockdown had a significant impact on Bangladesh's key economic sectors, including agriculture, services, and industry. The usual sources of raw materials for pharmaceutical production include China and India, both of which were affected by the pandemic (Begum et al., 2020). As a result, during the lockdown, numerous medication shortages were noted. During the lockdown that caused major issues for the vast majority of people, the cost of face masks and hand sanitizer rose by roughly 400 percent (Dhaka-Tribune 2020). On March 16, 2020, Bangladesh issued a proclamation closing all schools, colleges, and institutions, with the assumption that it would begin on April 5, 2020. (MOE 2021). However, educational institutions remained closed as of July 27, 2021, as the COVID crisis worsened. Additionally, the government provided subsidies to help the underprivileged enroll in online courses. Many graduate students are experiencing extreme stress and anxiety problems as a result of their delayed graduation. During the lockdown phase, significant social effects were seen in Bangladesh. Due to the dissemination of various misleading or fabricated information, social media was used to spread social panic and hostility across the nation. People spent much of their spare time at home, which led to increased use of social media. During the lockdown, there was a noticeable increase in both crime and poverty. The lockdown era was accompanied by a sharp increase in domestic violence against women, according to research, and many of these women also had anxiety disorders (Banna et al. 2020). According to many research, the lockdown period increased food consumption (Mostafa et al. 2021; Nile 2020). Obesity and significant waste generation are caused by increased food consumption. By shortening the period between waste collection visits, the authorities took the necessary action. However, both sick individuals who did not get a disease test and regular persons disposed of their waste at the same location.

4. Conclusion

This study aims to detect the variations of AOD levels during strict and partial lockdown periods. In this study, Moderate Resolution Imaging Spectroradiometer (MODIS) satellite data sets were used to observe the changes of AOD levels over strict and partial lockdown timelines. Ground station based costly aerosol measurement techniques are not available throughout the country. Satellite based observation technique may be an effective way for aerosol study for a developing country like Bangladesh. Findings had shown that the spatial distribution of AOD had a comparatively lower value during strict lockdown period than partial lockdown period. Time series analysis exhibited a drastic fall in AOD after starting the lockdowns. The conditions of all the other air pollutants such as NO_2, SO_2, O_3, CO, PM2.5 and PM10 were more improved during strict lockdown period than partial lockdown period. Restrictions upon vehicles, shut down of industries, limiting mass activities during lockdowns helped to reduce the emission of air pollutants in Bangladesh. Air quality of Bangladesh is strongly affected by climatic and meteorological conditions. The condition of different meteorological parameters were also compared during strict and partial lockdown periods. Result exhibited better conditions for most of the meteorological parameters during strict lockdown period than partial lockdown period. Further investigation is needed to understand the impacts of meteorological conditions during lockdown period. Bangladesh has a high aerosol concentration along with other air pollutants throughout the country. The tight lockup, however, can significantly reduce their concentrations. For AOD and pollution-control techniques, the benefits of air quality limitation measures during COVID-19 lockdown scenarios appear to be a rare opportunity. This study will influence different stakeholders to identify the sources or atmospheric air pollutions and to plan a sustainable strategies to improve air quality.

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Predicting spatial-temporal assessment of threatened wetland and sensitive ecosystem for 2029 using CA-Markov chain model, Bangladesh

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ABSTRACT

Spatiotemporal distribution of Land Use and Land Cover (LULC) changes, in addition to a variety of socio-ecological issues, such as decadal changes in LULC with anthropogenic activities, relationships between the physical environment, cultural landscape and human activities, are all important topics that can be studied using satellite imagery. This study used eastern part of Dhaka, Bangladesh as a case study. However, there are five multi-temporal Landsat images were used in this study which is obtained in 1991, 2001, 2011 and 2021 respectively. Among them, threes are from Landsat 5 Thematic Mapper (TM) and one is from Landsat 8 Operational Land Imager (OLI) were acquired. This study explores the spatial-temporal assessment of threatened wetland and sensitive ecosystem for 1991-2021 and predicts the threatened wetland due to rapid disorganized urbanization, encroachments and renovation as well as drawbacks from agricultural development for 2029 using CA-Markov chain model. Images were classified into six classes using the maximum likelihood supervised method, where the training sample consists of at least 10 polygons and a total of approximately 90 to100 pixels per class. Hereafter, their accuracy was measured by *kappa* statistics and overall accuracy methods. Finally, this paper reveals that the spatial-temporal assessment of wetland has been identified from 1991-2021 and predicted the next 10 years using different social, environmental and physical parameters. Wetlands are decreased from 27.22 % to 22.70 % and the settlement areas are increased from 15.06% to 32.12% within 30 years interval. If this trend continues, it looks that wetlands will permanently lose their unique traits and ecosystems, having a severe influence on Dhaka.

Keywords: Spatio-temporal, threatened wetland, sensitive ecosystems, CA-Markov model, prediction

1. Introduction

Wetlands are important for maintaining ecological, biological, zoological, hydrological, industrial, economical, and characteristics that differentiate, including subterranean rivers (Islam and Gnauck, 2007). Because of their splendor and biodiversity, wetlands are increasingly being recognized as regions of great natural beauty (Finlayson and Moser, 1991). Human has relied on much of wetland’s bio-production for years of age, including fish for protein, peatland for fuel, and lumber and stalks for construction materials (Maltby, 1986). It not only protects fragile species, but also contributes significantly to the financial well-being of millions of citizens in distant areas by providing jobs, irrigation, fuel, fodder, transportation, food, and nourishment (Islam, 2010). However, wetlands around the Dhaka city are under threatened due to disorganized utilization, encroachments and renovation, flood control actions, urbanization as well as drawbacks from agricultural development (Ishtiaque et al., 2015). Consequently, each year with the rainy season, city residents have severe water logging issues. Water logging is one of the key issues facing the City, according to a report on the Integrated Environment Assessment of Dhaka (World Bank, 2007). Furthermore, wetlands are becoming well-known as a home to a wide range of animals. Most of the wetlands are perennial around the Dhaka city which include brick fields, water shade, industries, rice field, *beels*, and ponds (Forests, 2010). Wetland habitats include canals, lagoons, marshland, paddy fields, and coastal areas, which provide a range of functions that aid human well enough and socioeconomic alleviation (François et al., 2005). The remnants of an ecosystem that formerly spanned a larger area but has gradually contracted due to human influence. Ecologically fragile, vulnerable, or extinction-threatening ecosystems exist. Local elite groups have authority over wetlands and environmentally sensitive regions. Bangladesh's control and safety status is more difficult and harsher as a result of financial, technological, cultural and political choices, and often a lack of cooperation among those fields (Gopal and Wetzel, 1995, 1999). Due to the absence of a central authority, coordination amongst the relevant entities is lacking for the oversight of wetlands in the city of Dhaka. Water logging is one of the City's major problems, so it is urgently necessary to put in place rules on land use, strict enforcement procedures, limitations on encroaching land on the khals river bank in the city, and urban and drainage planning strategies (Khan, 2001). Unsystematic usage, invasion and redevelopment, development and agricultural expansion challenges, and flood mitigation measures are now threatening the bulk of the country's designated wetlands (Nishat, 1993; Gopal, 1999; Islam and Gnauck, 2009).

The goal of this research is to map the current and future biological conditions of significant vulnerable wetlands, as well as their economic advantages in various ways. Therefore, this study sets major three objectives to fulfill the aim which includes 1) to identify the chronological changes of threatened wetlands and environmentally sensitive ecosystems from 1991 to 2021; 2) to explore the functioning of freshwater wetlands and their importance in socioeconomic development in Dhaka's outskirts; and finally, 3) Applying geographic simulation (Markov Chain and Cellular Automata) in Land Use land cover Modeler, anticipate wetlands and ecologically sensitive ecosystems for 2029.

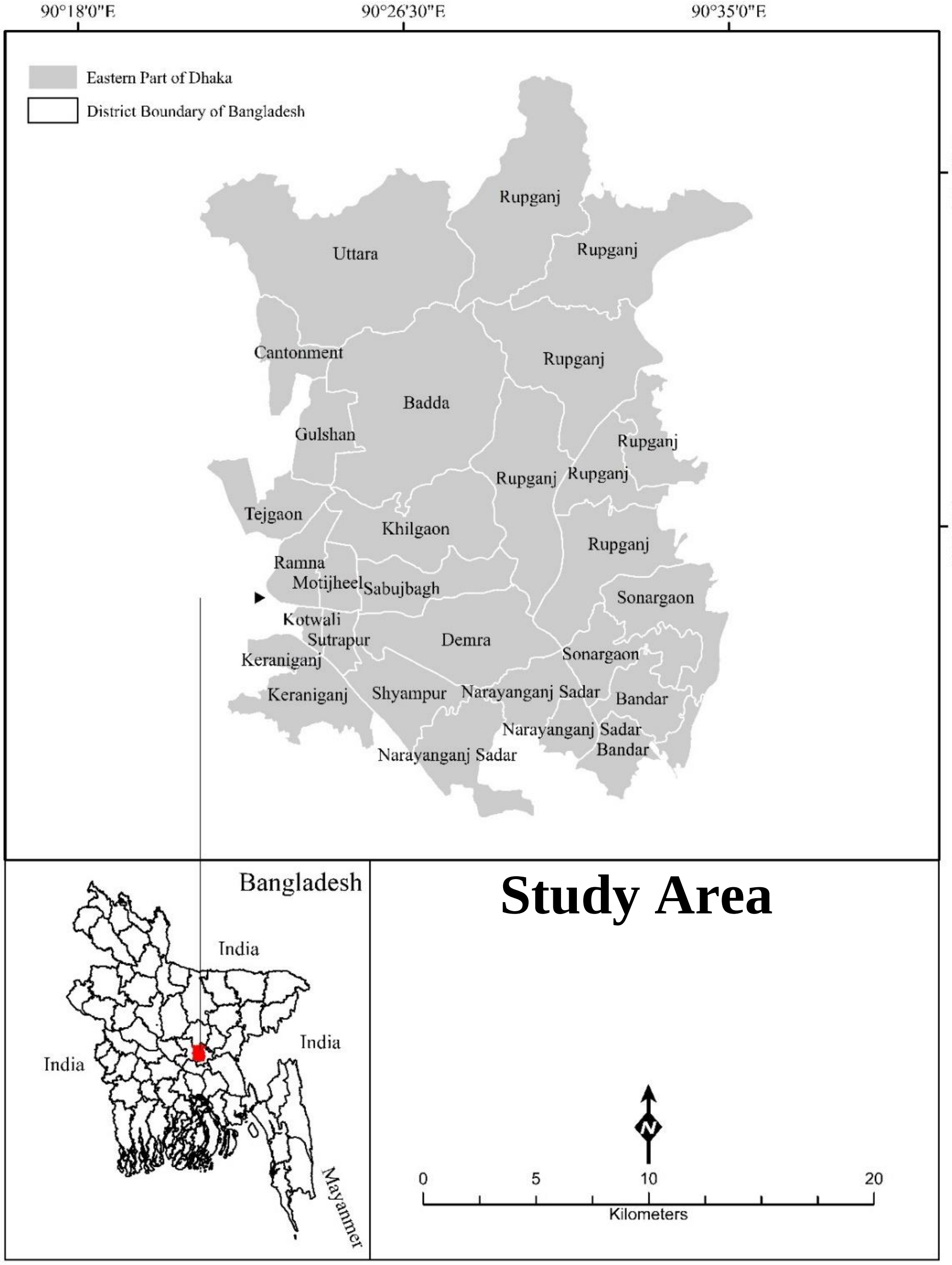

Fig. 1. Study area map of eastern part of Dhaka, 2023 (*Source*: compiled by author, 2023)

2. Methodology

2.1 Selection of the study site

The eastern part of Dhaka city was selected as a case study in this research (Fig. 1). With a local jurisdiction of 43,843 hectares, the study location is located between 23°42'30"N to 23°50'00" N latitude and 90°25'00"E to 90°35'00" E longitude. Furthermore, the majority of the site is located in the floodplains of four active rivers: Balu, Buriganga, Turag, and Shitalakshya. It is bordered by Dhaka City Corporation (DCC) on the west, Gazipur district (Tongi upazila) on the north, Narayanganj district (Fatulla upazila) on the south and east (Bhulta upazila).

There are 8 Thana and 1 Upazila under this study site namely, Demara, Jatrabari, Khilgaon, Badda, Dakshin khan, Sutrapur, and Matijhil and Gulshan thana-18 ward along with Rupganj upazila. Until 2023, it had a population density of roughly 23,234 people per square kilometer and an extremely relatively low Gross Domestic Product (GDP) around USD$ 7,712 (Asian Development Bank (ADB), 2023).

2.2. Data and methods

2.2.1. Data

Landsat images from 1991, 2001, 2011, and 2021 were used in this study. Three Landsat 5 Thematic Mapper (TM) images and one Landsat 8 Operational Land Image (OLI) image were downloaded from the United States Geological Survey (USGS).

Table 1: Detail information of satellite images used in this research

Satellite Imagery	Path/Row	Acquisition Date	Spatial Resolution (m)
Landsat 5 Thematic Mapper (TM)	137/43, 137/44	22/01/1991	30m
Landsat 5 Thematic Mapper (TM)	137/43, 137/44	13/02/2001	30m
Landsat 5 Thematic Mapper (TM)	137/43, 137/44	17/01/2011	30m
Landsat 8 Operational Land Imager (OLI)	137/43, 137/44	31/01/2021	30m

Land Use Land Cover Changes (LULC) were further divided into six categories: rivers, wetlands, vegetation, settlements, agricultural land, and bare surfaces. This study used spatial modelling

(Markov Chain and Cellular Automata) for predicting wetland changes using LANDSAT TM. This spatio-temporal analysis using CA model has been facilitated us to predict spatial pattern of future LULC changes for the study area. In order to anticipate future change, a Markov chain model depicts the LULC change from one time to the next (Burnham, 1973). The primary data about environmentally sensitive ecosystems, wetland activities, and their critical importance in socioeconomic expansion was acquired from local people in the SE area of Dhaka city using structure and semi-structural questionnaires. Random sampling was used to choose 15 Participatory Rural Appraisal (PRA) and Focus Group Discussion (FGD) participants for the study.

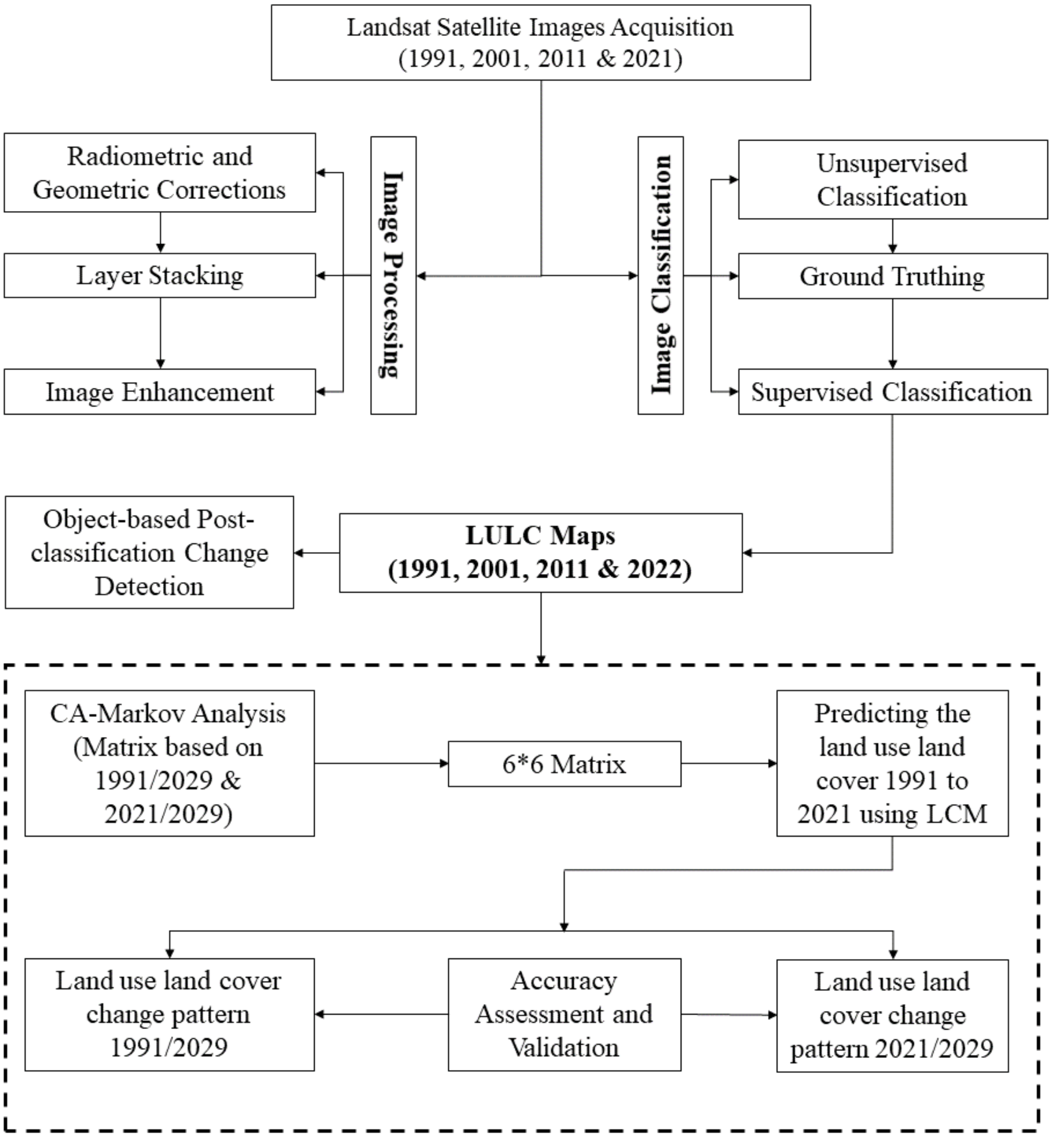

Fig. 2. Detailed methodological flow chart of the study (Source: Compiled by author, 2023)

Each group consisted 7/8 persons where 3/4 are males and 4/3 were females in the study site. Age, education, relationships to wetlands, wetland uses, ecosystem support, information sensitive vulnerable ecosystem, homeowners covering land tenure structure, rented property, farmland crop production and crops labeling, employment and finally, segment of the population protagonist were collected in 2021 through a questionnaire survey from the local community and various stakeholders. The research has been also based on secondary sources of data. A literature review was done to gather data, which helped to get a fundamental grasp of wetland deterioration, vulnerable ecosystems, wetland utilization, future wetlands use, and demographic information. Different national and international publications of government and non-government agencies, GO/NGO reports, and reputable research groups in Bangladesh were used to compile the literature. Hereafter, JMP, The Unscrambler X 10.5.1, EXCEL, ArcGIS 10.8, and Idrisi Selva (Clark Labs) tools were used to analyze the data. The overall supervised LULC classification performance for evaluating the quality of categorized Landsat TM images from 1991 to 2021 was calculated using kappa statistics and a misclassification rate.

2.2.2. Image processing

Following that, the geometric and radiometric corrections were made to all images using ENVI 5.5.2 software's Fast Line-of-Sight Atmospheric Analysis of Hypercubes (FLAASH). Using supervised classification, the image categorization was processed. This FLASSH tool, also called the "Radiative Transfer Model," supports lowering air perturbation on nadir viewing images, correcting the adjacency effect, and decreasing the consequences of scattering in neighboring sea surface pixels to recover substrates by minimizing radiances (Hashim et al., 2022).

FLAASH begins with the conventional equation for spectral radiance at a sensor pixel, L, which applies to flat, Lambertian materials or their equivalents and the solar wavelength range (thermal emission is ignored). The calculation corresponds to this:

$$\mathrm{L} = \left(\frac{\mathrm{A}\rho}{1 - \rho_{\mathrm{e}}\mathrm{S}}\right) + \left(\frac{\mathrm{B}\rho_{\mathrm{e}}}{1 - \rho_{\mathrm{e}}\mathrm{S}}\right) + \mathrm{L}_{\mathrm{a}}$$

Where:

ρ = is the reflectance of the pixel's surface;

ρe = is the average surface reflectance for the pixel and its surrounds;

S = is the atmosphere's spherical albedo;

La = is the radiance back scattered by the atmosphere;

A and B are coefficients that depend on atmospheric and geometric conditions but not on the surface.

2.2.3. CA-Markov model for LULC changes and prediction

In order to anticipate future change, a Markov chain model depicts the LULC change from one time to the next (Burnham, 1973). The following equation describes how to calculate the prediction of land use changes:

$$Pij \text{ X } S\ (t, t+1) = S\ (t, t+1)\ (t)$$

where S (t) denotes the current state of the system at time t, and S (t + 1) denotes the current state of the system at time t + 1; In a state, Pij is the transition probability matrix, which is determined as follows:

$$= \|P_{ij}\| = \begin{Vmatrix} P_{1,1} & P_{1,2} & \cdots & P_{1,N} \\ P_{2,1} & P_{2,2} & \cdots & P_{2,N} \\ \cdots & \cdots & \cdots & \cdots \\ P_{N,1} & P_{N,2} & \cdots & P_{N,N} \end{Vmatrix}$$

$$(0 \leq P_{ij} \leq 1)$$

P refers for the probability; Pij means for the probability of transferring from present state i to some other state j in the future. PN is the probability of a certain state at any given moment. The probability of a low transition will be near zero, whereas the probability of a high transition will be near one (Kumar et al., 2014) and (Behera et al.,2012).

2.2.4. Land loss and gain calculation

The total gain and loss of the various land cover classes were calculated in ArcGIS and Idrisi Selva’s Land Change Modeler: ES. The change analysis was calculated into two time periods: from 1991 to 2001 and from 2011 to 2021. Firstly, we extracted the area between the beginning and ending years of the study period using data management tool. After that, the overlay techniques were used to calculate the net change in the area between 1991 and 2001 as well as between 2011 and 2021. The analytical toolbox utilized the Buffers and Erases tool for identifying changes between accretion and erosion area. Finally, the total area of these polygons has been estimated in square kilometers using the Calculate Geometry Tool.

In LCM, the 1991 LULC classes were placed in the row whereas the 2001 put in columns. The cross-tabulation matrix for the changing probability helped to calculate the gain and loss of the land cover classes.

3. Results and Discussion

3.1. Decadal changes from 1991 to 2021

Table 3.1 shows the overall distribution in acres of LULC for years 1991, 2001, 2011 and 2021 respectively. Using Landsat 5 Thematic Mapper and Landsat 8 Operational Land Imager, Land Use Land Cover Changes (LULC) classes are divided into six categories: rivers, wetlands, vegetation, settlements, agricultural land and bares surface. The area of the river in the table1 has lost 0.24% in between 1991 and 2001. And in the year of 2011, the area of the river has reduced 0.36% compared to the year of 2001. However, the net loss of the area of a river from 1991 to 2021 is 0.85% of the total. The area of the water bodies/wetlands are 27.22%, 26.30%, 24.46% and 22.70% in the year of 1991, 2001, 2011 and 2021 respectively. This analysis reveals that the total amount of the area of water bodies/wetlands gradually decreases to 4.52% from 1991 to 2021.

Table 2: Chronological changes of LULC from 1991 to 2021.

Year	1991		2001		2011		2021	
Features	Area (ha.)	(%)	Area (ha.)	(%)	Area (ha.)	(%)	Area (ha.)	(%)
River	1549	3.96	1,392	3.72	1165	3.36	1,009	3.11
Water Bodies/wetlands	10127	27.22	9,544	26.30	8,384	24.46	7,269	22.70
Settlement	6232	15.06	10,722	22.15	12,887	25.57	17,030	32.12
Vegetation	10062	20.65	9,678	20.04	10,165	20.81	8,514	18.20
Agricultural Land	10603	21.65	9,474	19.86	9,105	19.28	8,184	17.83
Bare Land	5270	11.47	3,030	7.93	2,133	6.52	1,834	6.04
Total	43843	100	43843	100	43843	100	43843	100

Source: Calculated by author, 2023

This is happened due to rapid disorganized urbanization, encroachments and renovation as well as drawbacks from agricultural development. On the contrary, the area of the settlements has significantly gained which is 17.06% of the total because of the disorganized urbanization, employment opportunities, communication facilities and rapid growth of population. The study site is very close to the Dhaka which is capital of Bangladesh. Therefore, employment opportunities and communication facilities are much higher here. Besides that, due to the expansion of settlement, the area of the vegetation cover has lost to 20.65% to 18.20% in the year of 1991 and 2021 accordingly. The agricultural land has drastically changed in the year from 1991 to 2021 which is 3.82% of the total. Finally, the bare land has lost 5.43% in between year of 1991 and 2021.

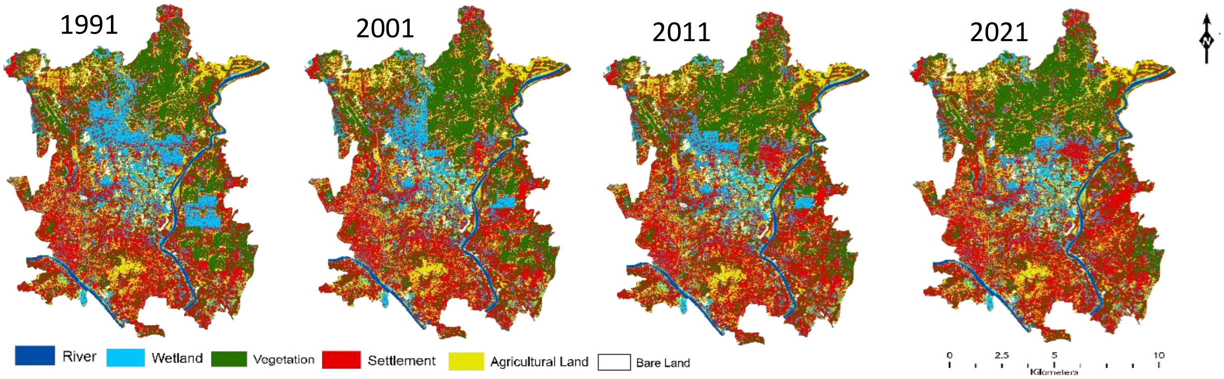

Fig. 3. LULC distribution map for eastern part of Dhaka of five different period. (*Source: Compiled by author, 2023*)

This study reveals that the area of the five LULC namely, rivers, wetlands, vegetation, agricultural land, and bares surface have lost its area from 1991 to 2021 accept settlements. This is related to urbanization's rapid expansion, education, political factors, natural population growth, economic factors, environmental deterioration and eventually, social factors.

Water bodies and agricultural land decreased slightly from 1991-2021. Settlements are increasing slightly where in 2001 it was 10,722 ha, it increased drastically in 2021 (17,030 ha). Agriculture land as well as bare land decreased over time with the enhancement of built-up area and development activities.

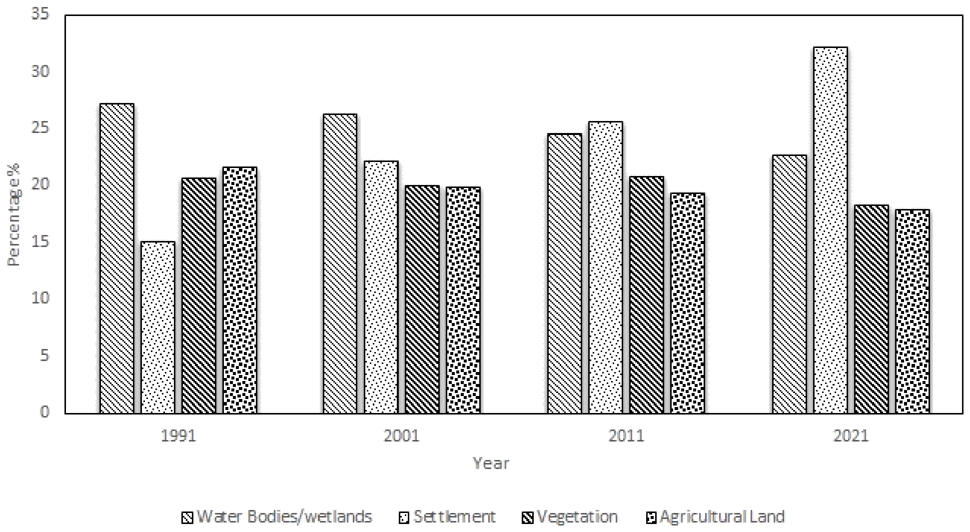

Fig. 4. Percentages of land features in the year of 1991, 2001, 2011 and 2021 accordingly.
(*Source: compiled by author, 2023)*

In the graph above, the reflection can be seen. It is apparent that the settlement is progressing day by day, while the other characteristics are gradually fading. This graph primarily depicts only four aspects connected to wetlands and their ecosystems. Wetlands are substantially less abundant in 2021 than what they were in 1991, and settlements are expanding at a disproportionately faster rate. As shown in this chart, wetlands are currently threatened in this part of Dhaka city. The ecosystem of the wetland, as well as the wetland itself, are relatively fragile, as may be seen by looking at other features. Human unconsciousness, inattention, unnatural competitiveness with each other and possessive attitude are some of the reasons behind this. Building infrastructure by consuming as much area as possible, resulting in the ecosystem's collapse. These infrastructures, with the exception of wetlands, should be created.

Human activities, like urbanization, unplanned infrastructure development, land graving and industrialization are wreaking havoc on wetlands. Due to development, the quantity of wetland in this part of Dhaka city is steadily reducing as well. Stream efficient allocation, irrigation schemes and municipal wastewater discharge, industrial pollution and drainage from urban and rural areas are all examples of human activities that can have long-term effects for wetland ecosystems. Wetland ecosystems' physical, chemical, and biological components have all been changed, resulting in these changes. This shift in the wetland environment has had an influence on all biodiversity in the region, putting other water-based activities, such as agriculture, in jeopardy.

3.2. Freshwater wetlands functions and socioeconomic expansion

According to this study, the amount of fresh water available in 2021 is lower than in 1991, which has a significant impact on the socioeconomic landscape. All types of livelihoods that rely on fresh water have dwindled in recent years. The volume of fresh water available is diminishing day by day due to various sorts of trash. A graph depicting the quantity of wetlands from 1991 to 2021 is presented below:

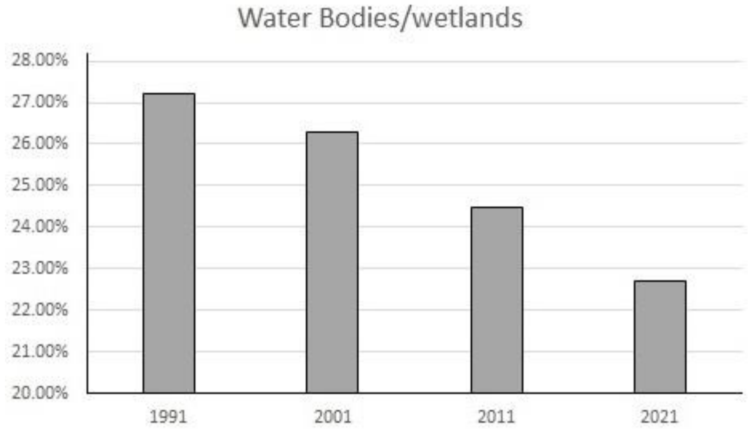

Fig. 5. Percentages of waterbodies in the year of 1991, 2001, 2011 and 2021 accordingly (*Source: compiled by author, 2023)*

The graph above illustrates that the quantity of wetland in 2021 is significantly smaller than in 1991, when it was 27.22 % in 1991, and just 22.70 % in 2021. From this it is clear that Wetland is under threat today for its city-centric way of life. Huge constructions are being created in diverse locations that were formerly wetlands and were inhabited to a variety of aquatic plants and creatures. All of those watery flora and fauna produced ecosystems that are now gone. This aquatic ecosystem was extremely helpful to the soil layers, allowing for the cultivation of a variety of crops. However, after the disappearance of this ecosystem, the soil around it has turned abrasive, making it impossible to cultivate.

Many people used to make a life off of this fresh water, but it is now nearly impossible. Many of the wasteland fish and other species that used to provide a source of revenue have vanished. The fundamental cause of all this life being wasted is industrial pollution. It has also had a significant impact on agriculture, with cultivable terrain no longer producing crops as efficiently as it formerly did. Buildings are increasingly being constructed on farmland as a result of urbanization, leaving essentially little agricultural activity in these areas. The city is already bursting at the seams with employment and businesses; farming and fishing are no longer viable options. The air here is becoming increasingly contaminated as a result of the buildings and automobiles. The degradation of vegetation and the aquatic environment are the primary causes. Humans ought to plant a lot more trees and protect the remaining wetlands in order to live.

3.3. Prediction of threatened wetland and sensitive ecosystem for 2029

All of the classes can be analyzed using the probability matrix and Land Class Modeler. Row categories are characterized by LULC classes in 1991 where columns are 2001. The cross-tabulation matrix for the changing probability from 1991 to 2001 are seen in Table 3, and for the changing probability from 2011 to 2021, they are included in table-3. The improvement is obtained by subtracting the data from each group's entire column, whereas the deficit is achieved by subtracting the value out of respective group's total row.

Table 3: Transition probability matrix during 1991-2001.

Changing From 1991	Probability of Changing by 2001						Subtotal	
	River	Wetland	Vegetation	Settlement	Agricultural land	Bare land	Total	Loss
River	0.4269	0.1455	0.1252	0.0708	0.2168	0.0147	1	0.5731
Wetland	0.0179	0.293	0.311	0.1247	0.2366	0.0169	1	0.707
Vegetation	0.0065	0.2618	0.4015	0.1005	0.2144	0.0153	1	0.5985
Settlement	0.0098	0.2891	0.3313	0.1208	0.2325	0.0165	1	0.8792
Agricultural land	0.0068	0.2821	0.3292	0.1251	0.2395	0.0174	1	0.7605
Bare land	0.0067	0.2704	0.3503	0.1194	0.2359	0.0174	1	0.9826
Total	0.4746	1.5419	1.8485	0.6613	1.3757	0.0982		
Gain	0.0477	1.3964	1.7233	0.5905	1.1589	0.0835		

Source: Calculated by author,2023

In order to predict the year 2029 using LULC map images from 1991 and 2021, transition probability matrices and transition area matrices were developed. This prediction for 2029 involved analyzing the LULC maps from 1991 to 2021 using the transition probability matrices and transition area matrices of 2021.

Table 4: Transition probability matrix during 2011-2021.

Changing From	Probability of Changing by 2021						Subtotal	
2011	River	Wetland	Vegetation	Settlement	Agricultural land	Bare land	Total	Loss
River	0.6571	0.2884	0.0052	0.0171	0.0299	0.0024	1	0.3429
Wetland	0.0868	0.1233	0.5507	0.0416	0.1916	0.0061	1	0.8767
Vegetation	0.0054	0.0306	0.5171	0.0584	0.36	0.0286	1	0.4829
Settlement	0.0045	0.0188	0.0609	0.5863	0.3252	0.0043	1	0.4137
Agricultural land	0.0016	0.008	0.4436	0.0731	0.4647	0.009	1	0.5353
Bare land	0.0003	0.0015	0.0459	0.1766	0.756	0.0198	1	0.9802
Total	0.7557	0.4706	1.6234	0.9531	2.1274	0.0702		
Gain	0.0986	0.1822	1.6182	0.936	2.0975	0.0678		

Source: Calculated by author, 2023

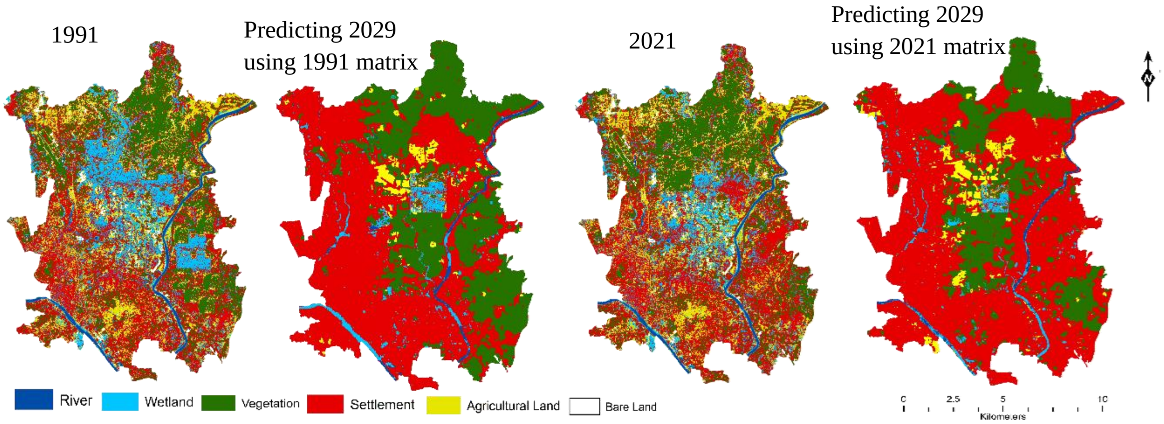

Fig. 6. Prediction LULC of eastern Part of Dhaka for 2029 (*source: Compiled by author, 2023*)

Here, presented two simulations where 2029 is predicted based on the matrix of 1991-2001 and another simulation presented for the matrix of 2011-2021. Wetlands have been progressively declining from 1991 to 2021, and it is expected to be substantially lower in 2029, according to the following predictions. It is decreasing slightly where in 1991 it was 10127 ha, it decreased in 2021 7,269 ha. And following the prediction, its value plummets, implying that by 2029, the amount of wetland would have decreased significantly. Vegetation pattern decreased over time with the enhancement of built-up area and development activities.

Table 5: Predicting land features for 2029.

LULC	LULC 1991 (ha.)	LULC 2021 (ha.)	LULC 1991-2029 (ha.)	LULC 2021-2029 (ha.)
River	1549	1,009	1015	775
Water Bodies/wetlands	10127	7,269	5057	3249
Settlement	6232	17,030	22884	29358
Vegetation	10062	8,514	8320	4964
Agricultural Land	10603	8,184	7846	7485
Bare Land	5270	1,834	957	876
Total	43843	43843	46079	46707

Source: Calculated by author, 2023

Table 5 above depicts how the 6 aspects of Dhaka's Eastern zone would seem in the future. A probable image of a part of Mainly 2029 in Dhaka may be seen here. There are two types of predictions: one based on Dhaka's land class in 1991 and the other based on the land class in 2021. This is the outcome of combining two different types of matrixes. The results are the same regardless of the value, according to the analysis. The predictions for 2029 based on the image of 1991 and the predictions for 2029 based on the image of 2021 are quite near, therefore the correctness of the predictions may be assumed.

Table 6: Accuracy assessment of LULC class for different time period.

Land Use/Cover	1991		2001		2011		2021	
	P	U	P	U	P	U	P	U
River	78	83	83	79	82	79	81	79
Water Bodies/Wetlands	79	78	80	81	78	79	79	78
Settlement	81	78	83	78	83	78	82	81
Vegetation	80	81	79	77	78	79	81	83
Agricultural Land	79	78	80	79	81	78	78	79
Bare Land	77	82	82	80	80	81	83	80
Overall accuracy	80		82		81		82	
Overall, Kappa Statistic	0.80		0.82		0.81		0.82	

Source: Made by authors, 2023

** P= Producer's accuracy and **U= User's accuracy.

3.4. Accuracy assessment

The accuracy assessment is essential for a research project since it determines the resemblance of the classified data to the ground data. Because the ground data is collected at the field level, there is no chance that it would be erroneous and when it is combined with the classified image, it is easy to fix any errors in the image.

For each LULC class of study area, the producer's and user's accuracy varies with time. Table 6 reveals that overall accuracy is 81 and overall kappa statistics are 0.81. Because of the mismatch between the training sample points and the ground points, the accuracy value is poor; if the value is too low, the research might be identified as weak. This accuracy assessment is primarily performed on six different types of land classes, revealing favorable findings.

3.5. Model validation

The accuracy evaluation is sufficiently accurate since all values are more than 80%. From the statistics, the κno for 1991 is 0.8788 where it is 0.8965 for 2021 (Table 7). The κlocation is 0.8352 for 1991 and 0.8070 for 2021. The value of κlocationstrata is 0.8352 for 1991 where 0.8070 for 2021. Last, κstandard value is 0.8320 for 1991 and 0.8820 for 2021. These are all values that are greater than 80%, which offers a satisfactory accuracy evaluation for this model.

Table 7: κ values for 1991 and 2021 to validate the model

κ Indicators	1991	2021
κ_{no}	0.8788	0.8965
$\kappa_{location}$	0.8352	0.8070
$\kappa_{locationstrata}$	0.8352	0.8070
$\kappa_{standard}$	0.8320	0.8820

Source: Calculated by author,2023

4. Conclusion:

Dhaka city’s wetland and its ecosystem are impacted by anthropogenic disturbance. Filing, grading, removal of vegetation, building construction and drainage pattern are main reason for causing the wetlands threatened lately. According to the matrix, wetland and agricultural land dropped modestly from 1991 to 2021 before substantially decreasing in 2029. Settlements are increasing slightly where in 1991 it was 6232 ha, it increased drastically in 2021 17,030 ha. Vegetation pattern increased from 2001-2011 than decreased over time with the enhancement of built-up area and development activities. It appears that pressure of human domination on Dhaka city advancing the risk of ecological threatened. This research reveals a pattern and anticipates the future based on that pattern, which may aid policymakers in making important decisions on ecosystem preservation, landscape design and understanding the current state of Dhaka for optimal management.

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Analyzing the pattern of land use land cover change: A case study of Lalmonirhat district in Bangladesh

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ABSTRACT

Most cities in Bangladesh have experienced rapid urbanization and continuous growth of population exerts serious pressure on land in the recent few decades. Present study aims to investigate and predict the spatiotemporal changes of land use land cover (LULC) in Lalmonirhat district of Bangladesh. This study explored LULC over the last 30 years at four intervals (1991-2021) by using Landsat Thematic Mapper (TM) for 1991 and 2001, Landsat 7 ETM+ for 2011, Landsat 8 OLI and TIRS for 2021. Maximum Likelihood Classification (MLC) have been executed into seven categories and change has been predicted for 2031 and 2041 by CA-Markov model. From 1991 to 2021, agricultural land, vegetation, settlement, chare land and wetland increased discretely by 121.36 km^2 (9.51%), 27.99 km^2 (0.40%), 62.97 km^2 (0.53%), 28.2 km^2 (2.21%) and 6.8 km^2 (0.53%). Nonetheless, open area and water bodies decreased by 214.84 km^2 (16.84%) and 9.7 km^2 (0.76%). Prediction (2021-2031) shows, agricultural land, vegetation, settlement and char land will be increased by 11.40% to 11.68%, 27.99% to 31.38%, 7.57% to 8.01%, 5.32% to 6.11% respectively, while open land, river and wetland decreased by 39.28% to 37.22%, 7.85% to 5.92%, 0.56% to 0.44% correspondingly. Besides, agricultural land, vegetation, settlement and char will be increased by 0.33%, 1.01%, 0.57%, 0.11% and open land, river, wetland will be decreased by 1.0%, 0.04%, 0.02% from 2031 to 2041 respectively. Expansion of crop land, growth of industry, deforestation for fuel, fish farming, global climate change impact etc. are associated as main driving forces for LULC changes.

Key Words: Spatiotemporal, Maximum likelihood classification, Supervised classification, CA-Markov model, Prediction

1. Introduction

Natural, anthropogenic and socio-economic variables are rapidly changing urban land usage and cover (LULC). Land usage (LU) is the area used by humans, whereas land cover (LC) is the area covered with environmental assets and other environmental components (Verburg et al., 2009; Rakib et al., 2020). Modern strategies for managing environmental assets and monitoring environmental changes include LULC (Prasad and Sreenivasulu, 2014; Fatemi and Narangifard, 2019). Despite the various perspectives on changing land patterns, in the last few years in developing countries, urbanization has been primary factor responsible for changes in LULC (Dawon and Yamaguchi, 2009; Jat et al., 2008; Mundia and Aniya, 2006). Human growth is largely accountable (Bekele, 2005) and economic advancement drive rapid urban expansion (Huang et al., 2019). By 2030, more than 60% of humanity will live in cities (Dissanayake et al., 2019; Liu et al., 2020). Uncontrolled urbanization in emerging nations like Bangladesh destroys farming land, water sources, and greenery in big towns (Abir and Saha, 2021; Gazi et al., 2021). If neglected, rapid urbanization and LULC changes might affect hydrology, radiative system, worsening climate change and heatwaves. LULC changes are one of the significant environmental concerns that need attention to analyse the management of land resources. Inventories are growing importance in various sectors like urban planning, agricultural and infrastructural development (Imura et al., 1999). Long-term sustainable community development plans and land feature need the understanding of spatio-temporal LULC transition (Kafy, Shuvo, et al., 2021).

Therefore, present study aims to investigate the Land Use and Land cover (LULC) changes through classification by using multitemporal Landsat satellite imageries for the past 30 years (1991-2021) with geo-spatial analysis to detect the subsequent altering pattern from 2031 to 2041 through the CA-Markov model. Geographic Information Systems (GIS) and remote sensing (RS) are powerful and cost-effective tools for assessing the spatial and temporal dynamics of LULC (Hathout, 2002, Herold et al., 2003, Lambin et al., 2003, Serra et al., 2008). Detection of land change could be essential for the local government planners in decision making of future ecological management and environmental planning. This quantitative analysis of LULC could be employed for developing adaptation strategies for the study area and other areas in Bangladesh.

2. Study Area

Lalmonirhat district is situated at the northern border of Bangladesh and were selected as study area to conduct present study. International border of Lalmonirhat district is 281.6 km long and total land area is 1241.46 sq km with two main rivers, Dharla and Teesta. This district is surrounded in the north by Coochbihar and Jalpaiguri District of West Bengal State of India, east by Kurigram District and Coochbihar District of West Bengal State of India, south by Kurigram District and Rangpur District and west by Rangpur District, Nilphamari District and the West Bengal State of India. Fig. 1 shows geographically study area lies between 25°46’ and 26°33’ north latitudes and 89°01’ to 89'36' East longitudes (Shahin et.al., 2022). Lalmonirhat might be called as a district of enclaves with 33 enclaves including two biggest enclaves named Dahagram and Angarpota which are connected with the main land by Tin Bigha Corridor (Banglapedia, 2021).

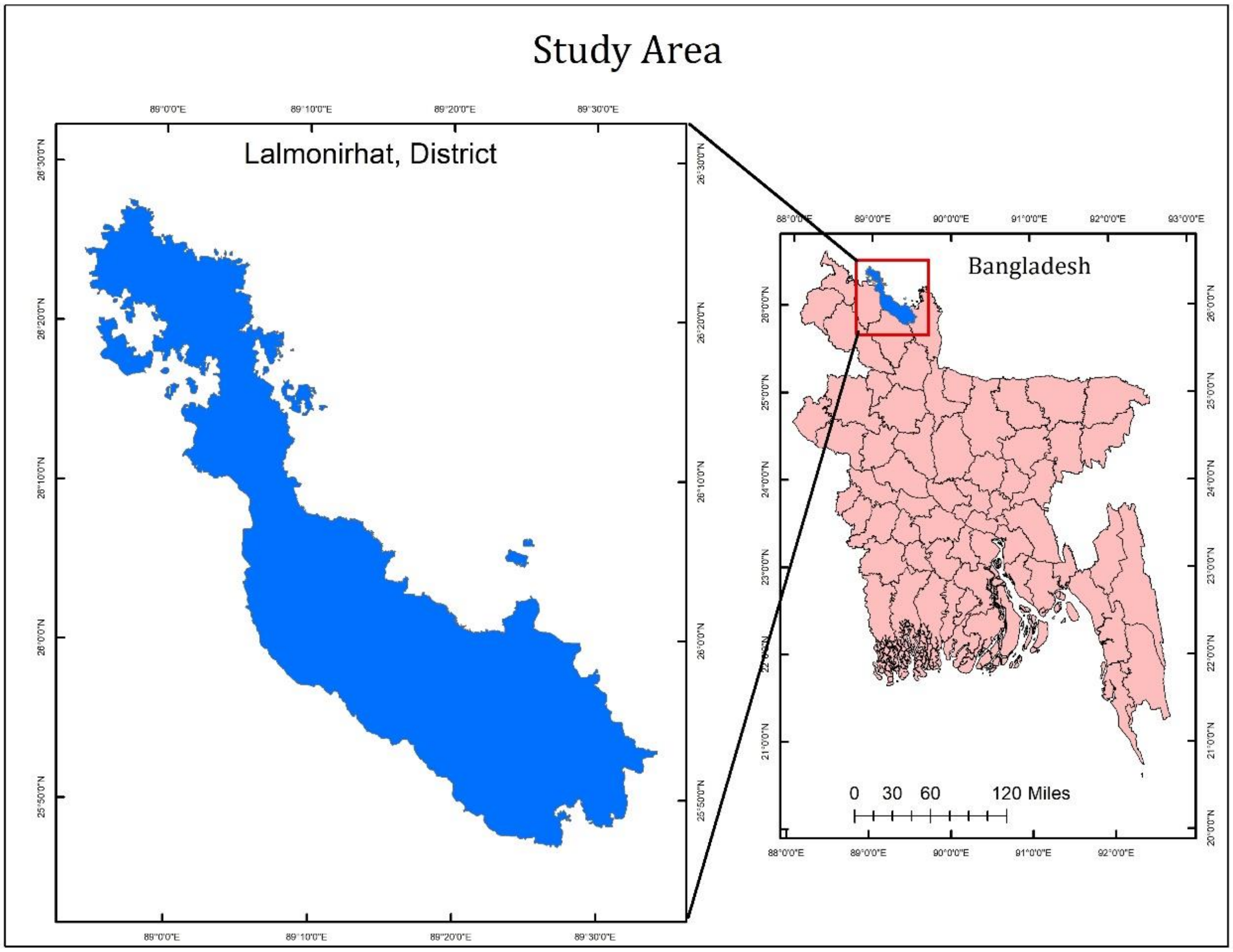

Fig. 1. Study area (Lalmonirhat district) (Source: Compiled by author).

3. Data and Methods

3.1. Image collection and properties

Multitemporal cloud-free Landsat satellite images covering the Lalmonirhat district have been downloaded from the United States Geological Service (USGS) Glovis (http://glo- vis.usgs.gov) website. Landsat satellite “collection-1 level-1” images have been used to explore LULC of Lalmonirhat district from 1991 to 2021. Landsat collection-1 level-1 images are the best-known quality to support time series analysis (United States Geological Survey USGS, 2021). Cloud free satellite images have been acquired in winter season from December to February and March is interim period of winter to summer. Four satellite images were selected with 10 years’ time interval starting from 1991 to 2021 for analyzing LULC changes over the 30 years. Satellite images of Lansat-5 TM for 1991 and 2001, Landsat-7 ETM for 2011, and Landsat-8 OLI and TIRS for 2021 have been used as georeferenced dataset (Earth explorer, 2021) with Universal Transverse Mercator (UTM) projection within Zone 46 N datum and World Geodetic system (WGS) 84 coordinate system. Table 1 shows and spatial resolution and data properties are same but vary due to the differential of sensor number of bands.

Table 1: Properties of satellite images

Satellite	Sensor	Band	Path/Row	Acquisition Date	Spatial Resolution
Landsat 4-5	TM	1,2,3,4,5,6,7	138/42	January 16, 1991	30 m
Landsat 4-5	TM	1,2,3,4,5,6,7	138/42	February 4, 2001	30 m
Landsat- 7	ETM	1,2,3,4,5,6,7,8	138/42	January 28, 2011	30 m
Landsat- 8	OLI & TIRS	1,2,3,4,5,6,7,8	138/42	January 19, 2021	30 m

Source: USGS Earth Explorer, 2022

3.2. Image classification and processing of satellite image

Collected satellite images have been processed through several steps before generating the final output. ArcGIS 10.8 was used to accomplish the preprocessing tasks. After downloading the images, layer-stacking tool merged the bands in RGB format for all images. Then, images were divided into subsets for classification with the help of study areas’ shape file. Then supervised image classification techniques has been used for mapping and monitoring LULC changes. Supervised image classification technique of Maximum Likelihood Classification was adopted to classify the Landsat images. In supervised classification, known classes are used to classify unknown areas/pixels in the whole images and the user selects training sites where software uses these training sites to classify the images (Juliev et al., 2019). After combining the required bands of each Landsat images, tiles are mosaicked into one piece and Area of Interest (AoI) is clipped for further analysis by using the shape file. Geometric registration and image reference is performed for all of the images in ArcGIS software. After that, Table 2 indicates imageries have been classified into seven classes (agricultural land, open land, vegetation, settlements, river, char and wetland) according to the scheme described, analysis and ground investigations performed during research. Maximum likelihood is a traditional supervised classification method has higher accuracy in detecting LULC. True color combination and different false-color combinations were visually investigated to select training samples. Change detection method has been employed to detect the changes between two images of subsequent years and area was calculated by using calculate geometry tool. Land use change matrix was prepared in Microsoft excel software using the data derived from image processing. Finally, layout for every output has been made by Arc GIS software.

Table 2: Classes delineated on the basis of supervised classification

Class Name	Description
Agriculture	All cropland farming area.
Open land	All land areas that exposed soil and barren area influenced by human
Vegetation	All types of tree forest and grassland
Settlement	Includes all types of houses and industrial area
River	River and canals
Chare	A tract of land surrounded by the water of river
Wetland	All pond lakes, gravels, stream, canals, and reservoirs

3.3. Accuracy assessment

Accuracy assessment shows to what extent the ground truth is represented on the equivalent classified images. Assessing the classification accuracy provides the degree of confidence in the results and the subsequent change detection. For accuracy assessment, the classified map was compared with ground truth data. For 1991, 2001, 2011 and 2021, the reference points were collected from Google Earth, original Landsat images, previous reports and maps. The common and most effective method used to measure the accuracy of the classified image is an error or confusion matrix. Confusion matrix provides overall accuracy, user accuracy, producer accuracy, and kappa statistics. Kappa coefficient was determined by using Equation (1). The Kappa coefficient values represent the measure of agreement or accuracy between the reference data and the land use and land cover values in the classified image and values ranges from +1 to −1. Kappa values of <0 reflect no agreement, 0–0.2 as slight, 0.2–0.41 as fair, 0.41–0.60 as moderate, 0.60–0.80 as substantial and 0.81–1.0 as almost perfect agreement.

$$\boldsymbol{k} = \frac{\boldsymbol{N \sum_{i=1}^{r} Xii - \Sigma_{i=1}^{r} (Xi+) * (X+i)}}{\boldsymbol{N^2 - \Sigma_{i=1}^{r} \; (Xi+(X+i)}} \quad \text{……………….. Equation 1}$$

Where, r- rows number in the matrix, xii- number of observations in row i and column i (the diagonal elements), x + i and xi+- marginal totals of row i and column i, respectively, and N-observations number.

The kappa statistic and confusion matrix are the most dependable quantitative measures for picture categorization accuracy (Story and Congalton, 1986; Foody, 2002; Pontius Jr and Millones, 2011; Kafy et al., 2020). A stratified random sample design with equal stratum sizes generates 160 check points to verify accuracy assessment fairness. Google Earth images compute accuracy, user accuracy, and Kappa Coefficient. Following formulas determine accuracy:

$$\text{User Accuracy} = \frac{\text{correctly classified points in each category (diagonal)}}{\text{Total reference points in each category (row total)}} \times 100$$

$$\text{Producer Accuracy} = \frac{cor\ rectly\ classified\ points\ in\ each\ category\ (diagonal)}{Total\ reference\ points\ in\ each\ category\ (column\ total)} \times 100$$

$$\text{Overall Accuracy} = \frac{Total\ cor\ rectly\ classified\ points\ (diagonal)}{Total\ reference\ points} \times 100$$

$$\text{Kappa Coefficient} = \frac{\text{Total Sample} * \text{Total Cor rect Sample} - \sum(column\ total * \text{ row total})}{(\text{Total Sample})^2 - \sum(\text{column. total} * \text{row total})} * 100$$

3.4. Change detection analysis

Changes obtained from two different time intervals were estimated in change analysis. Statistical technique (Equation 2) used to compile a detailed tabulation of continuous changes between two classified images. Area of land cover classes of each year and the area changed between each time interval has been calculated and change matrix has been prepared.

$$\text{Percent of change} = \frac{Ay-Ax}{\text{Ax}} * 100 \text{ .... Equation 2}$$

3.5 The CA–Markov model. The combination of Markov and Cellular Automata (CA-Markov) allows simulating the evolution of the geographical area represented by pixels. Each pixel can take a value from a finite set of states. All pixels are affected by a transition function that takes as arguments of the measured values and values of the neighboring pixels as a function of time (Quintero, et al. 2016). Markov Chain Model Analysis is extensively used in LULC modeling including both urban and non-urban areas at large spatial scales (Logsdon, et al., 1996, Zhang, et al., 2011; Kumar, et al., 2014). The Markovian chain analysis is represented as the Equation 3.

$$S\ (t, t+1) = Pij \times S(t) \text{ .... Equation 3}$$

Where, S (t) is system status at time of t, S (t + 1) is system status at time t + 1; Pij is transition probability matrix in a state, which is calculated using the following formula Equation 4.

$$\mathbf{P_{ij}} = \begin{vmatrix} P_{11} & P_{12} & P_{1m} \\ P_{21} & P_{22} & P_{2m} \\ \vdots & \vdots & \vdots \\ P_{1m} & P_{2m} & P_{mn} \end{vmatrix} \text{ .... Equation 4}$$

Where, P is the Markov probability matrix, and Pij stands for the probability of converting from current state i to another state j in next time period.

Markov Chains model analysis describes the probability of change LULC from one period to another (Eastman, 2009; Nguyen and Ngo, 2018) and can use this as the basis to project future changes (Wang et al., 2021). Transitions between the states of the system are recorded in the forms of a transition matrix that recorded the probability of moving from one state to another state (Behera et al., 2012). Low transition will have a probability near (0) and high transition probability near 1. Land use and land cover image for 1991 was used as the base (t1) image while land use and land cover image for 2001 as the later (t2) image in Markov model to obtain the transition matrix between 1991, 2001. Likewise for 2011 and 2021 and for prediction of land use and land cover in between 2031 and 2041. Markov chain analysis generates two significant probabilities:

(i) transition probability matrix, where the probabilities of transition represent the probability that a pixel of a given class will move to some other cell class in the next time period, and (ii) transition area matrix, which represents the total area (in cells) expected to change from one land use and land cover class to another over the prescribed number of time units. It is generated by multiplying each column in the transition probability matrix by the number of pixels of corresponding class in the later image. The transition probability matrix is expressed in a text file that records the likelihood of moving each land use and land cover category to some other category, while the transition area matrix, also represented in a text file records the number of pixels required to transition from one land use and land cover class to another over the specified number of time unit. The transition area matrix obtained from the two time periods was used as a basis for predicting the future land use and land cover scenarios. Therefore, CA-Markov model has been used to in order to ensure that the model is reliable in predicting land use and land cover change for the year of 2031 and 2041 in Lalmonirhat.

3.6. Validating LULC prediction model

Model in order to avoid miscalculation, investigation between actual image and simulated image has been carried out, where the model's output was compared to present or actual land use map (Mathanraj, et al., 2021). Comparing the predicted LULC map representing 2021 LULC with actual LULC (Map 2021) was based on LULC change predictions. Additional map of 1991, 2001, 2011 will be used to help in validating process, before CA-Markov model can be applied for estimation of next 20 years. Validation module is available in QGIS 2.18 for this purpose. In order to validate LULC prediction given by CA-Markov model, simulated land use areas were used to compare actual present land use areas.

4. Results and Discussion

4.1. Classification accuracy results

Accuracy and validation of classification models is an important pre-requisite step in classification, detection and prediction of land use and land cover change studies. Table 3 indicated the Kappa statistics for the years 1991, 2001, 2011and 2021 were 84%, 87%, 88%, and 91% respectively. Kappa coefficient values ranges from 0.81-.89, a value greater than 0.8. These approximations indicate that the classification accuracies were almost perfect or a strong agreement. This level of agreement is acceptable for classification, detection and prediction of land use and land cover changes.

Table 3: Classification accuracy results

Year	Overall accuracy	Kappa coefficient
1991	84%	0.81
2001	87%	0.84
2011	88%	0.86
2021	91%	0.89

4.2 Validating LULC prediction model

Markov model simulated changes in LULC from one time to another in order to predict future change. Model validation is an important precondition for studies that attempt to predict LULC changes (Wang et al., 2021). LULC changes has been predicted for the years 2031 and 2041. The probable percentages of changes in LULC for the periods of 2021-2031 and 2031-2041 were analyzed by transition probabilities matrix. Extent of changes and spatial distribution of LULC predicted by CA Markov chain (Leta et al., 2021) indicates that agriculture, open land, vegetation, settlement, river, char, and wetland have the best pact. Table 4 shows for agriculture, open land, vegetation, settlement, river, char, and wetland simulated areas were 150.24 km^2, 478.38 km^2, 375.89 km^2, 99.31 km^2, 94.08 km^2, 71.49 km^2 and 6.10 km^2 respectively, while the actual areas were 145.50 km^2, 501.03 km^2, 357.06 km^2, 96.57 km^2, 100.22 km^2, 67.91 km^2 and 7.20 km^2 respectively. As actual areas and simulated areas are almost identical, CA-Markov modeling is suitable for accurate prediction of LULCs.

Table 4: Comparison of actual and projected LULC in 2021

LULC Classification	Actual area (km^2) in 2021	Simulated area (km^2) in 2021
Agriculture	145.50	150.24
Open land	501.03	478.38
Vegetation	357.06	375.89
Settlement	96.57	99.31
River	100.22	94.08
Char	67.91	71.49
Wetland	7.20	6.10

4.3 Change detection (1991-2021)

Entire research area has been divided into seven land coverage categories. Table 5 shows over the last 30 years from 1991 to 2021, agricultural cropland increased by 121.36 km^2 (9.51%). Besides, for the same period open land has been decreased by 214.84 km^2 (16.84%) and vegetation increased very slightly 27.99 km^2 (0.40%). Settlement area increased by 62.97 km^2 (0.53%) and river area decreased by 9.7 km^2 (0.76%). Chare land increased by 28.2 km^2 (2.21%) and wetland area increased by 6.8 km^2 (0.53%). Agricultural cropland was 24.14 km^2 (1.89%), 78.65 (6.16%), 115.28 (9.03%) and 145.50 (11.40%) in 1991, 2001, 2011 and 2021 respectively. The result indicated that the Agricultural cropland significantly increased by 121.36 km^2 (9.51%) during the last 30 years although most of the cropland was vacant with a few cultivated lands in January (when satellite images were taken) and some of the non-cultivated bare soil is converted into urban areas. Especially the low-lying rice fields converted into fish farming and also infrastructural development due to rapid growth of urbanization. In contrast, most remarkable changes observed for open land expanses, decreased by 214.84 km^2 (-16.84%) from 1991 to 2021. In 1991, 2001, 2011 and 2021, quantity of open land was 715.87 km^2 (56.12%), 686.29 (53.82%), 566.81 (44.43%) and 501.03 (39.28 %) respectively. Perhaps some of the non-cultivated bare soil is converted into agricultural land and urban areas. Vegetation was decreased by 351.88 km^2 (27.58%), 349.84 km^2 (27.42%) and 305.49 km^2 (23.95%) in 1991, 2001 and 2011 respectively. Result indicated that vegetation was decreased very slightly 44.35 km^2 (3.47%) during the last 20 years but in 2021 area with vegetation was increased by total area 357.06 km^2 (5.17%). However, total vegetation area was increased from 1991 to 2021 very slightly 5.17 sq.km. (0.40%) during the last 30 years. Area occupied by settlement was 33.61 km^2 (2.63%.), 46.86 km^2 (3.67%), 88.00 km^2 (6.89%), 96.57 km^2 (7.57%) in 1991, 2001, 2011 and 2021 respectively. So, settlement area was increased continuously by 62.97 km^2 (0.53%) in between 1991 to 2021 during study period.

Table 5:*Land use land cover changes (1991-2021)*

Land Use Land Cover	Area									
	1991		2001		2011		2021		Changes (1991-2021)	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Agriculture	24.14	1.89	78.65	6.16	115.28	9.03	145.50	11.40	121.36	9.51
Open land	715.87	56.12	686.29	53.82	566.81	44.43	501.03	39.28	-214.84	-16.84
Vegetation	351.88	27.58	349.84	27.42	305.49	23.95	357.06	27.99	5.17	0.40
Settlement	33.61	2.63	46.86	3.67	88.00	6.89	96.57	7.57	62.97	0.53
River	110.0	8.62	65.24	5.11	132.86	10.41	100.22	7.85	-9.7	-0.76
Chare	39.6	3.10	47.46	3.72	64.75	5.07	67.91	5.32	28.2	2.21
Wetland	0.33	0.02	1.16	0.09	2.30	0.18	7.20	0.56	6.8	0.53

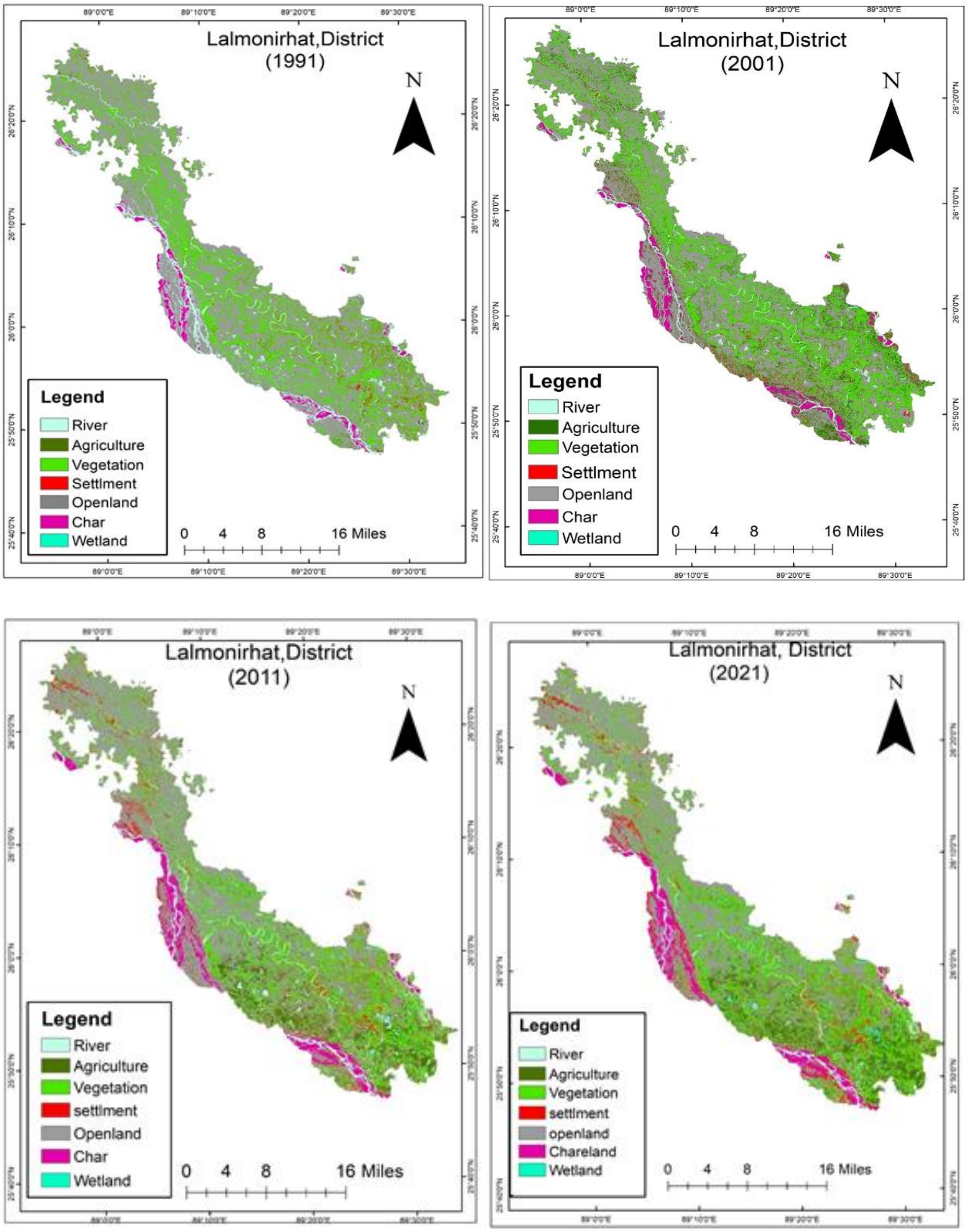

Fig. 2. Land Use Land Cover changes (1991-2021).

Then again, Fig. 2 and Fig. 3 show that total river decreased by 9.7 km^2 (-0.76%) over the last 30 years. In 1991, 2001, 2011 and 2021 area occupied by river was 110.0 km^2 (8.62%), 65.24 km^2 (5.11%), 132.86 km^2 (10.41%), 100.22 km^2 (7.85%) correspondingly. Lack of water in river, conversion of some part of the river to char, agricultural land, settlement or open land would be identified as reasons for the decrease of river area. Char land was 39.6 km^2 (3.10 %.), 47.46 km^2 (3.72 %), 64.75 km^2 (5.07 %), 67.91 km^2 (5.32%) in 1991, 2001, 2011 and 2021 respectively. Result indicates that char land was increased by 28.2 km^2 (2.21%) in between 1991 and 2021. Sedimentation and inadequate flow of water in the river and impact of climate change would be the possible reason for this. In 1991, 2001, 2011 and 2021 area occupied by wetland was 0.33 km^2 (0.02%), 1.16 km^2 (0.09%), 2.30 km^2 (0.18%), 7.20 km^2 (0.56%) correspondingly. Wetland was increased by 6.8 km^2 (0.53%) in between 1991 to 2021 due to the increasing trend of fish farming.

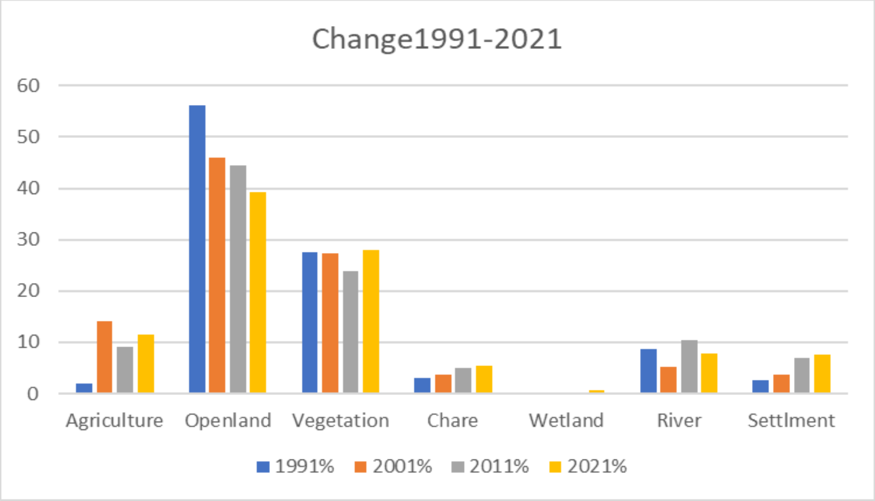

Fig. 3. Changes of areas (%) from 1991 to 2021.

4.4. Change prediction (2031-2041)

Significant changes was observed from Table 6 in between 2021 and 2041. Agricultural land will be the predominant LULC type as the area of agricultural land increment from 145.50 km^2 (11.40%) in 2021 to 149.04 km^2 (11.68%) in 2031 and 153.08 km^2 (12.01%) in 2041. Area for vegetation and settlement would be increased from 31.38% and 8.01% in 2031 to 32.39% and 8.58% in 2041. A continuous increase in Chare land has been observed in 2031 (6.11%) to 2041 (6.20%). Area of open land and river decreased from 39.28 % in 2021 to 37.22 % in 2031 to 36.22 % in 2041 and 7.85% in 2021 to 5.92% in 2031 to 5.88% in 2041. While the area of wetland decreased from 0.56 % in 2021 to 0.44 % in 2031 to 0.42% in 2041. So, Fig. 4 and Fig. 5 show the overall result of agricultural land, vegetation, settlement and char land which would be increased from 0.61% 4.4%, 1.01%, 0.68% between 2021 to 2041 respectively. And open land, river and wetland will be decreased from 3.06%, 1.97%, -0.14% in 2041 respectively.

Table 6: *Prediction of Land Use Land Cover Changes (2021-2031-2041)*

Categories	Area						Change					
	2021		2031		2041		2021-2031		2031-2041		2021-2041	
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Agriculture	145.50	11.40	149.04	11.68	153.08	12.01	3.54	0.28	4.04	0.33	7.58	0.61
Open land	501.03	39.28	474.83	37.22	462.03	36.22	-26.20	-2.05	-12.80	-1.0	-39	-3.06
Vegetation	357.06	27.99	400.08	31.38	412.89	32.39	43.02	3.39	12.81	1.01	55.86	4.4
Settlement	96.57	7.57	102.23	8.01	109.50	8.58	5.66	0.44	7.27	0.57	12.93	1.01
River	100.22	7.85	75.62	5.92	75.0	5.88	-24.59	-1.92	-0.59	-0.04	25.22	-1.97
Chare	67.91	5.32	78.0	6.11	78.57	6.20	10.12	0.79	-1.45	-0.11	8.66	0.68
Wetland	7.20	0.56	5.67	0.44	5.39	0.42	-1.53	-0.12	-0.27	-0.02	-1.81	-0.14

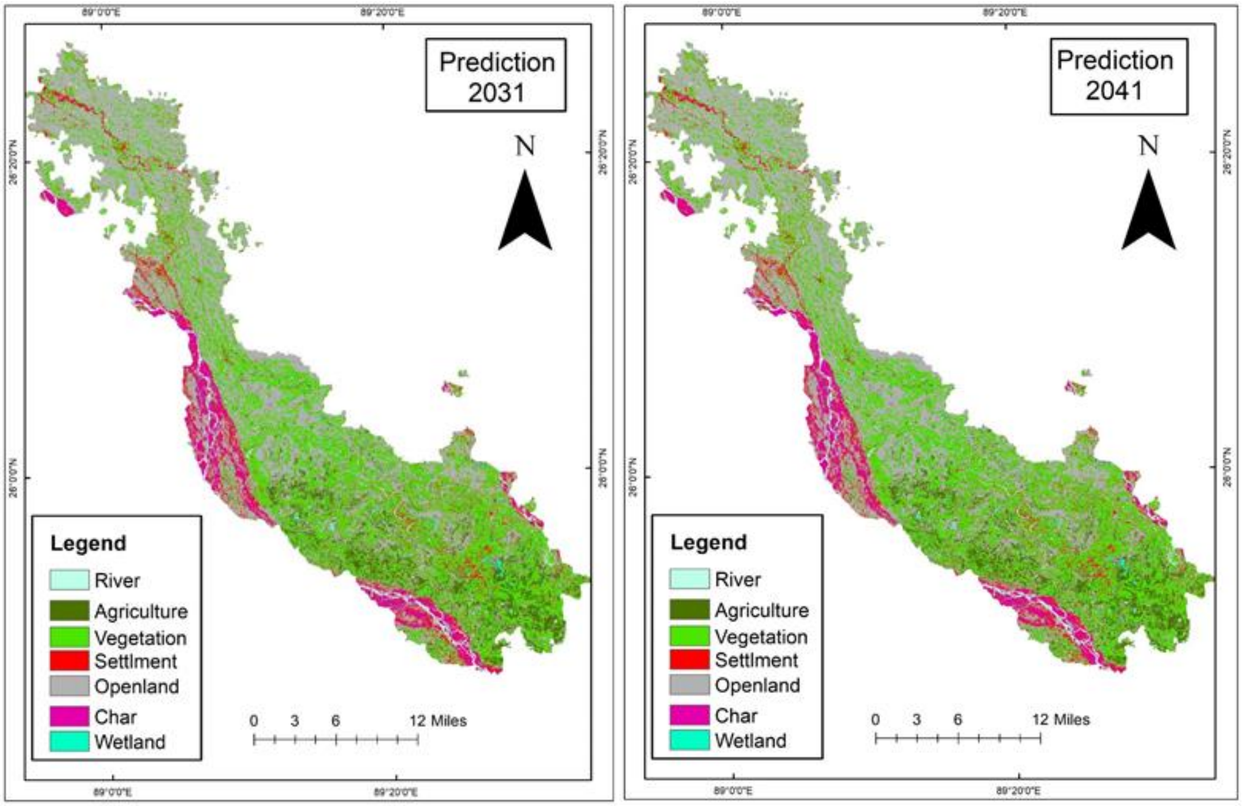

Fig. 4. Land use and land cover prediction in 2031 and 2041

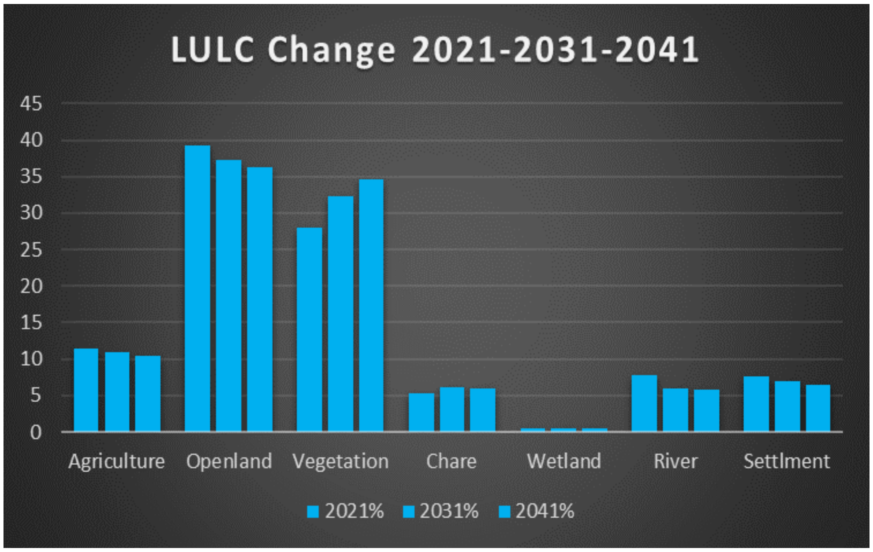

Fig. 5. Land use land cover changes prediction (2021, 2031 and 2041).

5. Conclusion

Over the past 30 years, agriculture, vegetation, chare, settlement have developed, causing rivers, wetlands and barren lands to diminish, according to LULC categorizations. Urban development, population growth, rural-to-urban migration, and the site's strategic and economic importance drive urban expansion and natural resource depletion. Gap between LULC classes is widening. Due to the complexity of geography, several variables affect fluctuation, and these factors often interact. District and upazila land use management strategy should be taken up in order to sustainable development planning munity empowered resource management activity should be increased. Alternative livelihood pattern and its involvement should be increased. Land use policies should be adopted to manage the land for optimum, economic and sustainable development and alternative livelihood pattern and its involvement should be increased.

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Trends of rainfall and temperature patterns and their impacts on rice production in Rangpur district of Bangladesh

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ABSTRACT

In climatic changing trends, rainfall, and temperature are also changing globally and regionally, influencing agricultural activities and water-related sectors. This study attempts to analyze the changing patterns of rainfall and temperature trends using the Mann-Kendall (MK) test and the impacts of climatic parameters on the production of rice by Pearson's correlation coefficient method on a rice-growing seasonal basis. Rainfall and temperature (1983-2022), humidity, and rice production data (2000-2020) were gathered from the Bangladesh Meteorological Department, Bangladesh Agricultural Research Council, Bangladesh Agricultural Research Institute, Bangladesh Rice Research Institute, and Bangladesh Bureau of Statistics. According to the MK S value, Rainfall has a slightly rising trend in the Boro season and a declining trend for the Aus and Aman seasons. Temperatures and production of rice are rising in all seasons. Rainfall has negative effects on the production of rice especially in the Aman season, as determined by the correlation coefficient. During the Boro and Aus seasons, there was usually moderate to slight soil water shortage, however, the Aman season had essentially no drought. The temperature and humidity have a positive impact on the production of rice. The key findings of this study are that rice production in the study region was impeded by excessive rainfall and low temperatures.

Keywords: Rainfall, temperature, rice production, rice-growing seasons, drought, Mann-Kendall trend test, Pearson's correlation coefficient

1. Introduction

Climate change has grown to be a serious issue worldwide due to its adverse effects on the environment and human life. The changing global and regional precipitation patterns are one of the main effects of global warming (Hossain et al., 2012). Precipitation, specifically rainfall, is a crucial hydrologic parameter that is a complex atmospheric process and depends on both space and time (Venkata Ramana et al., 2013). Rainfall variability is a crucial aspect of climate change and has significant impacts on agriculture, water resource management, and human life (Nury et al., 2016). Thus, trend analysis of rainfall has tremendous importance in government, scientific research (Hong, 2008), water resource management, production of hydroelectricity, warning for floods and droughts (Acar et al., 2022), and urban sewerage systems (Banik et al., 2009). Global climate change has resulted in wet areas getting wetter and arid areas getting drier due to rainfall pattern changes. Precipitation has increased in high altitudes in the Northern Hemisphere but has decreased in China, Australia, and small islands in the Great Pacific. The variability of precipitation has increased in the equatorial region (Dore, 2005), and changes in ocean currents affect precipitation patterns (Goswami, 2023). Studies on rainfall trends in Ethiopia's Tana Basin Lake by Weldegerima et al. (2018) indicate annual rainfall increases but are not statistically significant. Owusu et al. (2008) interpret rainfall variability as input in the Volta basin for water sharing in Ghana. Globally, human existence, biological communities, and socioeconomic growth are all threatened by the spatiotemporal temperature changes and associated effects of climate change (Cecco & Gouhier, 2018; Luintel et al., 2019). Over the previous few decades, the average pace of global temperature increase has been substantial (IPCC AR5, 2013), something ruins the livable planet Earth by upsetting the natural equilibrium and driving dramatic changes in weather patterns.

One of the most unpredictable climatic factors is rainfall. and has developed a more erratic pattern in Bangladesh (Bari et al., 2016). Prior knowledge of monsoonal rainfall helps farmers and policymakers use monsoon rainfall to minimize economic losses and crop damages (Kundu et al., 2023) during the adverse monsoon period (Sahai et al., 2000). The average temperature over a year was found to be higher in urban areas than in rural and maritime stations during the era of urbanization (Cetin et al., 2019). Bari et al. (2016) analyzed the seasonal and annual rainfall trends in Northern Bangladesh and detected the periodic fluctuation of rainfall after the 1990s for the major examined stations. Rangpur is a district located in northern Bangladesh and is known for its agriculture-based economy. According to Haque et al. (2019), the frequency and intensity of intense rains have significantly increased events in Bangladesh in recent years, resulting in flooding, landslides, and other natural disasters that have a considerable effect on the socioeconomic growth of the nation. The Intergovernmental Panel on Climate Change (IPCC) also states that global warming has increased the frequency and intensity of extreme weather events, including rainfall, in many parts of the world (IPCC, 2018).

The largest economic sector in Bangladesh is agriculture, which accounts for around 70% of labor force participation and 35% of GDP (BOB, 2022). Since agriculture is innately sensitive to local climate, it is one of the region's most susceptible to climate change and variation (Challinor et al., 2007). The variability of environmental factors including temperature, precipitation, and humidity has a major impact on agricultural production (Kabir & Golder, 2017). However, the tropical settings of Bangladesh cause a lot of problems with climate change, domination of floodplains, low altitude above sea level, and lack of technological and economic capabilities (Huq & Rabbani, 2011). Even slight warming in tropical areas will cause a significant drop in agricultural productivity. If no action is taken to combat the warming climate and the hydrologic system disturbance, South Asian agricultural productivity may decline by 30% by the 2050s (Parry et al., 2007). Being the primary food supply for more than 50% of the global population, rice is one of the most significant crops in Bangladesh (Sarker et al., 2012). Since the vast majority of Bangladeshis depend on agriculture for their livelihood, climate change has a significant impact on the local crops (Islam et al., 2022). The primary food crop in Bangladesh is rice, which is cultivated there three times a year in a variety of agroecological settings with varying temperatures and precipitation patterns (Sarker et al., 2012). The last ten years have seen a dramatic growth in rice output as a result of technological advancements like new cultivars and management techniques (Abbas & Mayo, 2021). Due to global warming, temperatures and rainfall patterns are changing, which affects the stages of rice production (Sridevi & Chellamuthu, 2015). Parry et al. (2013) also observed that, because changes in climatic variables negatively affect the stages of rice growth, resulting in lower rice yield. Shortening of the growth period, heat stress during crucial reproductive phases, a loss in photosynthetic capacity respiratory activity increasing, and increased water needs for rice crops are the primary causes of the fall in crop yield (Ullah, 2017).

Previous studies on climatic parameters and food production observed rainfall variability and rice production (Islam et al., 2022; Rokonuzzaman et al., 2018; Asada & Matsumoto, 2009). Some researchers observed temperature trends with rainfall to observe rainfall and temperature impacts on rice production (Abbas & Mayo, 2021; Akinbile & Akande, 2020; Rahman et al., 2017). However, these studies use simple linear regression methods. Though the MK test (Mann, 1945; Kendall, 1955) is a trustworthy non-parametric test for determining the significance of trends in data with seasonality and missing values (Helsel & Hirch, 1992; Chen et al. 2013). Pearson's correlation coefficient approach is ideal for determining how dependent one variable is on others (Gou, 2023). Non-parametric tests were never employed in these sorts of investigations in the past. Furthermore, previous research has never employed natural soil water drought analysis to assess the rainfall dependency of rice production. For the first time, this study assesses the true impact of rainfall by examining soil water shortage during distinct growing seasons. The purpose of this study is to close this gap (a) to identify trends in rainfall, temperature, and rice production over the last 20 to 40 years using the MK test; (b) to evaluate the impacts of rainfall, temperature, and humidity on the production of rice in Rangpur district, Bangladesh. The hypothesis of this study is that rainfall and temperature have a decline and rising trend respectively in this region and the overall rice production is more dependent on modern technology than the climatic parameter.

This study will contribute to understanding the historical rainfall pattern in this district and also determine how rainfall and the production of rice in the Rangpur district interacted.

2. Data sources and methods

2.1. Description of the study area

This study was conducted in Bangladesh’s Rangpur District (Fig. 1), which is situated in the northern part of this country. The Rangpur District area is approximately 2,524 square kilometers and is located between 25°18′N latitude to 25°57′N latitude and 88°56′E longitude to 89°32′E longitude. A typical arid environment with high temperatures (24.9°c) and 1927 millimeters of average rainfall characterizes the northern area of Bangladesh (Afzal & Bhuiyan, 2015).

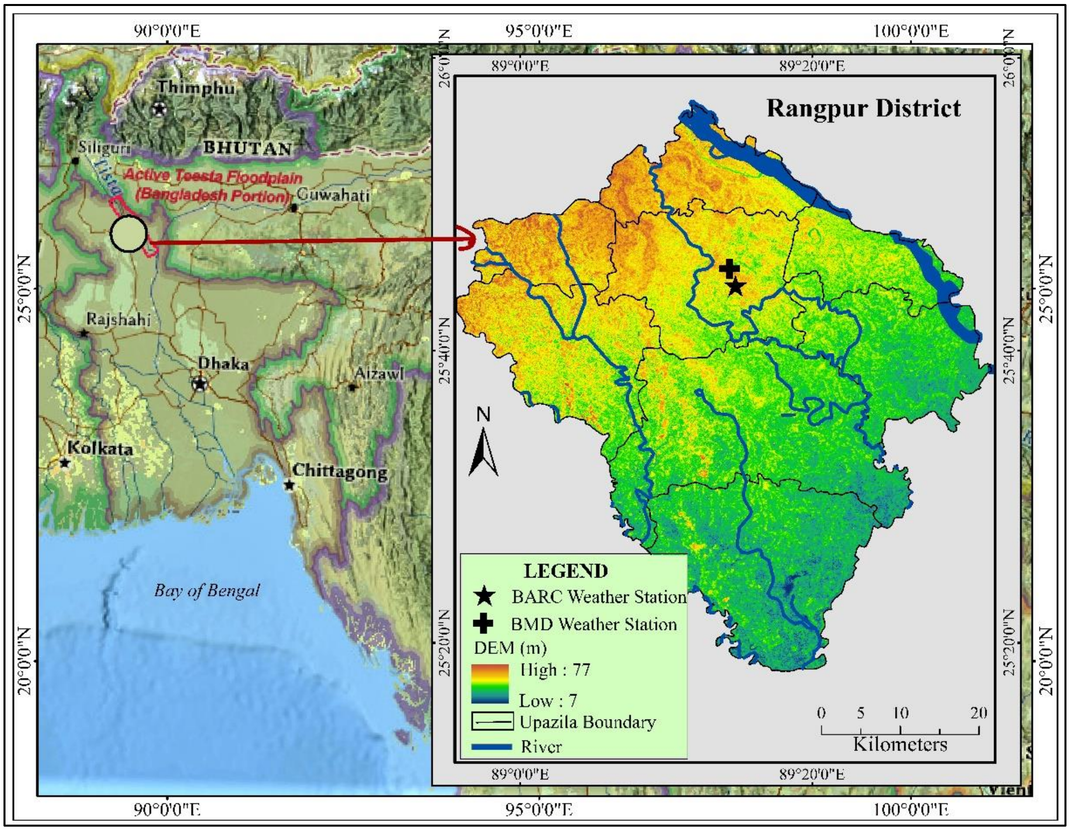


Fig. 1: Map of the research region showing where the weather stations are located.

2.2. Sources of data and data categorization

The present study on the changing pattern of rainfall and temperature and its impact on rice production in the Rangpur district used secondary data sources for data collection. Data on rainfall (1983-2022) were gathered from the Bangladesh Meteorological Department (BMD), temperature data (1983-2022) were collected from the Bangladesh Agricultural Research Council (BARC), and rice production data (2000-2020) were collected from the Bangladesh Agricultural Research Institute (BARI), Bangladesh Rice Research Institute (BRRI), and Bangladesh Bureau of Statistics (BBS). BMD, BARC, BARI, BRRI, and BBS employees verified the dataset's quality through data normalization and pre-processing. The data was arranged into three rice growing seasons. According to Sarker et al. (2012), these seasons are (a) December to May (Boro season), (b) March to August (Aus season), and (c) June to November (Aman season).

2.2.1. Quality assurance

The quality of data seat control with the missing data estimation, and outlier and auto-correlation identification and removed from the data set. Resolving the missing data by the standard ratio approach of the multiple imputation method (Piyoosh & Ghosh, 2017). Grubbs' test (Grubbs, 1950) is used to identify data outliers. Any number outside the predetermined range is considered an outlier. Autocorrelation was observed through the Durbin-Waston autocorrelation statistics (Kramer, 2011). The trend-free pre-whitening method was used to remove the auto-correlation.

2.3. Methods

The MK test (Mann, 1945; Kendall, 1975) was used to detect trends in rainfall, temperature, and rice production. The primary reason for using non-parametric statistical tests over parametric ones is that they are more suited to non-normally distributed and censored data, which is prevalent in hydro-meteorological time series (Monir et al., 2023a). The non-parametric MK trend test is said to be the most reliable technique for spotting trends in time series data because it is less susceptible to outliers (Weldegerima et al., 2018). Pearson's correlation coefficient method evaluated the impacts of rainfall and temperature on rice production. Pearson correlation coefficient techniques are in charge of determining the effects of two variables (Gou, 2023).

2.3.1 The MK test for identifying the trend

The following equation can be used to get the MK test statistic (Eq. 1; Eq. 2, Eq. 3) (Anand et al., 2020).

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} sign\ (x_j - x_k) \qquad (1)$$

Where

$$Sign\ (x_j - x_k) = \begin{Bmatrix} +1\ if\ (x_j - x_k) > 0 \\ -1\ if\ (x_j - x_k) < 0 \\ 0\ if\ (x_j - x_k) = 0 \end{Bmatrix} \qquad (2)$$

Similar to Monir et al. (2023b), the variance statistics (S) from Eq. 3 were derived.

$$Var\ (S) = \frac{[n(n-1)(2n+5) - \sum t(t-1)(2t+5)]}{18} \qquad (3)$$

MK test conducted on a 95% confidence level, S's positive value indicates an upward trend, whereas its negative value indicates an upward trend. (Kumar et al., 2018).

2.3.2. Pearson's correlation coefficient method for identifying the impact

The correlation coefficient calculated from Eq. 4 is similar to Gou (2023):

$$\mathbf{r} = \frac{n(\sum xy)-(\sum x)(\sum y)}{\sqrt{[n\sum x^2 -(\sum x^2]}\sqrt{[n\sum y^2 -(\sum y^2]}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (4)$$

The correlation coefficient has a range of -1 to 1, with -1 denoting a very negative association and 1 a strongly positive association.

3. Results

3.1. Historical trends in rainfall

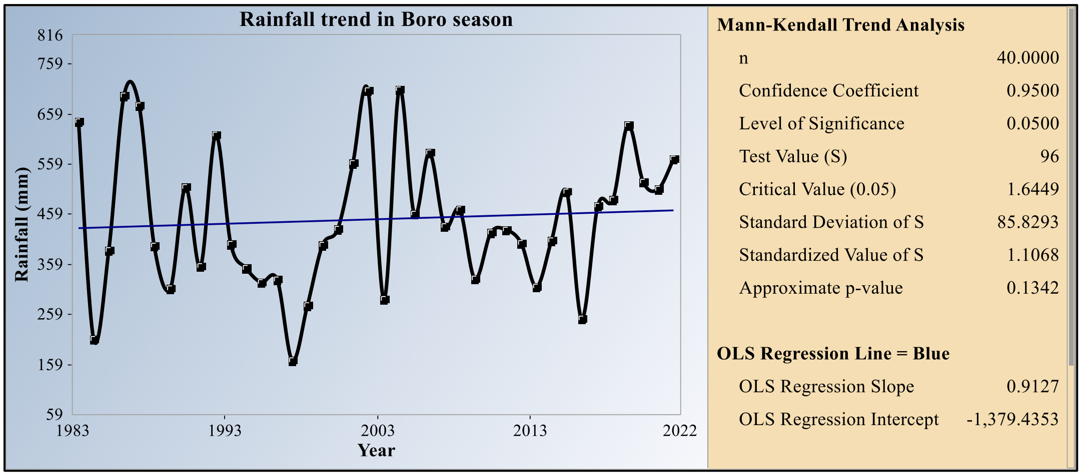
The amount of historical seasonal rainfall is shown in Table 1. During this time, the maximum rainfall for the Boro season was found in 2004 (707.59 mm), and the minimum rainfall in 1997 (166.79 mm).

Table 1: Amount of seasonal rainfall (mm) in Rangpur.

Year	Rainfall (mm)			Year	Rainfall (mm)		
	Season				Season		
	Boro	Aus	Aman		Boro	Aus	Aman
1983	643.20	1378.29	1068.68	2003	288.75	1433.52	2157.68
1984	209.11	1643.19	1960.48	2004	707.59	2447.39	2377.77
1985	386.72	1626.36	1802.48	2005	458.93	1766.00	1897.71
1986	695.94	2798.55	2989.13	2006	581.16	1682.19	2045.03
1987	675.91	2254.71	2155.39	2007	434.58	1878.74	2354.71
1988	395.35	1458.68	1828.97	2008	467.36	1269.26	1186.29
1989	309.72	2583.94	2863.68	2009	330.32	1532.16	1674.74
1990	511.72	1894.65	1967.42	2010	421.49	1437.35	1448.10
1991	354.12	1347.39	1485.71	2011	428.00	1863.35	1735.90
1992	617.97	1628.29	1825.87	2012	400.29	1615.45	1671.16
1993	398.20	1339.48	1835.84	2013	314.59	1500.13	1579.77
1994	350.96	1269.26	1624.00	2014	406.94	1378.71	1440.77
1995	322.32	1944.35	2141.52	2015	504.52	1362.32	1372.77
1996	327.81	997.61	953.94	2016	250.92	934.84	1362.06
1997	166.79	1451.94	2256.52	2017	475.81	1841.19	1902.19
1998	276.10	1464.68	1688.03	2018	488.35	1699.97	1630.16
1999	398.00	1447.71	1536.71	2019	637.48	1593.84	1205.55
2000	429.73	1650.84	1884.77	2020	523.58	1233.48	892.61
2001	559.94	2231.13	2309.42	2021	508.74	1557.39	1739.84
2002	704.97	1511.65	1013.55	2022	569.62	1727.87	1167.10

Source: BMD (http://live3.bmd.gov.bd/p/Rainfall-Analysis)

Figs. 2 to 4 show the historical rainfall trend. According to the MK test, a significant rising trend was observed in rainfall in the Boro season (Fig. 2), where the MK S value is 1.11 (P value = 0.13).



Mann-Kendall Trend Analysis

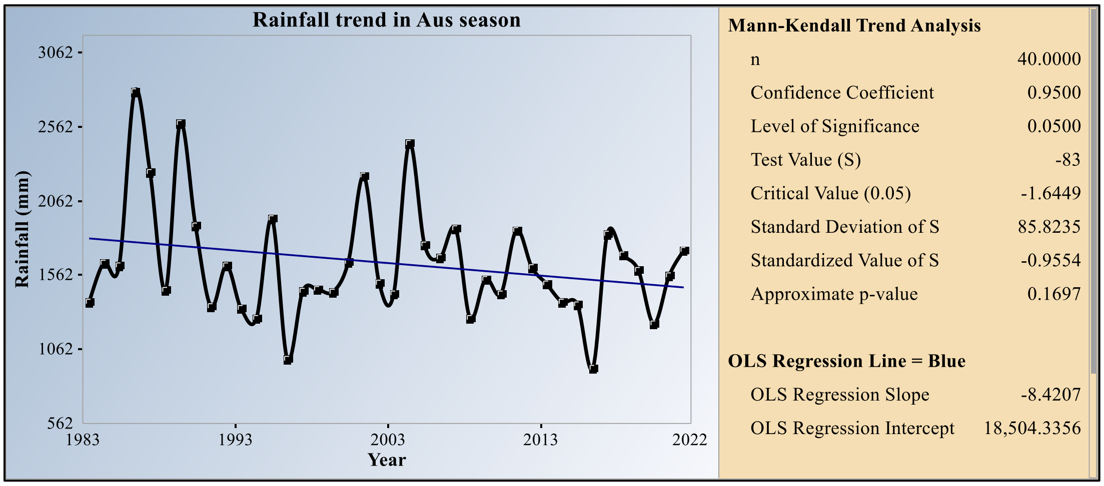
n	40.0000
Confidence Coefficient	0.9500
Level of Significance	0.0500
Test Value (S)	96
Critical Value (0.05)	1.6449
Standard Deviation of S	85.8293
Standardized Value of S	1.1068
Approximate p-value	0.1342

OLS Regression Line = Blue

OLS Regression Slope	0.9127
OLS Regression Intercept	-1,379.4353

Fig. 2: Rainfall trend in Boro season.

During the Aus season rainfall has a rapid declining trend (Fig. 3), where the MK S value is -0.96 (P value = 0.17). The maximum rainfall in the Aus season was observed in 1986 (2798.55 mm) and the minimum rainfall in 2016 (934.84 mm).



Mann-Kendall Trend Analysis

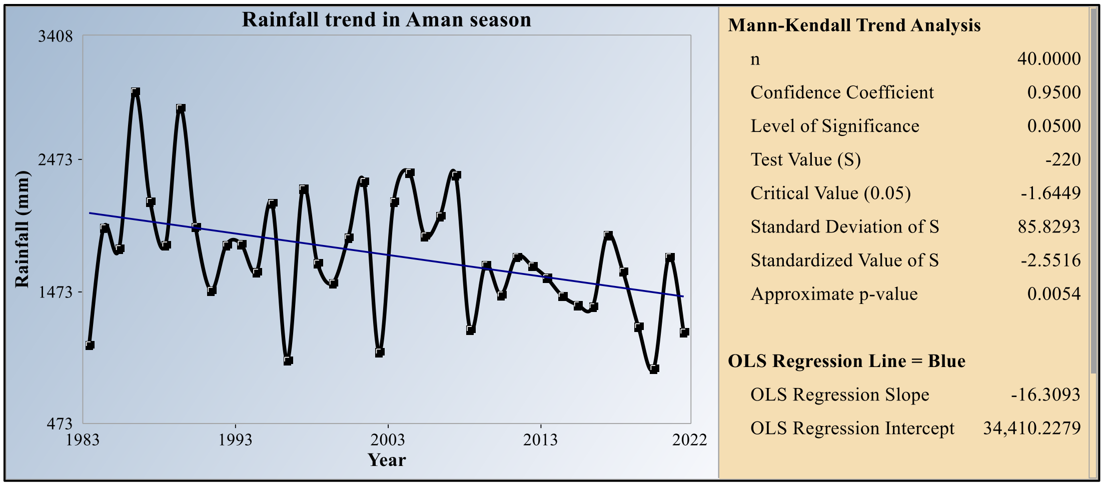
n	40.0000
Confidence Coefficient	0.9500
Level of Significance	0.0500
Test Value (S)	-83
Critical Value (0.05)	-1.6449
Standard Deviation of S	85.8235
Standardized Value of S	-0.9554
Approximate p-value	0.1697

OLS Regression Line = Blue

OLS Regression Slope	-8.4207
OLS Regression Intercept	18,504.3356

Fig. 3: Rainfall trend in Aus season.

The amount of rainfall also declines in the Aman season. The rate of declination is maximum among other seasons. MK S value is -2.22 ((P value > 0.01) (Fig. 4). The maximum rainfall in the Aman season was observed in 1986 (2989.13 mm) and the minimum rainfall in 2020 (892.61 mm).



Mann-Kendall Trend Analysis

n	40.0000
Confidence Coefficient	0.9500
Level of Significance	0.0500
Test Value (S)	-220
Critical Value (0.05)	-1.6449
Standard Deviation of S	85.8293
Standardized Value of S	-2.5516
Approximate p-value	0.0054

OLS Regression Line = Blue

OLS Regression Slope	-16.3093
OLS Regression Intercept	34,410.2279

Fig. 4: Rainfall trend in Aman season.

3.2. Historical trends in temperature

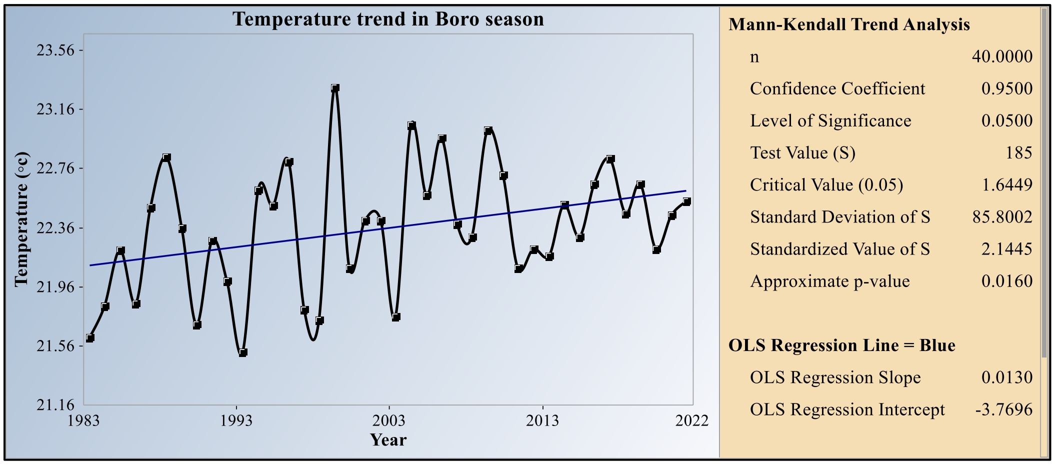
The time series seasonal temperatures of the Rangpur district are shown in Table 2. There is very little variation in seasonal temperature in this area.

Table 2: Temperature (˚c) during the rice growing seasons in Rangpur district.

Year	Temperature (˚c) Season Boro	 Aus	 Aman	Year	Temperature (˚c) Season Boro	 Aus	 Aman
1983	21.62	27.66	27.33	2003	21.76	28.26	27.70
1984	21.83	27.98	26.96	2004	23.06	27.81	27.15
1985	22.21	28.06	26.98	2005	22.58	27.85	27.41
1986	21.85	27.66	26.73	2006	22.97	28.46	27.81
1987	22.50	28.43	27.20	2007	22.39	28.54	27.81
1988	22.84	28.16	27.02	2008	22.30	28.01	27.38
1989	22.36	28.48	27.34	2009	23.02	28.54	27.98
1990	21.71	27.94	27.43	2010	22.72	28.56	27.84
1991	22.28	27.96	27.23	2011	22.09	28.24	27.90
1992	22.00	28.21	27.39	2012	22.22	28.49	27.57
1993	21.52	27.66	27.42	2013	22.17	28.52	27.96
1994	22.62	28.57	27.53	2014	22.52	28.99	27.96
1995	22.51	28.55	27.34	2015	22.30	28.17	28.07
1996	22.81	28.30	27.39	2016	22.66	28.53	28.29
1997	21.81	27.89	27.23	2017	22.83	28.54	28.23
1998	21.74	28.35	28.01	2018	22.46	28.63	28.24
1999	23.31	28.67	27.55	2019	22.66	28.81	28.38
2000	22.09	28.21	27.66	2020	22.22	28.52	28.43
2001	22.41	28.52	27.97	2021	22.45	28.48	28.44
2002	22.41	27.49	27.35	2022	22.54	28.65	28.42

Source: BARC (https://barc.gov.bd/)

significant rising trend was found in temperature for the Boro season. The MK S value is 2.14 (P value = 0.02) (Fig. 5).



Mann-Kendall Trend Analysis

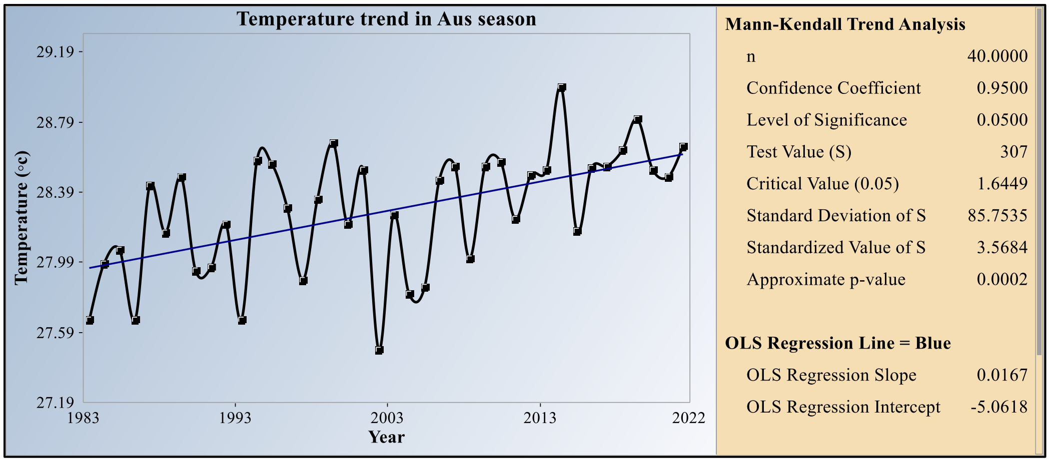
n	40.0000
Confidence Coefficient	0.9500
Level of Significance	0.0500
Test Value (S)	185
Critical Value (0.05)	1.6449
Standard Deviation of S	85.8002
Standardized Value of S	2.1445
Approximate p-value	0.0160

OLS Regression Line = Blue

OLS Regression Slope	0.0130
OLS Regression Intercept	-3.7696

Fig. 5: Temperature trend in Boro season.

A rapidly rising trend for temperature was found in the Aus season. The MK S value is 3.57 (P value >0.01) (Fig. 6).



Mann-Kendall Trend Analysis

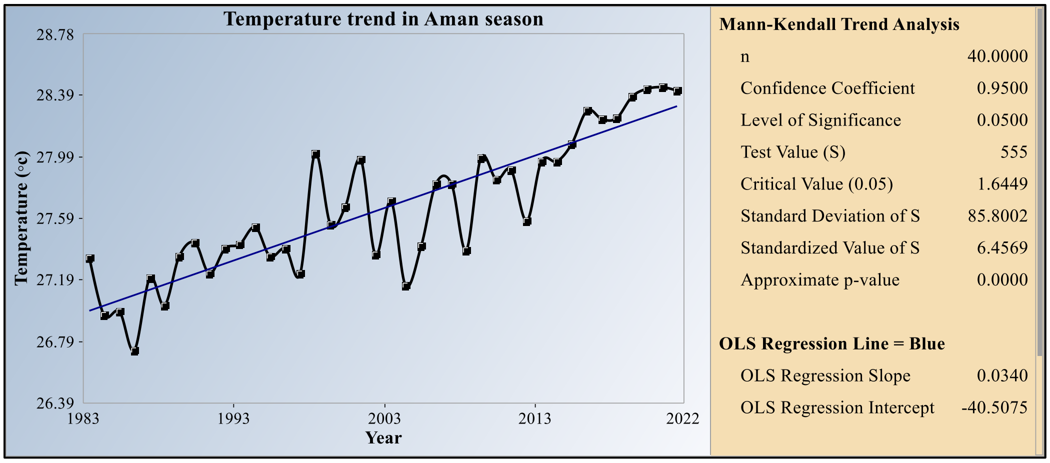
n	40.0000
Confidence Coefficient	0.9500
Level of Significance	0.0500
Test Value (S)	307
Critical Value (0.05)	1.6449
Standard Deviation of S	85.7535
Standardized Value of S	3.5684
Approximate p-value	0.0002

OLS Regression Line = Blue

OLS Regression Slope	0.0167
OLS Regression Intercept	-5.0618

Fig. 6: Temperature trend in Aus season.

A very rapidly rising trend for temperature was found in the Aman season. The MK S value is 6.46 (P value >0.01) (Fig. 7). This is an alarming threat to the sustainable environment.

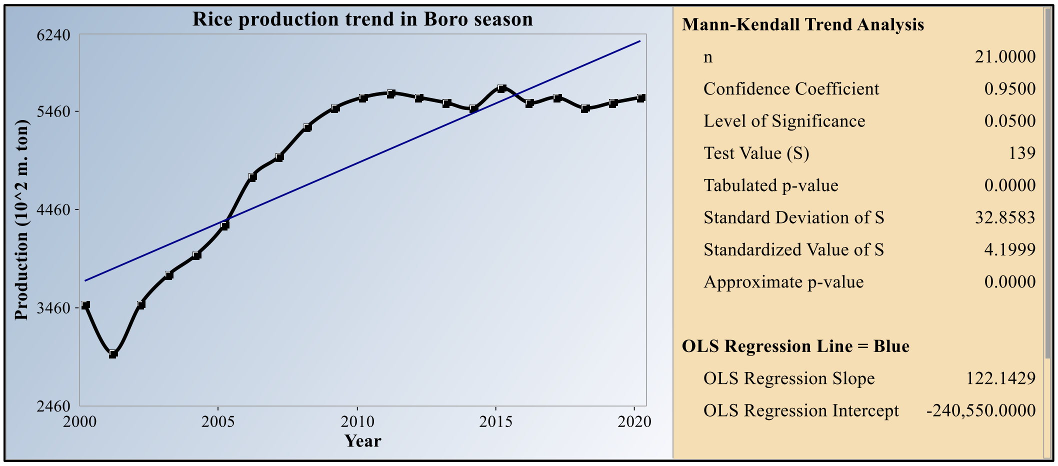


Mann-Kendall Trend Analysis	
n	40.0000
Confidence Coefficient	0.9500
Level of Significance	0.0500
Test Value (S)	555
Critical Value (0.05)	1.6449
Standard Deviation of S	85.8002
Standardized Value of S	6.4569
Approximate p-value	0.0000
OLS Regression Line = Blue	
OLS Regression Slope	0.0340
OLS Regression Intercept	-40.5075

Fig. 7: Temperature trend in Aman season.

3.3. Trend in rice production

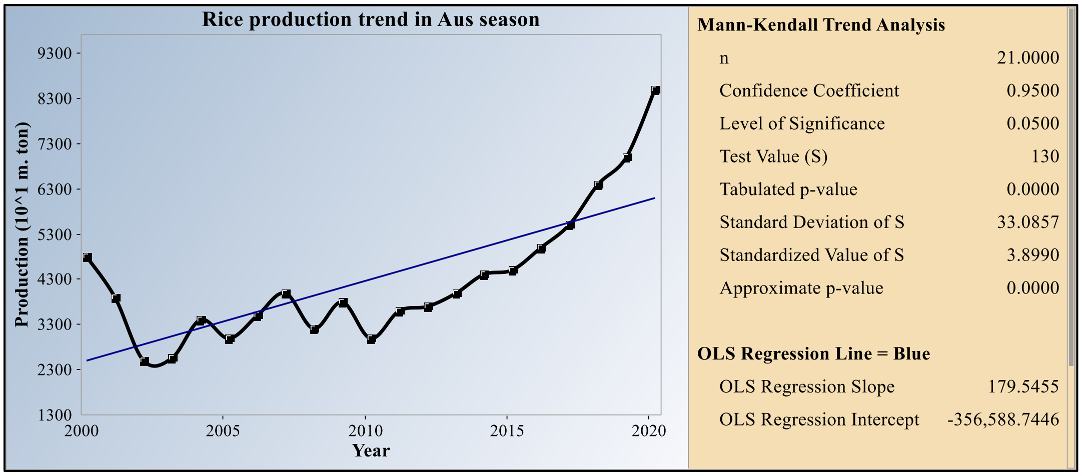
The trend in rice production is rising for every season (Figs. 8-10). A rapidly rising trend for rice production was found in the Boro season. The MK S value is 4.2 (P value >0.01) (Fig. 8).



Mann-Kendall Trend Analysis	
n	21.0000
Confidence Coefficient	0.9500
Level of Significance	0.0500
Test Value (S)	139
Tabulated p-value	0.0000
Standard Deviation of S	32.8583
Standardized Value of S	4.1999
Approximate p-value	0.0000
OLS Regression Line = Blue	
OLS Regression Slope	122.1429
OLS Regression Intercept	-240,550.0000

Fig. 8: Rice production trend in Boro season.

Among these seasons less rising rate was observed in the Aus season. A simple rising trend for rice production was found in the Aus season. The MK S value is 3.9 (P value >0.01) (Fig. 9).



Mann-Kendall Trend Analysis

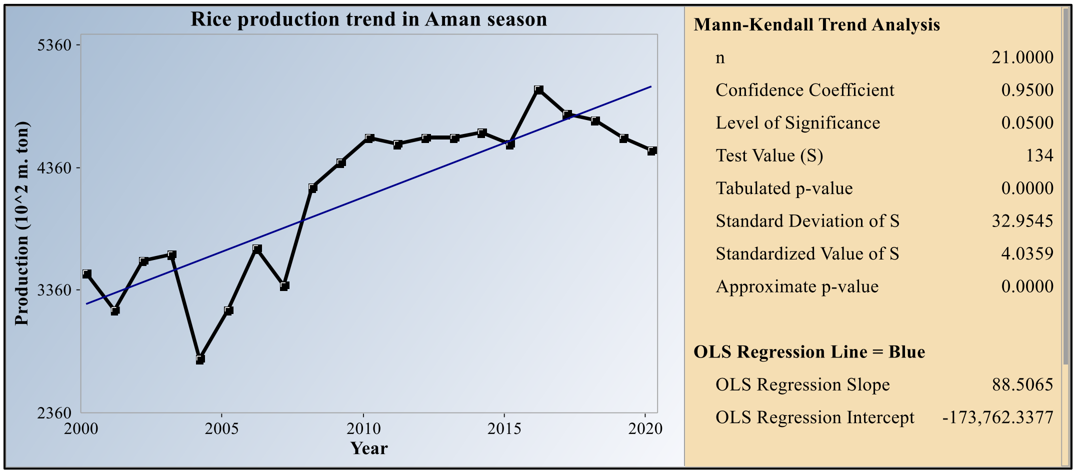
n	21.0000
Confidence Coefficient	0.9500
Level of Significance	0.0500
Test Value (S)	130
Tabulated p-value	0.0000
Standard Deviation of S	33.0857
Standardized Value of S	3.8990
Approximate p-value	0.0000

OLS Regression Line = Blue

OLS Regression Slope	179.5455
OLS Regression Intercept	-356,588.7446

Fig. 9: Rice production trend in Aus season.

A rapidly rising trend for rice production was found in the Aman season. The MK S value is 4.04 (P value >0.01) (Fig. 10).



Mann-Kendall Trend Analysis

n	21.0000
Confidence Coefficient	0.9500
Level of Significance	0.0500
Test Value (S)	134
Tabulated p-value	0.0000
Standard Deviation of S	32.9545
Standardized Value of S	4.0359
Approximate p-value	0.0000

OLS Regression Line = Blue

OLS Regression Slope	88.5065
OLS Regression Intercept	-173,762.3377

Fig. 10: Rice production trend in Aman season.

3.4. Effects of rainfall, temperature, and humidity on the production of rice

According to Pearson's correlation coefficient method, the production of rice is negatively impacted by rainfall (Fig. 11). It means extreme rainfall as flood affects rice production, especially in the Aman season. The correlation coefficient (r) value between rainfall and the production of rice are -0.35 in the Boro season, -0.20 in the Aus season, and -0.62 in the Aman season.

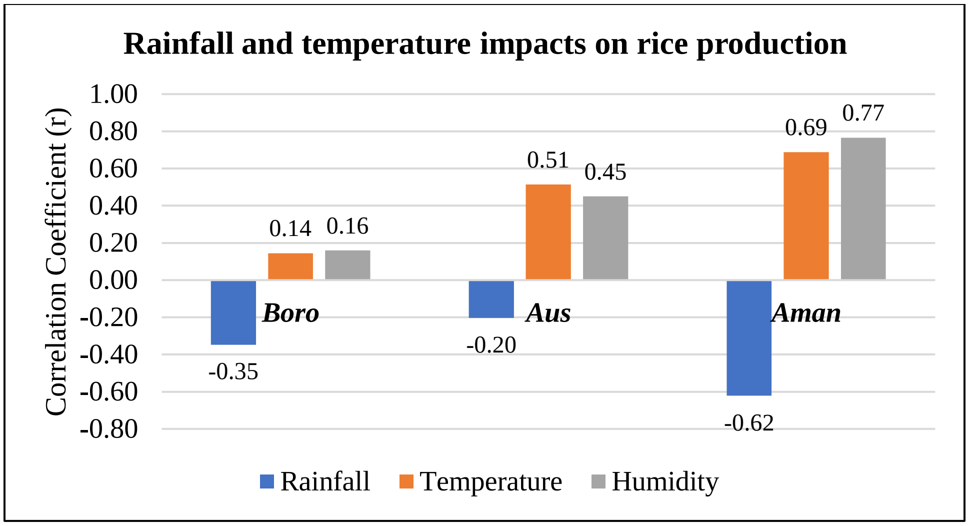


Fig. 11: Effects of rainfall, temperature, and humidity on the production of rice.

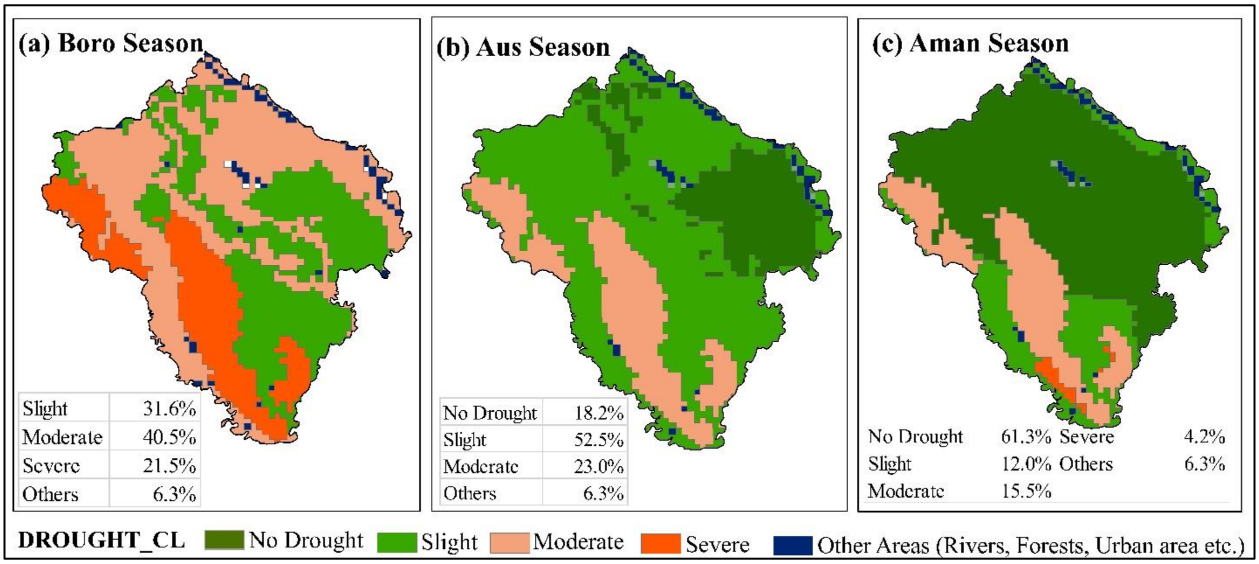


Fig. 12: Spatial distribution of natural soil water drought behind the rice production: (a) during Boro season, (b) during Aus season, and (c) during Aman season.

There is a different state of lack of natural water for rice production among different rice growing seasons (Fig. 12). During the Boro season, every place in the study area is affected by drought. More than 40% area is affected by moderate drought. In the Aus season, no drought in 18.2% areas, and slight drought in more than half of the areas. During the Aman season, more than 60% of areas have no drought (Fig. 12).

Temperature and humidity play a positive impact on the production of rice (Fig. 11). The production of rice is hampered due to the cold wave and insufficient temperature. The correlation coefficient values between temperature and the production of rice are 0.14, 0.51, and 0.69 and the correlation coefficient values between humidity and temperature are 0.16, 0.45, and 0.77 for the Boro, Aus, and Aman seasons respectively.

4. Discussion

Bangladesh is among the nations most at risk from climate change because of its geographic location and hydrological variability (Bari et al., 2016). Recent research indicates that Bangladesh's climate has changed (Shahid & Khairulmaini, 2009). In northern Bangladesh, winter rainfall has not changed significantly. In this investigation, no discernible trend in rainfall was seen during the Boro season (December to May). However, the rainfall during the Aus and Aman seasons is rapidly declining. Similarly, Shahid (2010) evaluates declining monsoon and post-monsoon seasons' rainfall trends. Previous studies also observed rainfall trend anomalies in this region (Agrawala et al., 2003; Shahid, 2010; Bari et al., 2016; Rahman et al., 2017), but this study provides new knowledge about the rainfall anomalies during different rice growing seasons. The present study observed a rising trend in temperature for all seasons. Bhuyan et al. (2018) also evaluate average maximum temperatures are increasing at a rate of 0.29˚C and 5.3˚C per century, respectively in northwestern Bangladesh. However, the present study observed a rapidly rising trend in temperature in the Rangpur district. Worldwide rice output rose day by day (Akinbile & Akande, 2020). Parry et al. (2007) state South Asian agricultural productivity may decline by 30% by the 2050s. However, after 16 years from Parry (2007), the present study observed a rapidly rising trend in rice production in this study area. The changing pattern of rainfall and temperature has a great impact on rice production (Abbas & Mayo, 2021; Acar et al., 2022; Islam et al., 2022; Kundu et al., 2023). Also, in this study, the rice production growth rate in the Aman season is lower than in the Boro season due to the rapidly declining rainfall in the Aman season.

From the statistics of Pearson's correlation coefficient method, rice production is negatively associated with rainfall, especially, a significant negative correlation during Aman season. Also, there was a positive correlation of rice production with temperature and humidity. The previous study also observed similar results for rainfall and temperature in other regions of the world (Abbas & Mayo, 2021; Islam et al., 2022). In this present study we added the association of humidity behind the rice production. In this present study, the result shows there was observed a non-stationary trend in rainfall (Figs. 2-4) and a rising trend in temperature (Figs. 5-7) and rice production (Figs. 8-10). Though there is a lack of natural water in the soil for rice production in the Boro and Aus seasons, and available natural water in the Aman season (Fig. 12), the overall average yield of rice production in the Boro season is 41% greater than Aman season (Rahman et al., 2023). So, the soil water drought does not strongly affect the amount of rice production. Also, the amount of rice production increased day by day due to modern technology (irrigation, fertilizer, chemicals, seeds) in this region (Salam & Sarker, 2023). This study reveals that rice production has a positive dependency on climatic variables (temperature, humidity), though it was a slight dependency (Fig. 11). It was also defined by earlier studies (Rahman et al., 2023). Rainfall and temperature variations impact rice production, especially, monsoon rainfall greatly influences Aman rice production in this study region.

5. Conclusion

The study has provided valuable insights into the rainfall and temperature patterns of the Rangpur district over the last 40 years into three dominated rice-growing seasons. This study demonstrated the non-stationary influence of rainfall fluctuation on rice farming in the Rangpur district, one of Bangladesh's most populous and significant rice-producing regions. According to the MK test, a rapidly decreasing trend in rainfall was observed during the Aus and Aman seasons, while there was a slightly increasing trend for the Boro season’s rainfall. The study of historical seasonal temperature data revealed a fast-growing tendency. This study also found a rising trend in rice production for all seasons in this district, though the Boro rice production has a higher rate than others. Rice production in this region overcomes climatic variability and soil water shortage due to the practices of modern technology. The production of rice dependency on rainfall, temperature, and humidity patterns was evaluated by Pearson’s correlation coefficient method. There was observed a negative correlation between rainfall and rice production and others are positive correlation. A significant negative dependency was observed between rainfall and the production of rice during the Aman season. Rice cultivation in the Aman season fully depends on rainfall amount and pattern in this region. Extreme rainfall, floods, and low temperatures hampered normal rice production, also the lack of rainfall in the Aman season impact on rice production. The alone weather station utilized for climatic parameter monitoring is one of the study's shortcomings. As a result, the spatiotemporal analysis was left out of this work. Another limitation of this current study is: this study was not able to consider the species types of rice and modern technology (fertilizer, irrigation, chemicals) as a factor for rice production. Despite these limitations, this study can be helpful for determining water and disaster management, and the agricultural sector's decision in this district and the same region over the world. However, further research is necessary to identify the spatial variation of rainfall patterns in the region and consider species and modern technology with climatic variables as a factor for rice production variability. To increase the crop model's ability in the future, the mechanism of non-stationarity has to be further investigated. The study recommends that policymakers and stakeholders use the findings to inform their decision-making and highlights the need for continued monitoring and analysis of rainfall patterns.

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Competing interests

The authors declare that they have no conflict of interest.

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Effect of soil texture and its moisture content on river bank erosion in the Teesta river basin, Bangladesh

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ABSTRACT

Riverbank erosion is one of the most unpredictable and critical type of disaster that takes into account the quantity of rainfall, soil structure, river morphology, topography of river and adjacent areas, and floods. The Teesta River and its floodplain area do not apart from this trend. This study assesses river bank erosion using soil moisture and textural characteristics and evaluates the impact of climate change on riverbank erosion in the Teesta river basin. The ROM (Roslan and Mazidah) scale is used to determine the degree of soil erodibility of Kawnia-Pirgacha Upazila in upstream and Ulipur-Rajarhat Upazila in downstream of the Tistal valley based on the percentage of sand, silt and clay of sixty samples (30 from upstream and 30 from downstream) and their moisture contents. The soils with higher sand content are low in moisture content and have high probability to bank erosion as in Kaunia and Ulipur Upazila. The soil textural composition is an important factor that significantly contributing to river bank collapses that is represented by the degree of soil erodibility. Our observation suggests that Kaunia Upazila in the upstream and Ulipur Upazila in the downstream of the Teesta River are more vulnerable to soil erodibility than other Upazila of Teesta basin area.

Keywords: River bank erosion, river morphology, EiROM Indexing, textural composition, soil erodibility, soil moisture.

1. Introduction

Natural disasters like river bank erosion happen all across the world, especially in Bangladesh. Multiple variables, such as the geometry of the river, the volume of rainfall, the frequency of floods, and others, can contribute to river bank erosion. The amount of silt added by bank erosion to a river's bank load depends on a number of variables (Selim et al., 2022). The movement of soil particles, botanical change, and the existence of unusual morphology are indicators of river bank erosion (Lawler, 1993). Organic matter concentration, infiltration rates, soil structure, and soil erodibility all affect how resistant a soil is to erosion. The problem of river pollution may be made worse by silt buildup brought on by river bank erosion. The beginning of sediment flow is influenced by velocity, bed form parameters, and kinetic energy at the riverbed (Islam, 2021; Dekaraja and Mahanta, 2021). Subaerial preparation, mass collapse, and hydraulic shear all contribute to river bank erosion.

Bangladesh is one of the nations with the highest risk of natural disasters. One of Bangladesh's well-known natural calamities is riverbank erosion. Bangladesh has to deal with river erosion because it is a country of rivers. However, the rate of river erosion is accelerating daily for a variety of reasons, endangering a large population (Islam et al., 2020) .One of Bangladesh's main natural disasters, riverbank erosion has severe and protracted socioeconomic repercussions. About a million individuals are impacted by riverbank erosion each year. (Arseneault et al., 2015; Crawford et al., 2020; Barman et al. 2019) People are forced to relocate or leave their homes due to riverbank erosion, but it also destroys their possessions (Majumder et al., 2017; Goswami & Chowdhury, 2023)

Bangladesh is situated in the Ganges-Brahmaputra-Meghna (GBM) river system and its various tributaries' alluvial floodplain. In this nation, riverbank erosion occurs frequently and is often very severe. (Rahman et al., 2020; Zaman and Alam 2021; Billah et al., 2022) Riverbank erosion has severe and protracted socioeconomic repercussions. About a million individuals are impacted by riverbank erosion each year. (Sarker, 2018; Billah, 2018; Akter et al., 2019) In Bangladesh, a river erodes around 10,000 acres of land annually (Islam, 2012), and erosion affects about 5% of the entire floodplain.

In this nation, there are about 750 rivers, but the Padma, Jamuna, and Meghna are the most significant. With so many rivers, many different types of natural disasters, including floods, landslides, and riverbank erosion, are produced. Of them, riverbank erosion is one of the most significant. Since the majority of this complex river's channels are unstable by nature, river bank erosion is more frequent as a result (Siddik et al., 2017; Ali et al., 2021). In addition, erosion affects 241 locations across 58 districts in the 64 districts. Such a natural calamity evicts and impoverishes individuals on a long-term basis and occurs virtually every day of the year. (Nishat and Mukherjee, 2013; Islam et al. 2014) Additionally, it is claimed that the erosion of riverbanks accelerated the process of poverty in the Bangladeshi regions affected (Zaber et al., 2018; Bhuiyan et al., 2017). Climate change is tremendously hazardous for Bangladesh. Riverbank erosion is occurring more frequently and intensely as a result of climate change, causing serious human and financial losses. It concentrated on the problems of the marginalization process for a group of people who are currently displaced by river bank erosion (Hasan et al., 2017). The year-round natural calamity of river bank erosion occurs. It appears that the victims in Bangladesh have suffered from the institutional response's abject failure to develop and implement adjustment methods. Bangladesh's overall crisis situation is progressively getting worse. (Islam, 2020; Shetu et al., 2017; Zaman et al., 2015)

A significant resource management issue on a global scale is riverbank erosion, along with the risks of accompanying sedimentation and land loss. Given the amount of rainfall, soil composition, river shape, terrain of the river and its surroundings, and floods, it is one of the most unpredictable and dangerous types of disasters. Fewer lives were lost due to this catastrophe, but more livelihoods were lost due to the evacuation of homesteads and agricultural land (Rahman, 2017; Alam, 2016).

The study was conducted at one of the vulnerable regions of Bangladesh due to riverbank erosion. The study tried to determine the probability of Teesta riverbank erosion based on the soil moisture characteristics and textural classification using the "ROM" scale, to determine the erosion rate in conjunction with various soil sample characteristics, and to suggest a new practical method for the stability analysis of the riverbank.

2. Materials and methods

2.1.Teesta River

The Teesta River has a length of 414 km (257 mi), rises in the eastern Himalayas, travels through Bangladesh, the Indian States of Sikkim and West Bengal, and finally empties into the Bay of Bengal. 4,840 square miles (12,540 km^2) are drained by it. It passes through the Indian cities of Rangpo, Jalpaiguri, and Mekhliganj as well as the Darjelling district. In Bangladesh, it merges with the Jamuna River at Fulchhari. The Teesta once flowed in three channels, the Karatoya to the east, the Punarbhaba to the west, and the Atrai to the centre, all running directly south from

Jolpaiguri. The Teesta River abandoned its former path and rushed south-east to join the Brahmaputra during the devastating flood of 1787.

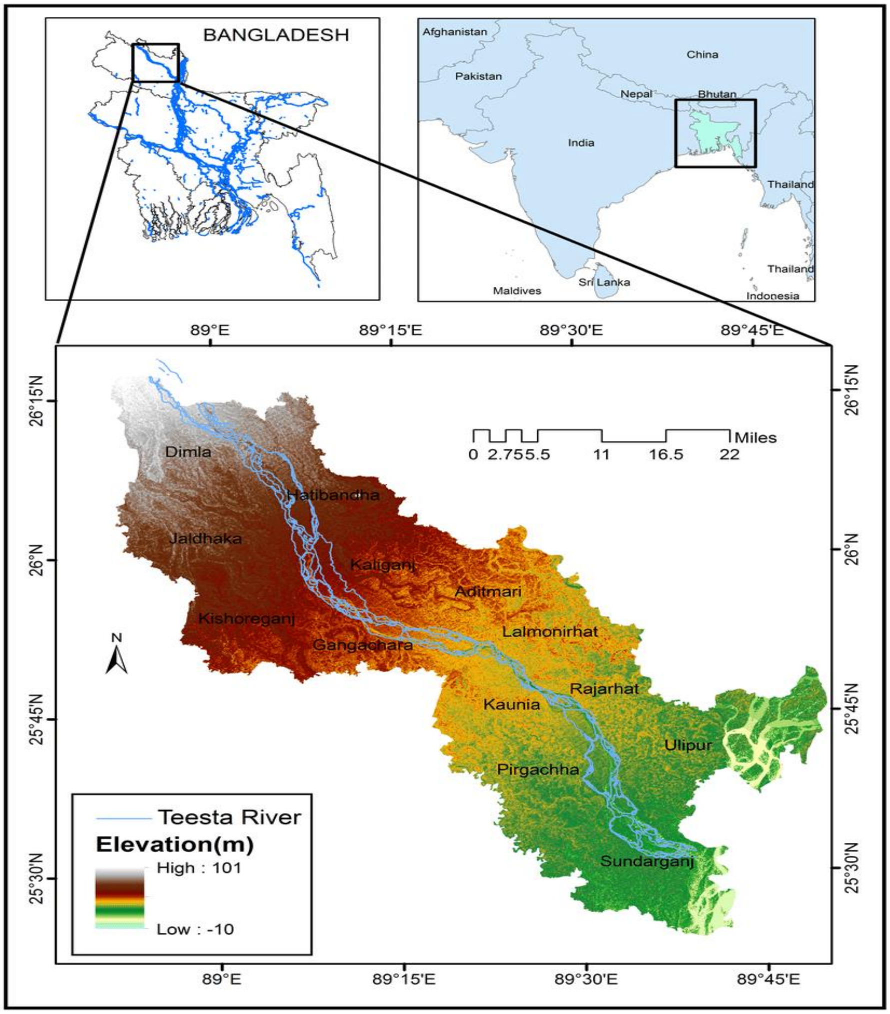

Fig. 1. Location map of Teesta River in Bangladesh

2.2. Study area

The research area is in the northern Bangladesh, in the Rangpur division. Kaunia, Pirgacha, Rajarhat, and Ulipur Upazila are the primary research areas. At 25.7708°N 89.4167°E, Kaunia may be found. This Upazila is bordered to the north by Gangachara and Lalmonirhat Sadar Upazila, to the south by Pirgachha Upazila, to the east by Rajarhat Upazila, and to the west by Rangpur Sadar Upazila with a total area of 147.6 $\boldsymbol{km^2}$. Teesta and Burail are the main rivers. 265.32 square kilometers make up Pirgachha Upazila (Rangpur district), which is situated between 25°33' and 25°45' north and 89°18' and 89°32' east.

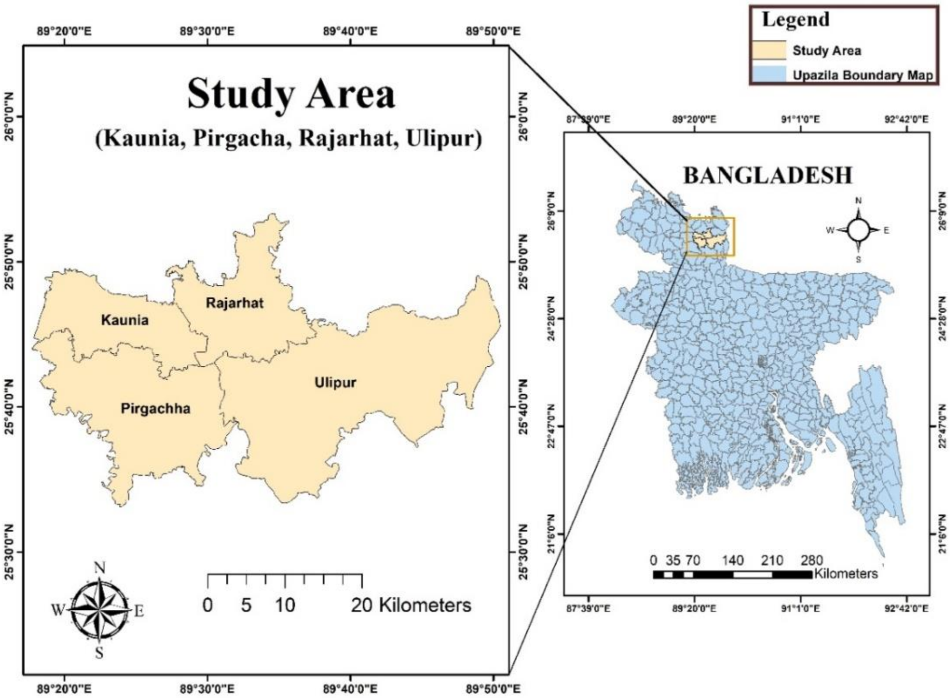

Fig. 2. Location of the study area

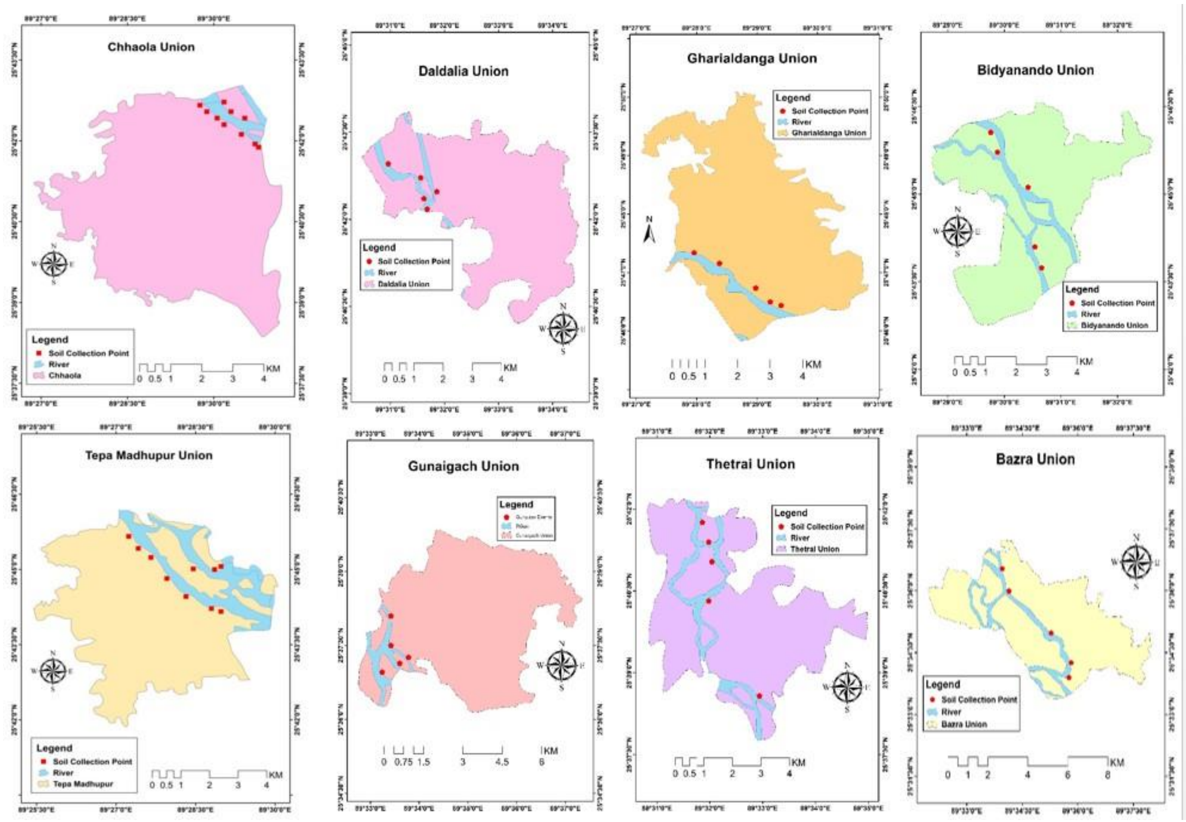

Fig. 3. Soil sample Collection point in different union

Its northern and southern boundaries are Kaunia and Rajarhat Upazila, its eastern and western boundaries are Ulipur and Sundarganj Upazila, and its eastern boundary is Sundarganj Upazila. In the northern region of Bangladesh, the Teesta River basin is made up of Rajarhat and Ulipur Upazila in the Kurigram district. It is located in Rajarhat and Ulipur Upazila at 26°10'43"N latitude and 89°3'6"E longitude. The Sikkim state in West Bangle, India, accounts for 8051 sq. km of the Teesta River catchments total area, whereas Bangladesh, accounts for 4108 sq. km of it as flat terrain.

2.3. Methods to identify the riverbank erosion

‘ROM’ scale calculation

The 'ROM' scale was developed solely on the basis of the properties of the soil, and it employs the EI_{ROM}equation to determine the soil erodibility index in addition to serving as an indication of the configuration of the erosion features. In other words, the ‘ROM’ scale is used to assess the degree of soil erodibility based on EI_{ROM}equation. This scale was created for the first time ever to grade the severity of erosion in relation to the soil erodibility index and erosion characteristics. Several regions and sites were still in the early stages of 'ROM' scale development. Physical surveying, observation of soil erosion characteristics, and recording of fundamental soil classification information were done in the designated locations. In order to determine the danger of erosion-induced landslides, the soil's textural composition, namely its sand, silt, and clay content, must be identified. As was previously noted, the EI_{ROM}equation was developed to produce appropriate sound erodibility values in comparison to other scales of measurements. There have been several attempts to develop a straightforward indicator of erodibility based on either the soil's characteristics as discovered in the lab or on the ground, or on how the soil reacts to rainfall. Theoretically, when the clay particles interact with organic matter to create soil aggregates or clods, the use of clay content as a measure of erodibility was found to be more gratifying. The resistivity of the soil is determined by how stable they are. The construction of the "EI_{ROM}equation” was made possible by the clay ratio used in Equation () to calculate the Bouyoucoserodibility index.

$$\text{Bouyoucoserodibility index} = \frac{\%\text{Sand} + \%\text{Silt}}{\%\text{Clay}} \text{-------(i)}$$

An advance and new improved soil erodibility index was then developed by the name of EI_{ROM}or ‘ROM’ Scale.This new equation is still using the original principal of Bouyoucos which is analyzing the soil textural composition of sand, silt and clay. The new equation clearly has shown the significant value and threshold for soil erodibility demarcation and at the same time indicated the expected erosion feature. With the new EI_{ROM} equation as in Equation (ii), the more realistic and significant value of soil erodibility index can be used simultaneously with its risk category as shown in Table 1 to indicate the degree of soil erodibility.

$$EI_{ROM} = \frac{\%\text{Sand} + \%\text{Silt}}{2(\%\text{Clay})} \text{------------------(ii)}$$

After taking into account the range of values to be categorized in relation to other standards of international values, such as the Richter scale for earthquake strength, the digit 2 is utilized in the denominator. Table 1 may be used to classify the risk of erosion using the computed soil erodibility index based on soil composition.

To determine the real amount of sand, silt, and clay in the soil samples, sieve analysis and hydrometer analysis tests must be carried out in order to determine the soil's sensitivity to erosion. The relationship clearly shows that when the percentage of clay is raised, the erodibility index value decreases and the danger of erosion decreases, and vice versa. This indicates that a key factor in river bank erosion is the soil's clay concentration.

Table 1 'ROM' Scale with regards to soil erodibility category.

'ROM' Scale	Soil Erodibility Category
<1.5	Low
1.5~4.0	Moderate
4.0~8.0	High
8.0~12.0	Very High
>12.0	Critical

Available soil moisture content calculation and identify soil textural classes in wet weight basis

The method to calculate the soil moisture Content followed by SRDI (Soil Resource Development institute) in Rangpur Division is based on wet weight basis and the equation is-

$$\% \text{ moisture content (MC)} = \frac{(\text{b - c}) \times 100}{\text{b} - \text{a}} ------------ (\text{iii})$$

(Wet weight basis)

Where,

a = Weight of Aluminium box

b = Weight of Aluminium box + Sample soil

c = Weight of Aluminium box + Oven dry soil

b-c = Amount of water lost

b-a = Amount of sample taken

Available soil moisture content calculation and identify soil textural classes in dry weight basis

Drs. Ian Pepper and Charles Gerba discovered a new method to determine the soil moisture content through laboratory tests in 2019. The dry soil particles and the weight of the water present in the soil make up the weight of the moist soil. The moist weight of the soil increases as more water is put to it. The soil's individual soil particles each have a set dry weight, which is the only weight that matters. As more water is added to the soil, there are an endless number of wet weights available. As a result, during laboratory tests with soil, the moisture content might fluctuate over time, but the weight of the soil can remain constant. Use the formula below to get the soil moisture content for each replicate sample:

$$\% \text{ moisture content (MC)} = \frac{\text{Weight of moist soil(M) - Weight of dry soil(D)}}{\text{Weight of dry soil(D)}} \times 100 - (iv)$$

(Dry weight basis)

2.4. Statistical analysis

The Microsoft Office Excel was used to initiate descriptive statistics. Before the statistical analysis the raw data was prepared by using the Statistical Package for Social Sciences (SPSS) ver. 20.0. Furthermore, a quality check was done accordingly in this present research. The significant differences of parameters among sampling sites were demonstrated with different significant test like, one sample test and one sample Kolmogorov-Smirnov (KS) test and were found statistically significant ($p < 0.05$). Microsoft Office Excel was used to create several types of diagrams, such bar (Textural element of different soil types, comparative changes of soil moisture content), pie (Erosion risk level at different union), and many more. One of the most widely utilized methods is inverse distance weighted (IDW) interpolation since it is simple and reliable. In this study, spatial analyses were done using the IDW interpolation technique in ArcMap 10.5.

Table 2 Sample test and one sample Kolmogorov-Smirnov (KS) test

One-Sample Test

	t	df	Sig. (2-tailed)	Mean Difference*	95% Confidence Interval of the Difference	
					Lower	Upper
% Sand	25.019	29	.000	55.98300	51.4065	60.5595
% Silt	15.076	29	.000	30.74267	26.5721	34.9132
% Clay	20.011	29	.000	13.30767	11.9476	14.6678

One-Sample Kolmogorov-Smirnov Test

		% Sand	% Silt	% Clay
Most Extreme Differences*	Absolute	.103	.090	.148
	Positive	.103	.069	.148
	Negative	-.073	-.090	-.085
Kolmogorov-Smirnov Z		.564	.493	.810
Asymp. Sig. (2-tailed)		.009	.041	.029

** Test distribution is Normal*

3. Results and Discussion

3.1. Assessing of river bank erosion using various indicators

Soil moisture content

The amount of water in the soil is known as its moisture. It can be explained in terms of volume or weight. Soil moisture can be monitored using both in-situ probes (such neutron and capacitance probes) and remote sensing methods. The key determinants of how much water a soil can hold are its organic matter concentration and texture. The texture of a soil can reveal the distribution of its particle sizes.

Table 3 Soil moisture content

Sample No.	Location	Moisture content in dry weight basis ((b-c) ×100)/(b-a)	Moisture content in wet weight basis (M-D)100/D	Average Moisture content (%)
1	Bidyanando	0.58	36.62	18.59
2	Bidyanando	0.60	5.38	2.99
3	Bidyanando	0.61	37.96	19.28
4	Bidyanando	0.66	39.86	20.26
5	Bidyanando	0.66	39.93	20.29
6	Gharialdanga	0.62	5.47	3.05
7	Gharialdanga	0.78	44.06	22.42
8	Gharialdanga	0.61	5.41	3.01
9	Gharialdanga	0.52	34.49	17.50
10	Gharialdanga	0.63	38.78	19.70
11	Daldalia	0.56	36.14	18.35
12	Daldalia	0.92	6.87	3.90
13	Daldalia	0.76	6.21	3.49
14	Daldalia	0.61	38.15	19.38
15	Daldalia	0.60	37.83	19.22
16	Thetrai	0.51	34.19	17.35
17	Thetrai	0.63	38.78	19.71
18	Thetrai	0.78	43.96	22.37
19	Thetrai	0.67	40.31	20.49
20	Thetrai	0.51	4.85	2.68
21	Bazra	0.64	39.17	19.90
22	Bazra	0.50	33.52	17.01
23	Bazra	0.755	43.04	21.90
24	Bazra	0.66	39.84	20.25
25	Bazra	0.54	5.05	2.80
26	Gunaigach	0.53	4.97	2.75

Sample No.	Location	Moisture content in dry weight basis ((b-c) ×100)/(b-a)	Moisture content in wet weight basis (M-D)100/D	Average Moisture content (%)
27	Gunaigach	0.42	4.25	2.33
28	Gunaigach	0.61	5.44	3.03
29	Gunaigach	0.60	5.36	2.98
30	Gunaigach	0.57	5.20	2.88
31	Tepamodhupur	17.5	21.9	19.3
32	Tepamodhupur	21.9	28.1	25.02
33	Tepamodhupur	46.8	87.8	67.3
34	Tepamodhupur	26.5	36.04	31.2
35	Tepamodhupur	46.5	86.8	66.6
36	Tepamodhupur	45.7	83.9	64.8
37	Tepamodhupur	36.9	58.6	47.7
38	Tepamodhupur	40.8	69.04	54.9
39	Tepamodhupur	50.7	102.9	76.8
40	Tepamodhupur	56.1	127.8	91.9
41	Kaunia, Balapara	25.7	34.7	30.2
42	Kaunia, Balapara	37.05	58.9	47.9
43	Kaunia, Balapara	41.6	71.2	56.4
44	Kaunia, Balapara	62.4	166.1	114.4
45	Kaunia, Balapara	51.2	104.8	77.9
46	Kaunia, Balapara	17.6	21.4	19.5
47	Kaunia, Balapara	36.3	56.9	46.6
48	Kaunia, Balapara	49.3	97.1	73.2
49	Kaunia, Balapara	34.9	53.7	44.3
50	Kaunia, Balapara	58.2	139.4	98.8
51	Chaola	44.3	79.4	61.8
52	Chaola	32.09	47.5	39.7
53	Chaola	26.1	35.4	30.7
54	Chaola	53.8	116.3	85.05

Sample No.	Location	Moisture content in dry weight basis ((b-c) ×100)/(b-a)	Moisture content in wet weight basis (M-D)100/D	Average Moisture content (%)
55	Chaola	40.7	68.6	54.6
56	Chaola	51.2	104.7	77.9
57	Chaola	29.7	42.2	35.9
58	Chaola	38.7	63.1	50.8
59	Chaola	44.2	79.2	61.8
60	Chaola	55.2	123.4	89.3

(Source: SRDI, Rangpur Division, 2021)

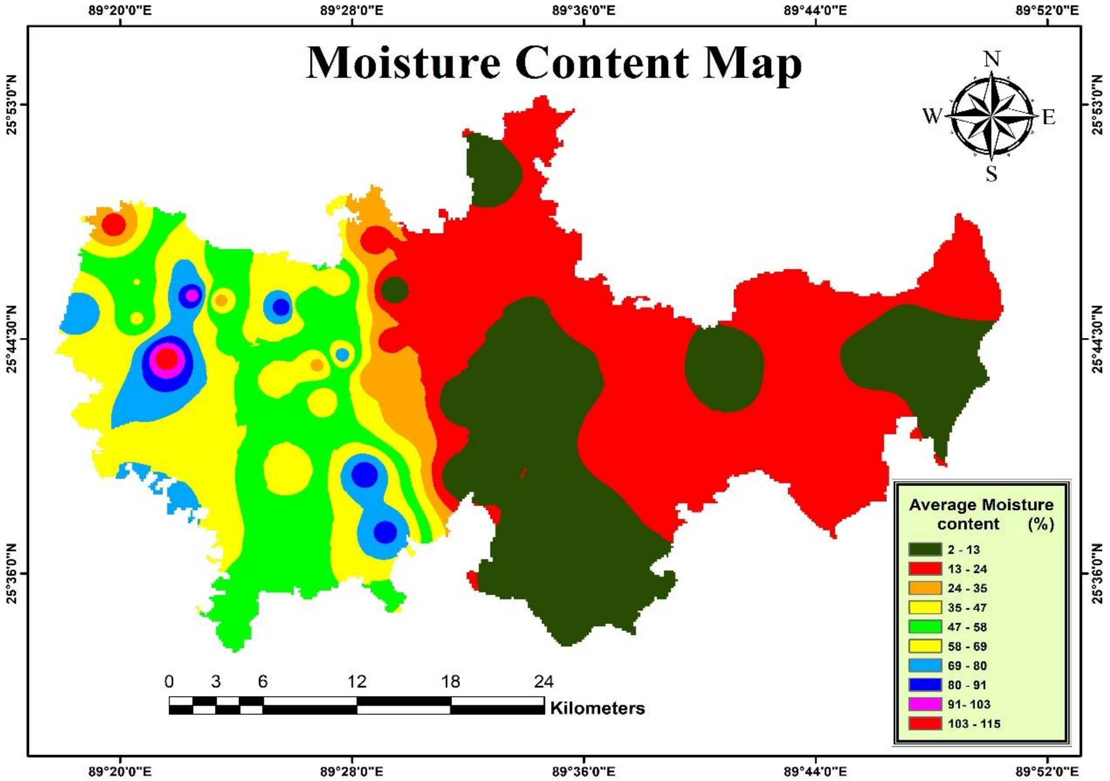

Fig. 4. Moisture content in different area

With an increase in silt and sized particles, the water holding capacity rises. The smaller particles (clay and silt) have a substantially larger surface area than the larger sand particles. Due of its large surface area, earth can hold more water. The amount of organic matter in a soil also affects its capacity to hold water. Organic matter has an affinity for water, hence a soil's capacity to hold water increases as its organic matter level does. Throughout the past century, a variety of laboratory approaches have been used to measure the capacity of soil to hold water. (Seneviratne et al., 2010; Bauer-Marschallinger et al., 2018; Stocker et al., 2018; Caldwell et al., 2018; Chew and Small, 2020)

Without using outside pressure, there are a few methods for calculating the water holding capacity. With "0 Bar" water holding capacity technique, a soil sample is saturated with water from a nearby container, maintaining the water level in the middle of the soil. Once this system has stabilized, the soil sample is weighed. The sample's capacity to hold water is calculated using the weight of the water retained in the sample in relation to the dry weight of the sample. (Bilgili et al., 2017; Barman and Choudhury, 2019)

Soil textural classification based on particle size analysis

The most crucial quality of soil is its texture. Whether the soil material is fine and smooth or coarse and textured, the term "soil texture" describes the qualitative component of the "feel" of the soil material. However, in terms of numbers, this statement refers to the observed distribution of particle sizes as well as the relative proportions of the various size ranges of particles in a particular soil. (Plante et al., 2006; Gerrit Angst et al., 2021; Liu et al., 2021)

The proportions of each class (clay, silt, and sand) in the soil are once again referred to as the "soil texture". Sands provide the mixture its structural integrity, clay holds everything together, and silt acts as a less obvious intermediary. The texture of a soil is important because it affects the soil characteristics that have an effect on plant development. Three of these characteristics are soil workability, permeability, and water-holding capacity. (Bünemann et al., 2018; Nunes et al., 2018) The ability of a soil to hold water is known as its water-holding capacity. The majority of plants require a steady supply of water from the soil. Along with water, plants also need air in their root zones. The permeability of the soil describes how easily air and water can pass through it. (Adhikari et al., 2013; Arrouays et al., 2017; Amsili et al. 2021; Wills et al., 2018)

Examples of soil work skills include the simplicity with which soil may be tilled and the effectiveness of the labor. The importance of soil structure cannot be overstated. Pends create larger pore spaces than the spacings between individual sand, silt, or clay particle. More air and water flow as well as healthy root growth are encouraged by this. The larger areas act as the animals' travel routes. The aggregates have also enhanced nutrition and water retention. (Liu et al., 2021, Liu et al., 2020; Zheng et al., 2016)

Table 4 Results of particle size analysis

Sample No.	% Sand	% Silt	% Clay	Textural Class
1	83.36	6	10.64	Loamy sand
2	42.24	45.28	12.48	Loam
3	44.24	41.28	14.48	Loam
4	42.24	45.28	12.48	Loam
5	36.24	45.28	18.48	Loam
6	48.24	36.28	15.48	Loam
7	61.47	18	20.53	Sandy Clay Loam
8	51.26	25	23.74	Sandy Clay Loam
9	54.68	32.28	13.04	Sandy loam
10	42.24	47.28	10.48	Loam
11	66.68	22.28	11.04	Sandy loam
12	60.68	29.28	10.04	Sandy loam
13	54.24	37.28	8.48	Sandy loam
14	46.24	37.28	16.48	Loam
15	62.24	25.28	12.48	Sandy loam
16	58.24	31.28	10.48	Sandy loam
17	46.24	40.28	13.48	Loam
18	80.64	9	11.36	Loamy sand
19	38.68	46.28	15.04	Loam
20	56.24	30.28	13.48	Sandy loam
21	68.68	24.28	7.04	Sandy loam
22	68.24	19.28	12.48	Sandy loam
23	56.68	26.28	17.04	Sandy loam
24	58.24	28.28	13.48	Sandy loam
25	58.24	27.28	14.48	Sandy loam
26	48.24	41.28	10.48	Loam
27	54.24	32.28	13.48	Sandy loam
28	64.68	25.28	10.04	Sandy loam
29	46.24	36.28	17.48	Loam

Sample No.	% Sand	% Silt	% Clay	Textural Class
30	79.68	11.28	9.04	Sandy loam
31	81.36	8.0	10.64	Loamy sand
32	83.36	6.0	10.64	Loamy sand
33	69.36	14.0	16.64	Sandy loam
34	65.36	18.0	16.64	Sandy loam
35	51.36	34.0	14.64	Loam
36	51.36	34.0	14.64	Loam
37	59.36	22.0	18.64	Sandy loam
38	57.36	26.0	16.64	Sandy loam
39	55.36	22.0	22.64	Sandy Clay Loam
40	73.36	8.0	18.64	Sandy loam
41	69.36	12.0	18.64	Sandy loam
42	67.36	14.0	18.64	Sandy loam
43	47.36	35.0	17.64	Loam
44	57.36	26.0	16.64	Sandy loam
45	63.36	15.0	21.64	Sandy Clay Loam
46	73.08	12.0	14.92	Sandy Loam
47	81.08	6.0	12.92	Sandy loam
48	70.08	14.0	15.92	Sandy loam
49	76.08	8.0	15.92	Sandy loam
50	73.08	12.0	14.92	Sandy loam
51	84.08	6.0	9.92	Loamy Sand
52	80.08	10.0	9.92	Loamy Sand
53	82.08	8.0	9.92	Loamy Sand
54	82.08	1.0	16.92	Sandy loam
55	82.08	9.5	8.42	Loamy Sand
56	32.08	52.0	15.92	Silt loam
57	82.08	5.0	12.92	Sandy loam
58	61.08	23.0	15.92	Sandy loam
59	52.08	35.0	12.92	Sandy Clay Loam
60	64.08	23.0	12.92	Sandy Loam

Source: SRDI, Rangpur Division, 2021

Textural element of different soil types

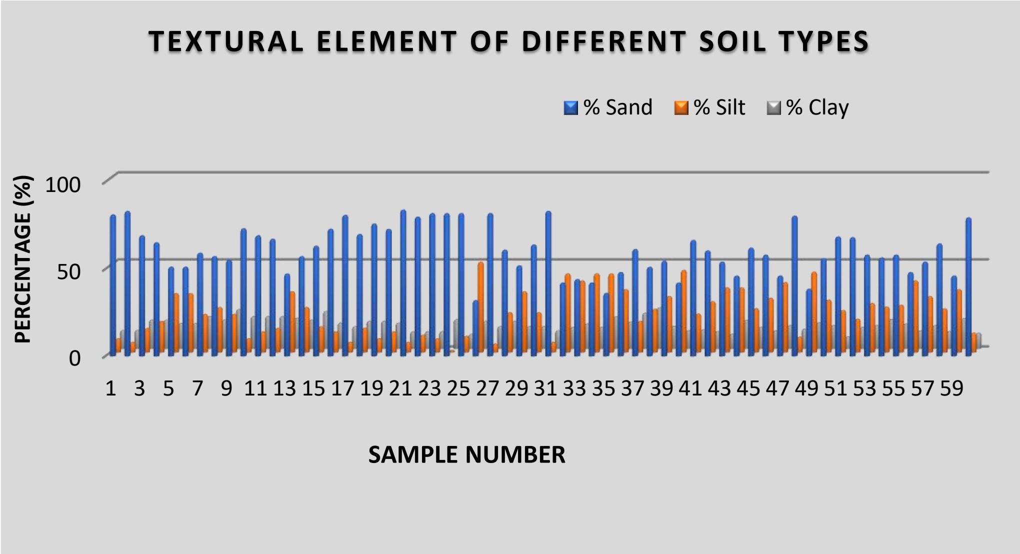

Fig. 5. Textural element of different soil types (*Source: soil texture data analysis, SRDI, Rangpur Division, 2021*)

According to the soil texture, the bar graphs display the proportional percentages of sand, silt, and clay. The amounts of sand, silt, and clay in each of the aforementioned categories genuinely vary. Big amounts of sand in a soil make it easier to work than big amounts of clay. Sandier soils are looser and easier to break up or cultivate than clay soils, which tend to be tighter. Additionally, following a rain, a clay soil takes longer to dry than a sandy soil. A sandy soil may be handled sooner due to greater drainage. A grower must wait longer for a moist clay soil to dry sufficiently.

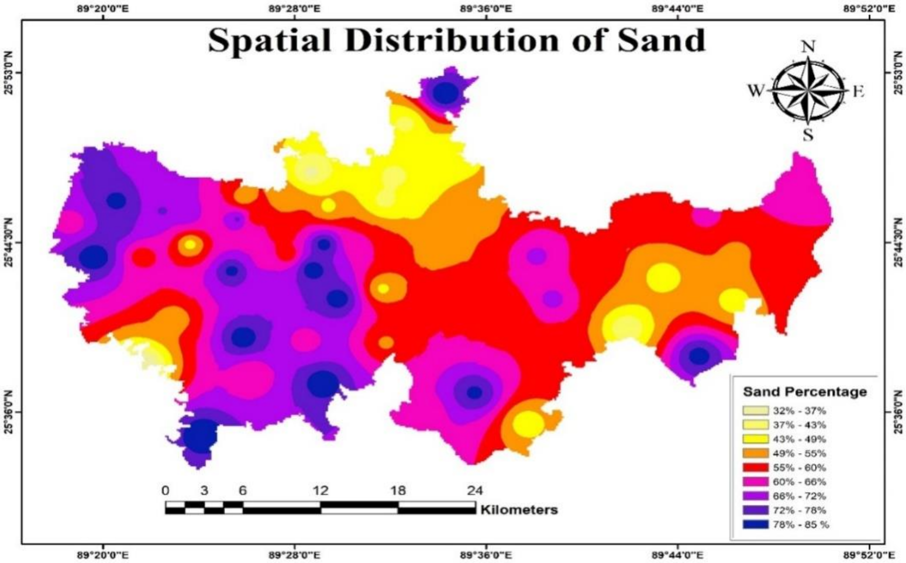

Fig. 6. Percentage of sand in different study area

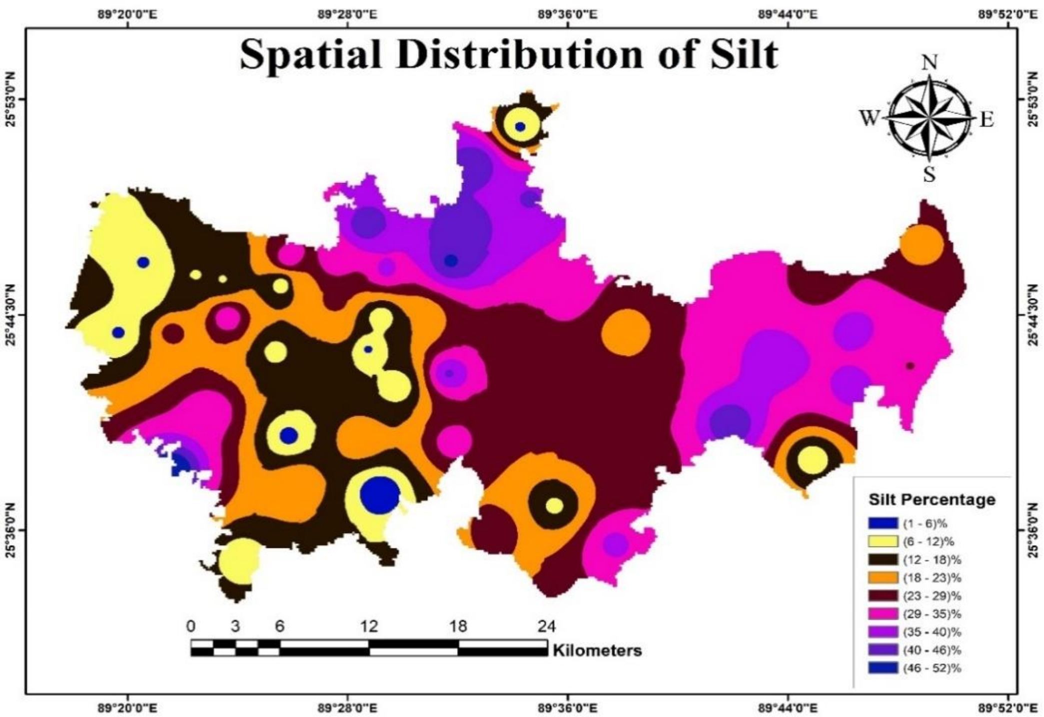

Fig. 7. Percentage of silt in different study area

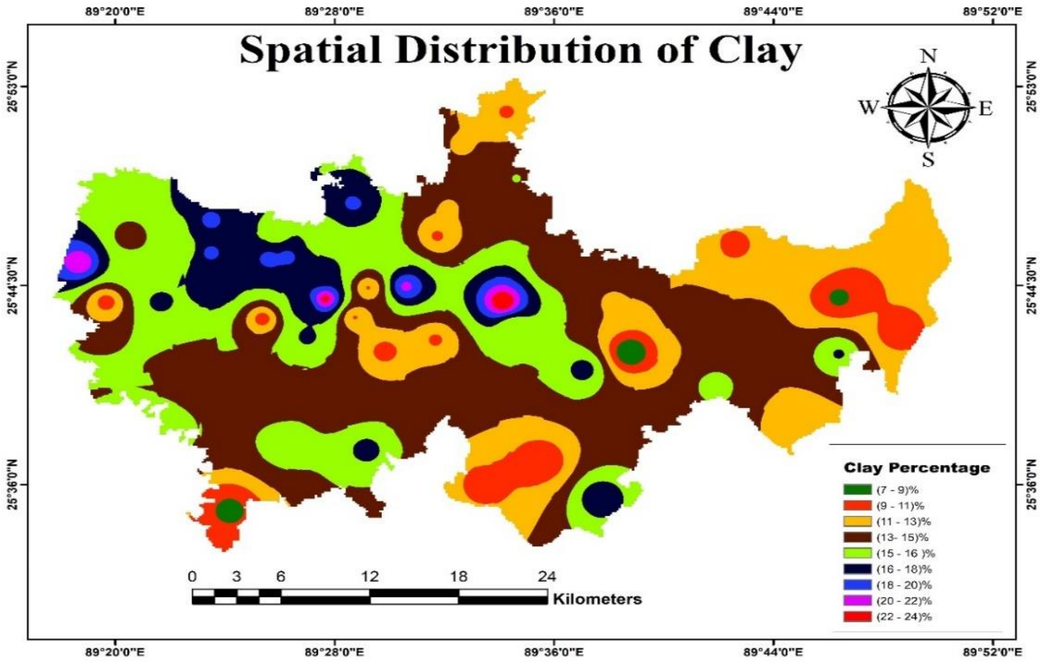

Fig. 8. Percentage of clay in different study area

River bank erosion rate identification and vulnerable zone identification based on soil moisture content, 'ROM' scale and textural element of different soil

Comparative changes of soil moisture content

To analyze the comparative changes of soil moisture level firstly 100 milliliter of water has been added in each soil sample. Then the soil sample has been weighted and final reading is collected.

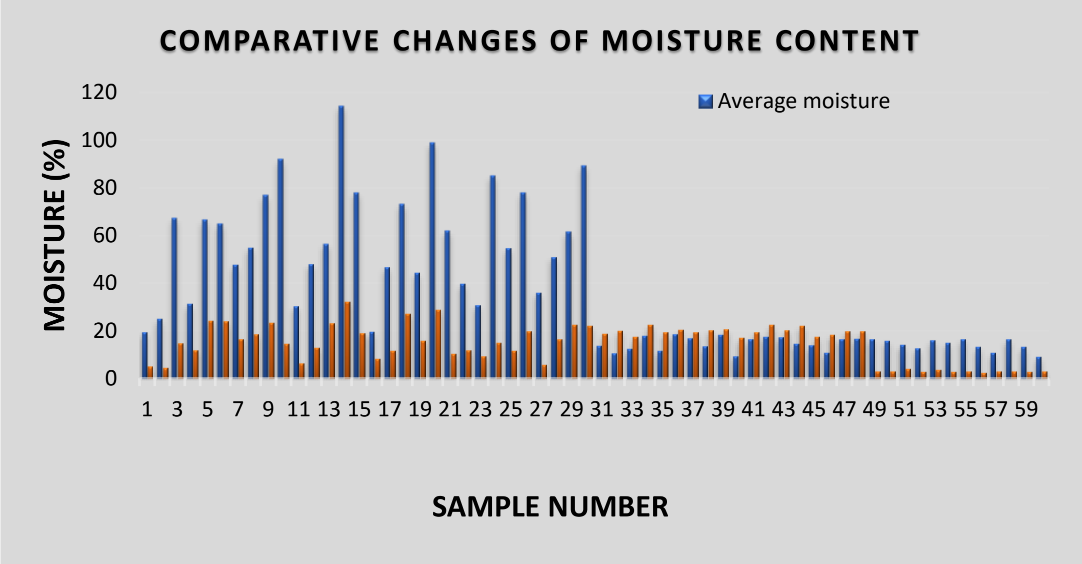

Fig. 9. Comparative changes of soil moisture content (*Source: Soil sample data analysis*)

Then the final value was subtracted from the initial value and changes of soil moisture have been found. From the above figure it has been found that the high moisture level change has occurred in sample 5,6,9,13,18,20 and 30 which have been collected from different location of three unions. From those samples 5,6 and 13 have fallen in loam category; sample 18,20 and 30 has fallen in sandy loam category; and sample 9 has fallen in sandy clay loam category.

Soil texture influences the characteristic soil water curve due to differences in the particle composition. The higher the soil clay content, the slower the water infiltration and the smaller the scope of the wetting body, which in turn increases the soil moisture content and soil moisture retention (Zhang et al., 2023). Wang et al., 2020), in their research showed that the soil moisture content of clay and loam in different soil layers was significantly higher than that in sandy soil; thus, compared with sandy soil, loam has better water retention. (Luo et al., 2010; Wang et al., 2020)

Comparison of average soil moisture content (%) in each soil type of Rajarhat and Ulipur Upazila

Table 5 Average soil moisture content (%) in each soil type

Soil types	Average moisture content (%)
Sandy loam soil	38.11
Loamy sand soil	40.29
Sandy clay loam soil	38.29
Loam soil	40.17

Source: Soil moisture data analysis (SRDI, Rangpur Division, 2021

In Sandy Loam soil that has been collected from Gharialdanga (Sample 9), Daldalia (Sample 11,12,13 and 15), Thetrai (Sample 16 and 20), Bazra (Sample 21,22,23,24 and 25), and Gunaigach (Sample 27,28 and 30) average moisture content is lower than loam soil by 2.06%, loamy sand soil by 2.18% and sandy clay loam soil by 0.18%. In Loam soil that has been collected from Bidyanando (Sample 2,3,4 and 5), Gharialdanga (Sample 6 and 10), Daldalia (Sample 14), Thetrai (Sample 17 and 19), Bazra (Sample 21,22,23,24 and 25), and Gunaigach (Sample 26 and 29) average moisture content is lower than loamy sand soil by 0.12%, Higher than sandy loam soil by 2.06% and sandy clay loam soil by 1.88%.

In Loamy sand soil that has been collected from Bidyanando (Sample 1), Thetrai (Sample 18), and average moisture content is higher than sandy loam soil by 2.18%, loam soil by 0.12% and sandy clay loam soil by 2%. In Sandy clay loam soil that has been collected from Gharialdanga (Sample 7 and 8) average moisture content is higher than sandy loam soil by 0.18%, Lower than loam soil by 1.88% and loamy sand soil by 2%.

According to various studies (Zhang et al., 2008), the clay has fine soil particles, producing a large surface area and large water absorption capacity. In contrast, sandy soil has a high sand content, which was conducive to water penetration.

The least amount of water was accessible and the soil drought index increased in coarse textured soils. Previous studies on the impact of texture on soil physical properties came to the conclusion that the addition of organic matter can greatly increase the soil's ability to store water when the sand content of the soil is between 30 and 70 percent (Wang et al., 2019). The thermal characteristics of soils with various textures and soil water suction have a good quantitative relationship.

Comparison of average soil moisture content (%) in each soil type of Kaunia and Pirgacha Upazila

Table 6 Average soil moisture content (%) in each soil type

Soil types	Average moisture content (%)
Sandy loam soil	79
Loamy sand soil	47.7
Sandy clay loam soil	81.6
Loam soil	86.3
Silt loam soil	97.8

Source: Soil moisture data analysis (SRDI, Rangpur Division, 2021

In sandy loam soil which has been collected from Tepamadhupur (Sample 3,7,8 and 10), Kaunia Balapara (Sample 11,12,14,16,17,18,19 and 20), Chaola (Sample 24,27,28 and 30) average moisture content is lower than sandy clay loam soil by 2.6%; loam soil by 7.3%; silt loam soil by 18.8; but higher than loamy sand soil by 31.3%.

In sandy loam soils, sand is the principal component, but there is also a sufficient amount of clay and silt to provide the soil some structure and fertility. There are four basic types of sandy loam soil based on the size of the sand particles in the soil. There are four divisions of sandy loam soils: coarse sandy loam, fine sandy loam, sandy loam, and very fine sandy loam (Renard et al.; 1996; Wang et al., 2022). The millimeter size of the sand particles and their concentration in the soil determine the classification of the soil. Sandy loam soils are composed of 60% sand, 10% clay, and 30% silt particles (Horn et al., 1994). In loamy sand soil that has been collected from Tepamadhupur (Sample 1 and 2), Chaola (Sample 21,22,23 and 25) average moisture content is lower than sandy loam soil by 31.3%; loam soil by 38.6%; silt loam soil by 50.1%; and sandy clay loam soil by 33.9%.

In sandy loam soils, sand is easily identifiable. Sand and loamy soils can be broken yet still retain their original form. Sand makes up a large portion of sandy loam soils, giving them a gritty texture. The excess water from lawns and gardens can be quickly drained away by sand and loam soils, but they are unable to hold much water or nutrients for your plants. Plants growing in this type of soil will require more frequent watering and fertilizing compared to soils with a higher percentage of clay and silt. To maintain robust plant development, specific micronutrient shortages in sandy loam soils may require additional fertilization (Talukder, 2012). In sandy clay loam soil that has been collected from Tepamadhupur (Sample 4,9), Kaunia Balapara (Sample 15), Chaola (Sample 29) average moisture content is lower than loam soil by 4.7%; silt loam soil by 16.2%; and higher than sandy loam soil by 2.6%; higher than loamy sand soil by 33.9%.

Clay loam soil mixture has more clay than any other kinds of rock or mineral. The soil type that makes up the majority of a loam's structure is called that soil combination. The small particle size of clay is one of its most notable characteristics. Loams containing a lot of clay have a propensity to be heavy due to their high density. It may be difficult to deal with this type of soil, but it may also be improved to be a very effective growing medium. The density of the clay is what causes the two main issues with clay loam. When it gets extremely wet, it becomes difficult to handle because it expands to hold the water. Over time, this poor drainage may also hinder the growth of plants. Dry clay shrinks but does not release its packing, forming tight clods and cracking the soil's surface. These issues can be reduced by gradually introducing organic material. (Haines, 1930; Wright and Upadhyaya, 1998)

In loam soil that has been collected from Tepamadhupur (Sample 5 and 6), Kaunia, Balapara (Sample 13), average moisture content is lower than silt 11.5%, and higher than sandy loam soil by 7.3%; loamy sand soil by 3 8.6%, sandy clay loam soil by 4.7%. The three components that make up loamy soil's texture are silt, sand, and clay. These elements are combined with organic matter, water, and air to form loam soils. According to government estimates, loam comprises between 7 and 27% clay, between 28 and 50% silt, and between 52 and 50% sand. When sand makes up a larger fraction of the combination, loam is referred to as sandy loam. If there is more clay present, it is referred to as clay loam. As long as the proportions of the spectrum of diverse textures are preserved, the soil is considered to be a type of loam.

In Silty loam soil that has been collected from Chaola (Sample 26), average moisture content is higher than sandy loam soil by 18.8%, loamy sand soil by 50.1%, sandy clay loam soil by 16.2%, loam soil by 11.5%. The term "silt loam" describes the topsoil's texture. It describes a type of soil texture that feels loamy when damp soil is rubbed between the thumb and fingers and is primarily made up of silt-sized particles (0.05 to 0.002 mm). (Sudarsan et al., 2018)

As can be observed, silt loam soil has a higher overall moisture content than other types in each calculation. In general, silt loam soil has a lower rate of bank erosion than any other form of soil. While silt loam soil has a higher overall moisture content than loamy sand soil, sandy loam, loam soil, and sandy clay loam all have lower overall moisture content. Therefore, the total rate of bank erosion is of a modest nature. In contrast to other soil types, loamy sand soil has the lowest overall moisture content. In general, loamy sand soil has a higher rate of bank erosion than any other type of soil. (Kaya et al., 2022)

3.2. Determination of erodibility index by using 'ROM' scale

After finding the percentage of sand, silt and clay and using the equation or relation (ii) the ROM scale erodibility index for all locations are determined and soil erodibility category are assigned as per Table 4 and all these results are tabulated in Table 6.

Table 6 Assessed value of ROM index and erodibility category of all locations

Union	Sample No.	% Sand	% Silt	% Clay	$EI_{ROM} = \frac{\%Sand + \%Silt}{2(\%Clay)}$	Erodibility category in different union
Tepamadhupur	1	81.36	8.0	10.64	4.2	2.78
	2	83.36	6.0	10.64	4.2	Moderate
	3	69.36	14.0	16.64	2.5	
	4	65.36	18.0	16.64	2.5	
	5	51.36	34.0	14.64	2.9	
	6	51.36	34.0	14.64	2.9	
	7	59.36	22.0	18.64	2.2	
	8	57.36	26.0	16.64	2.5	
	9	55.36	22.0	22.64	1.7	
	10	73.36	8.0	18.64	2.2	
Kaunia, Balapara	11	69.36	12.0	18.64	2.2	2.54
	12	67.36	14.0	18.64	2.2	Moderate
	13	47.36	35.0	17.64	2.3	

Union	Sample No.	% Sand	% Silt	% Clay	$EI_{ROM}= \frac{\%Sand + \%Silt}{2(\%Clay)}$	Erodibility category in different union
	14	57.36	26.0	16.64	2.5	
	15	63.36	15.0	21.64	1.8	
	16	73.08	12.0	14.92	2.9	
	17	81.08	6.0	12.92	3.4	
	18	70.08	14.0	15.92	2.6	
	19	76.08	8.0	15.92	2.6	
	20	73.08	12.0	14.92	2.9	
Chaola	21	84.08	6.0	9.92	4.5	3.68
	22	80.08	10.0	9.92	4.5	Moderate
	23	82.08	8.0	9.92	4.5	
	24	82.08	1.0	16.92	2.5	
	25	82.08	9.5	8.42	5.4	
	26	32.08	52.0	15.92	2.6	
	27	82.08	5.0	12.92	3.4	
	28	61.08	23.0	15.92	2.6	
	29	52.08	35.0	12.92	3.4	
	30	64.08	23.0	12.92	3.4	
	31	83.36	6	10.64	4.2	
Bidyanando	32	42.24	45.28	12.48	3.5	3.26
	33	44.24	41.28	14.48	2.9	Moderate
	34	42.24	45.28	12.48	3.5	
	35	36.24	45.28	18.48	2.2	
	35	48.24	36.28	15.48	2.7	
Gharialdanga	37	61.47	18	20.53	1.9	2.76
	38	51.26	25	23.74	1.6	Moderate
	39	54.68	32.28	13.04	3.3	
	40	42.24	47.28	10.48	4.3	
	41	66.68	22.28	11.04	4	
	42	60.68	29.28	10.04	4.5	
Daldalia	43	54.24	37.28	8.48	5.4	3.98
	44	46.24	37.28	16.48	2.5	Moderate
	45	62.24	25.28	12.48	3.5	
	46	58.24	31.28	10.48	4.3	
	47	46.24	40.28	13.48	3.2	
Thetrai	48	80.64	9	11.36	3.9	3.48

Union	Sample No.	% Sand	% Silt	% Clay	$EI_{ROM}=\frac{\%Sand+\%Silt}{2(\%Clay)}$	Erodibility category in different union
	49	38.68	46.28	15.04	2.8	Moderate
	50	56.24	30.28	13.48	3.2	
	51	68.68	24.28	7.04	6.6	
	52	68.24	19.28	12.48	3.5	
Bazra	53	58.24	28.28	13.48	3.2	3.72
	54	56.68	26.28	17.04	2.4	Moderate
	55	58.24	27.28	14.48	2.9	
	56	48.24	41.28	10.48	4.3	
	57	54.24	32.28	13.48	3.2	
Gunaigach	58	64.68	25.28	10.04	4.5	3.88
	59	46.24	36.28	17.48	2.4	Moderate
	60	79.68	11.28	9.04	5	

The results obtained from particle size analysis are put in the EIROM equation to find the ROM values for different location to categorize the erodibility. The new improved ‘ROM’ scale reveal that if the percentage of clay is more than 20 % then the soil erodibility category will be low. In our case soil that has been collected from Tepamadhupur (Sample 9), Kaunia, Balapara (Sample 15) is found with clay content more than 20% and hence these locations with soil erodibility category low is obtained. Out of considered thirty locations most of the locations are of moderate category of erosion.

According to Table 6, the majority of the locations had soil that included less than 20% clay, meaning that the river bank was only slightly susceptible to erosion or collapsing into the river. Since clays are pastier and stickier than other materials, they may provide a "adhesive pattern" to soil particles that are interlocking, which is the logical explanation for this result. (Ahmadi et al., 2011; Ghosh and Sahu, 2022) In any case, the majority of soil samples contained a modest number of sand textures, which means that the pace of soil erosion is unquestionably moderate. This is because the sand texture can't support or hold the river bank in place when it is subjected to torrential rain or is affected by river flow. (Das et al., 2014; Abidin et al., 2017)

3.3. Risk categorization of different union

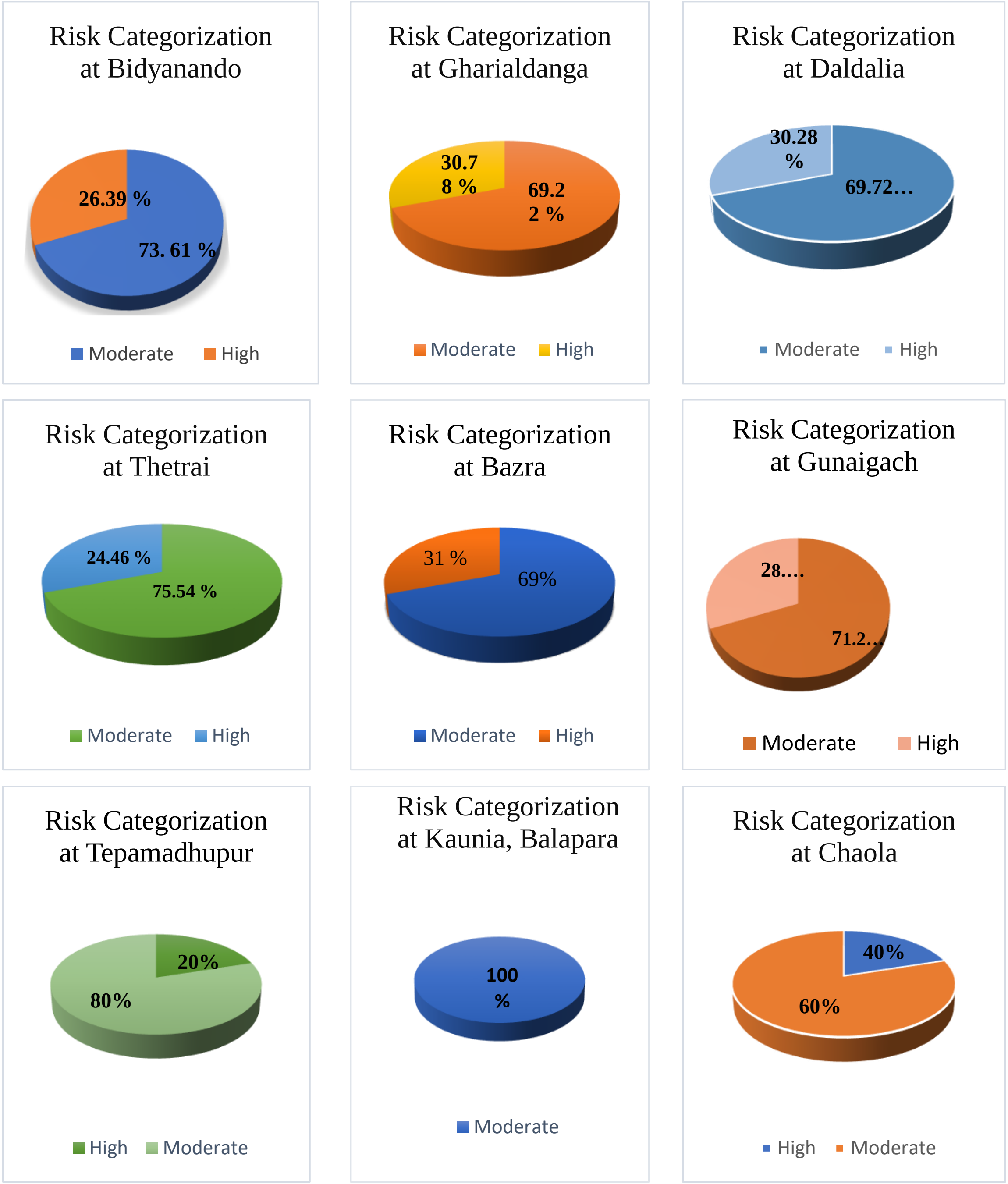

Fig. 10. Percentage of erosion risk level at different union

Two unions of Rajarhat Upazila; Bidyanando and Gharialdanga were connected with the Teesta River. So, the riverbank of these two unions was taken for the research area. Soil erodibility risk at Bidyanando union were 26.39% indicated as high and 73.61% indicated as moderate, and at

Gharialdanga union were 30.78% indicated as high and 69.22% moderate. As in the time of collecting soil sample a physical survey was conducted on the study area. The respondents stated that river bank erosion is occurring comparatively every year. Erosion rate depends on the climatic condition of that area as; heavy rainfall, river current velocity, dry season etc. Intensity of bank erosion is higher in Gharialdanga than Bidyanando union. Soil characteristics have an impact on the erosion rate.

Erodibility Risk at Daldalia union were 69.73% high which was greater than Thetrai and Bazra union, Lower than Gunaigach union, 30.28% moderate which was greater than Gunaigach union and lower than Thetrai and Bazra union. At Thetrai union, soil erodibility risk were 24.46% high which was lower than Daldalia, Bazra and Gunaigach union, and 75.54% indicated as moderate which was greater than Daldalia, Bazra and Gunaigach union. Bazra union were 35.30% high which was greater than Thetrai union and Lower than Daldalia and Gunaigach union, and 64.70% moderate which was greater than Daldalia and Gunaigach union. Gunaigach union were 71.22% high which is greater than Daldalia, Thetrai and Bazra union, and 28.78% moderate which was lower than Daldalia, Thetrai and Bazraunion. So we can say that Gunaigach union is more vulnerable than other three unions.

Soil sample that has been collected from Tepamodhupur Union (Sample 1-10) here 80% area are moderately eroded and the above figure also illustrated that 20% of the location are highly eroded. The above figure illustrated that soil sample that has been collected from Kaunia, Balapara Union (Samples 11-20) are moderately eroded and no location with soil erodibility category low is obtained. Soil sample that has been collected from Chaola Union (Samples 21-30) here 40% area are highly eroded, no location with soil erodibility category low is obtained 60% are moderately eroded. Researchers Chakraborty and Saha (2022) found that non-cohesive bank material, such as coarse sand, causes the most erosion and causes the channel bank to broaden and recede.

These results confirmed those of Hasan et al. (2018), who claimed that sandy soil along riverbanks with high moisture content are typically loose and that one of the major contributing factors to soil erosion along riverbanks is soil properties that are unstable and have low shear strength due to the presence of coarse sand. The results of this research are also compatible with those of Majumdar and Mandal (2020), who investigated the erodibility analysis of soil of Ganga river and reported that the level of soil erodibility become low to moderate because of the presence of high percentage of sand particles.

The EIROM equation is used to calculate the ROM values for various locations in order to categories the erodibility using the data from the particle size study. Due to the highest value reported as a moderate degree of erosion risk under the "ROM" scale categorization, Chaola Union was determined to have the highest potential for riverbank erosion danger. It indicates that the soil was very erodible in Chaola Union. The Kaunia Balapara union's moderate degree of erosion danger, meanwhile, was at its lowest point since the ROM was just 2.54 at the time.

4. Conclusions

Riverbank erosion, a serious natural calamity that is displacing thousands of people, has been stressing Bangladeshis, especially those in the study region. Although it occurs naturally in stable rivers, bank erosion may be hastened and made worse by both direct and indirect human activities. The soil moisture content rate, which exhibits varying values in various soil samples and describes soil compaction rate and chance of affecting soil deformation, is one of the study's most significant discoveries.

All values from the result refer loamy sand and sandy loam soil as more likely of being eroded because of lower content of soil moisture. One of the significant root causes of soil erosion at riverbank side is soil properties not being stable due to presence of course sand.It can be seen that the overall moisture content of Silt loam soil is higher than other type in each calculation. So generally the bank erosion rate of silt loam soil is lower than any other soil type. On the other hand overall moisture content of sandy loam, loamy soil, and sandy clay loam soil is lower than silt loam soil but higher than loamy sand soil. So the overall bank erosion rate is moderate in nature. At the same time the overall moisture content in loamy sand soil is lower than any other soil type. So generally the bank erosion rate of loamy sand soil is higher than any other soil type. The likelihood of an earthen river bank failing is influenced by a number of geotechnical factors, including water content, plasticity index, untrained shear strength, mean grain size, percent passing, soil clay minerals, soil dispersion ratio, water salinity, soil pH, and water pH. Due to the presence of coarse sand, soil characteristics are unstable, which is one of the major reasons of soil erosion along riverbanks.

Prediction of the resilience of a river bank against erosion can be done by the well-established and incredibly straightforward way that is to gauge erosion severity based on soil composition is the EIROM equation. Following an analysis of the data, it was discovered that while this method provides very effective results in identifying highly erosion-prone areas, already high erosion-prone areas are displayed or identified as very high and critical—it exaggerates the results when it comes to areas with less erosion by assigning a moderate category rather than a low one. Since correctly identifying erosion-hazardous places is our first priority.

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Riverbank erosion and human mobility: An insight from the bank of Padma River, Bangladesh

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Abstract

The riverbank erosion is widespread along the central river systems in Bangladesh and is one of the silent tragedies of the nearby people. The present study evaluates riverbank erosion along the left bank of the mighty Padma River in Charghat and Bagha Upazilas (sub-districts) of Rajshahi District. The mixed-method research approach has been adopted in this research. In the study area, approximately 7297 hectares of bank land have eroded during the past 40 years, starting in 1975, according to an examination of remote sensing data. The Pakuria and Gargari Unions, estimated to be 5392 hectares in size and making up 74% of the overall degraded land, were under serious threat from erosion in 2015. The primary reasons for the left bank erosion include excessive channel sedimentation and changes in flow directions brought on by the negative impacts of the Farakka barrage. The survey identifies riverbank erosion as a big catastrophe in the region; while most of the residents observed that the river's path is changing, they identified flood as a severe disaster. Riverbank erosion was highlighted by the majority of residents of the study area as having an impact on their livelihood. Additionally, 100% of respondents stated that the economic crisis (95%) has increased poverty levels due to migration and housing instability, loss of farms and crops, loss of original location, and loss of property. The severe effects of the Padma River's left bank erosion include a reduction in children's educational opportunities (85%) and a 9% increase in food insecurity. Finally, this research would help formulate any erosion-related management and policy implications that will mitigate the erosion.

Keywords: River erosion, human migration, livelihood, remote sensing, Padma River

1. Introduction

1.1. Background

Riverbank erosion is the wearing away of the banks of a stream or river. When rivers enter the mature stage, they become sluggish, meander, or braided. These oscillations cause massive riverbank erosion. It affects the areas near rivers globally, and the common impacts are the property damage and displacement of the nearby people. In Bangladesh, riverbank erosion is one of the most frequent but unpredictable hazards yearly and causes people's economic damages and displacement and forces them to migrate to another place from their native place (Elahi, 1991; Mutton and Haque, 2004; Rahman and Gain, 2020).

The river known as the Ganges in India bears the name ‘Padma River’ once it enters Bangladesh. Its source lies in the Western Himalayas of India, and as it enters the Chapai Nawabganj district from India, it eventually joins the Jamuna River and the Meghna River in Chandpur district, Bangladesh. Upon reaching the Meghna estuary, it adopts the name ‘Meghna’ and ultimately flows into the Bay of Bengal. Throughout its lengthy course, the Padma River causes erosion to numerous bank lines, creating several channel bars. Unfortunately, certain bank lines are particularly vulnerable to erosion, posing potential threats to the surrounding areas (Haque and Zaman, 1989). Notably, Charghat Upazila and Bagha Upazila in Rajshahi district are at a higher risk of riverbank erosion.

Research on Charghat and Bagha Upazila has been quite limited, with only a few studies exploring some socioeconomic aspects in Bagha Upazila. Therefore, this study aims to investigate the spatial pattern of riverbank transformation and to investigate the relationship between riverbank erosion and human mobility in Bagha and Charghat Upazila, Rajshahi, Bangladesh. The specific objectives of this study are- (1) To investigate the spatial and temporal patterns of riverbank erosion in the study area and (2) To explore the nexus among riverbank, socio-economic impact and human mobility. The research will utilize a combination of GIS, Remote Sensing, and Qualitative approaches to gain a comprehensive understanding of the situation.

1.2. Study Area

The study area, illustrated in Fig. 1, includes Charghat and Bagha Upazilas, situated in Rajshahi district, located in the north-western region of Bangladesh (Fig. 1). Charghat Upazila is positioned at approximately 24.2833°N latitude and 88.7750°E longitude, encompassing an area of approximately 164.52 square kilometers. Conversely, Bagha Upazila is situated between 24.1917°N latitude and 88.8333°E longitude, covering around 184.25 square kilometers. Bagha Upazila shares its boundaries, where it borders Charghat Upazila to the south, Puthia, and Paba

Upazilas to the north, Bagha and Bagatipara Upazilas (Natore District) to the east, and Paba Upazila of Rajshahi District and West Bengal State of India to the west. Similarly, Bagha Upazila is surrounded by Daulatpur Upazila (Kushtia District) to the south, Bagatipara Upazila (Natore District), and Charghat Upazila to the north, and Lalpur and Bagatipara Upazilas of Natore district to the east, while it shares its western border with West Bengal State of India.

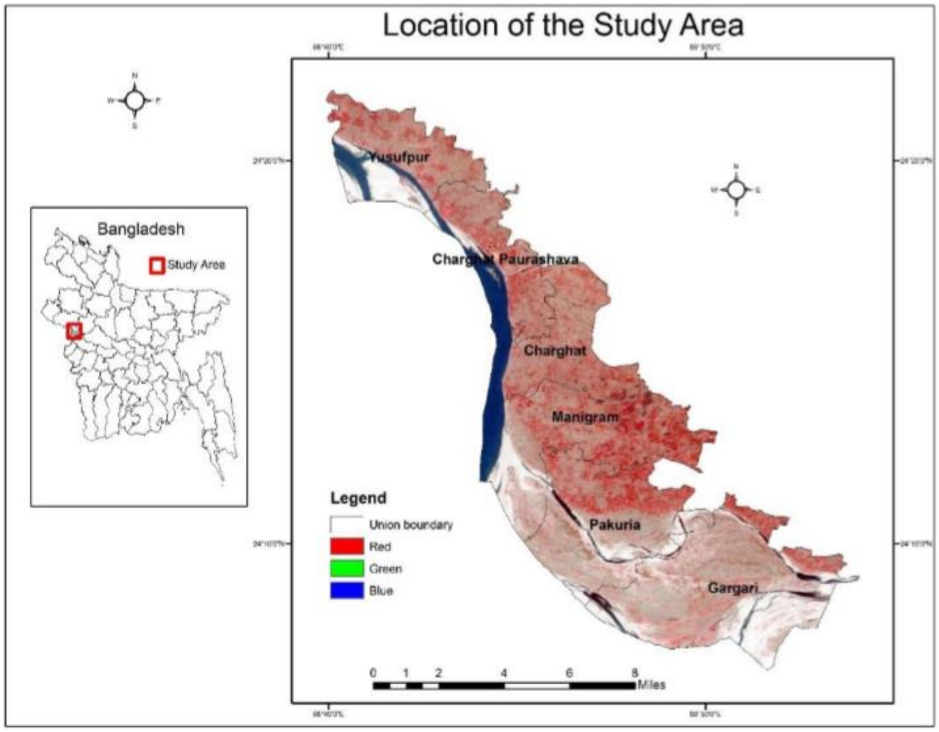

Fig. 1. Study area.

1.3. Literature review

In 2018, Billah conducted a research project in the Padma River of Bangladesh, employing Remote Sensing (RS), Geographic Information System (GIS), and various statistical data techniques. The study explored the riverbank erosion and accretion, track the changing pattern of the river's bank line, and measure alterations in the area of islands over a period of time.

Mollah and Ferdaush (2015) conducted a study in the Kazipur Upazila of the Sirajganj District. Their main objectives were to assess the number of climate-induced migrants, specifically related to riverbank erosion, and to determine the rate of migration. Additionally, they maped and analyzed the vulnerability of the study area to riverbank erosion.

Dewan et al. (2017) studied the changes in the Ganga Padma River system in Bangladesh using Landsat images and flow data from 1973 to 2011. The main objective was to analyze the river's plan form dynamics. They investigated bank line movements, channel patterns, erosion, deposition, flood impacts, and utilized GIS for analysis. The study revealed a balance between erosion and accretion on both riverbanks, with a slight tendency towards the right bank. The Ganges River's width also varied during the studied period.

In 2015, Hazarika and colleagues conducted a study in the Gai and Simen tributaries of the Brahmaputra River in Assam, India. Their research focused on evaluating land-use changes driven by river dynamics and reconstructing historical channel movements using historical maps and satellite imagery. Moreover, the study quantified erosion and deposition processes. The findings revealed an increasing utilization of floodplains for various human activities, with agriculture being a significant contributor to this trend.

Akter et al. conducted a study in 2017, specifically focusing on the Kazipur to Sirajganj Hardpoint region. Their research involved mapping and monitoring changes in river flow, examining riverbank erosion, and determining the universal erosion coefficient. They also calculated the erosion rate in the study area. This study's findings are valuable for predicting erosion scenarios in any river, providing essential insights to facilitate precautionary measures against the risks of riverbank erosion.

Guite et al. (2016) conducted their research in the Lower Subansiri River Flood Plain, encompassing the Jorhat, Lakhimpur, and Dhemaji districts. The study aimed to map the land cover, mark the bank lines, and evaluate the extent of land loss by observing areas with severe bank erosion and analyzing Surface/Hydrology through satellite image processing using GIS software. The research revealed significant changes in agricultural and forested regions, particularly regarding the loss of land. Increased erosion has led to changes in the amount of agricultural land. However, this study specifically focused on investigating changes in forest and land cover.

Islam et al. conducted a research study in 2017 in five villages located in the Mymensingh district along the Brahmaputra River. The objective of the study was to examine the impact of the Brahmaputra riverbank erosion on the livelihood patterns, agriculture, and environment of the local population. The research employed various methods, including a semi-structured questionnaire, interviews, secondary data sources, field observations, and focus group discussions. The findings of this study demonstrated the significant influence of erosion on livelihood, agriculture, environment, and other sectors. It emphasized the importance of the government and non-profit organizations taking personal responsibility for addressing the dire situation caused by riverbank erosion.

Rahman and Gain (2020) investigated that riverbank erosion in the Koyra riverine area of Khulna district has significant adverse impacts on people's livelihoods, leading to economic, social, and psychological distress. The communities in Dakshin Bedkashi, Choramukha, and Ghorilal villages are highly vulnerable to the effects of erosion, resulting in internal displacement and fragile economic conditions. The study utilized mixed research methods to gather data, revealing the extent of damage caused by erosion, such as full house destruction and loss of land. Livelihoods have been severely affected, and coping strategies include reducing meals and taking on additional work. The paper highlights riverbank erosion as a causal factor for migration and socio-economic hindrances. The affected people often migrate to safer places temporarily and later relocate permanently for survival.

Table 1: The satellite imageries information used in the study are summarized in the table below:

Landsat	Row/Path	Year	Resolution (Meters)	Projection
Landsat 8-9 OLI/TIRS	043/138	1990	30	UTM/WGS 84
Landsat 7 ETM+	043/138	2000	30	UTM/WGS 84
Landsat 4-5 TM	043/138	2010	30	UTM/WGS 84
Landsat 1-5 MSS	043/138	2020	30	UTM/WGS 84

2. Data Source and Methods

This research utilized four multi-date Landsat imageries from 1990 (TM), 2000 (TM), 2010 (TM), and 2020 (TM). These imageries had a resolution of 30 meters and were projected with the Universal Transverse Mercator (UTM) system, specifically in zone 46N. The geospatial data in the study employed the World Geodetic System WGS84 datum. The Landsat imageries were obtained from the United States Geological Survey (USGS) website to analyze riverbank erosion. Satellite images proved effective in identifying the study area. To mask the study area during digital image processing, an Upazila shape file was obtained from the DIVA-GIS website.

The study utilized satellite images from 1990, 2000, 2010, and 2020, with various reflective bands, to process, classify, and analyze the scenery of the Padma Riverbanks in Charghat and Bagha Upazila. The main focus was on investigating riverbank erosion-accretion changes using GIS and digital image processing techniques. Normalized Difference Water Index (NDWI) and unsupervised classification methods were employed to distinguish water bodies from land features and to demarcate the river lines/banks in the images through ArcGIS 10.8. This approach aimed to identify dynamic changes and erosion-accretion patterns over the past 30 years. NDWI method is an index for delineating and monitoring content changes in surface water. It is computed with the NIR and green bands. NDWI is used for the identification of water bodies.

The NDWI is a remote sensing-based indicator sensitive to the change in the water content of leaves (Ji, Zhang and Wylie, 2009).

$$\text{NDWI} = (\text{Green} - \text{NIR}) / (\text{Green} + \text{NIR})$$

The following bands of Landsat TM 5 imageries were used to calculate NDWI.

$$\text{NDWI} = (\text{Band 2} - \text{Band 4}) / (\text{Band 2} + \text{Band 4})$$

At the same time, the following bands of Landsat TM 8 imageries were used to calculate NDWI.

$$\text{NDWI} = (\text{Band 5} - \text{Band 4}) / (\text{Band 5} + \text{Band 4})$$

Apart from the geospatial approach, others approach such as field observation, interviews with local populations and focus group discussions were carried out to understand the research problem deeply. Extensive data analysis has been done using ArcMap and Microsoft Excel. The analyzed data were visualized as maps and diagrams.

3. Result and Discussion

3.1. Erosion, accretion and extent Analysis

The riverbank erosion was identified using the 1990, 2000, 2010, and 2020 Landsat images. However, NDWI identified the water bodies from the land area and then identified the riverbank line from satellite images through unsupervised classification. Here calculated, the erosion, accretion and unchanged river area from the extracted river area and at last generated erosion accretion and unchanged area and bank line changing maps of those 30 years of the study area.

3.1.1. Erosion, accretion and extent from 1990 to 2000

From 1990 to 2000, the erosion rate surpassed the accretion rate (fig. 2). The erosion rate during this period was 9.54752 sq. km, while the accretion rate was 6.21362 sq. km, and the unchanged area measured 12.35574 sq. km. Although the eroded area exceeded the accretion area, the unchanged river area was greater than the eroded portion. However, the erosion percentage increased further in the following ten years. The riverbank erosion was significantly impacted by the floods in 1988 and 1998.

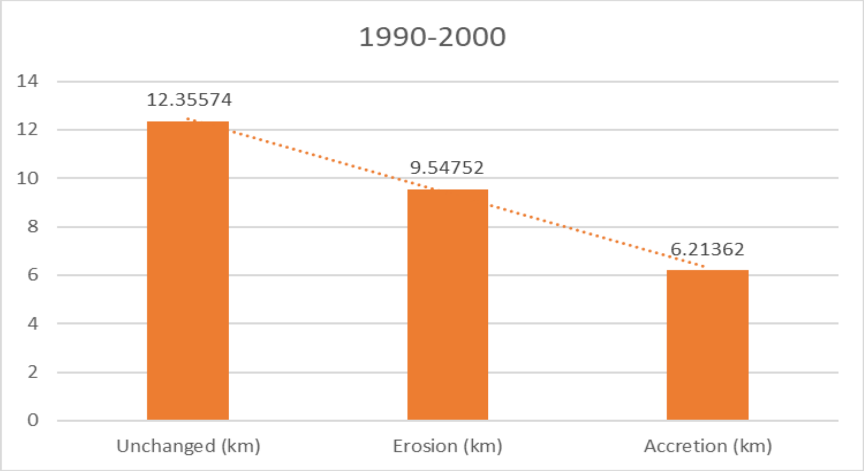

Fig. 2. Erosion, accretion and unchanged area between 1990 and 2000.

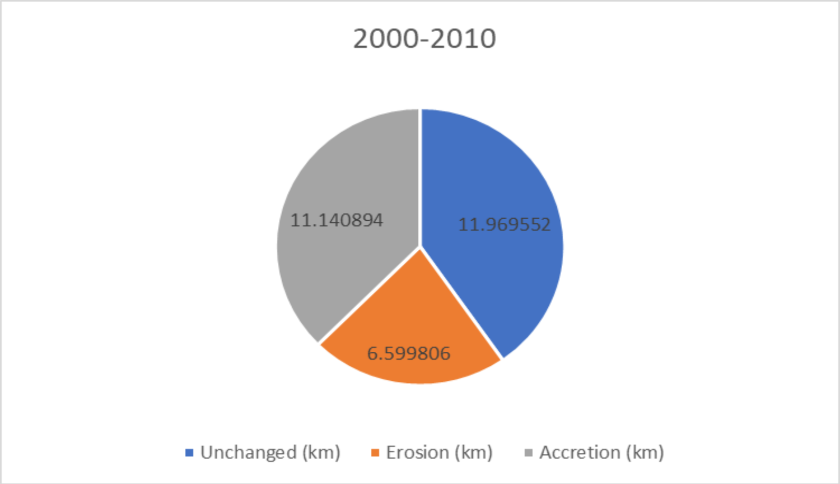

Fig. 3. Erosion, accretion and unchanged area between 2000 and 2010.

3.1.2. Erosion, accretion and extent from 2000 to 2010

Between 2000 and 2010, the accretion rate exceeded the erosion rate (fig. 3). Nevertheless, the unchanged river area remained greater than both the erosion and accretion areas.

In the depicted diagram (Figure 3), the accretion rate surpasses the erosion rate, while the unchanged area exceeds the accretion area. Specifically, the accretion rate recorded during the 2000 to 2010 timeframe is 11.140894 km. In contrast, the erosion rate amounts to 6.599806 sq. km, and the unchanged area covers 12.36 sq. km. Notably, the unchanged river area is greater than both the erosion and accretion areas in this particular period.

3.1.3. Erosion, accretion and extent area from 2010 to 2020

Between 2010 and 2020, the accretion rate significantly surpassed both the erosion and unchanged rates. Furthermore, the unchanged area remained higher than the erosion area during this period.

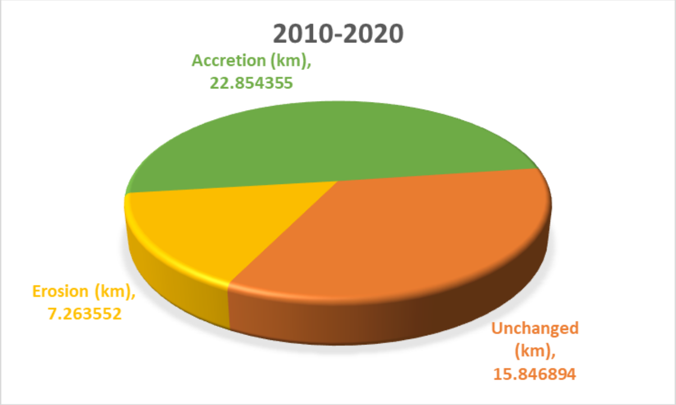

Fig. 4. Erosion, accretion and unchanged between 2010 and 2020.

In the depicted diagram (fig. 4), the erosion rate from 2010 to 2020 amounts to 7.263552 sq. km, whereas the accretion rate is 22.854355 sq. km. The unchanged river area measures 15.846894 km. The percentages for unchanged, erosion, and accretion areas are 34%, 16%, and 50%, respectively. During this period, there has been a notable shift in the erosion and accretion rates compared to the previous 20 years.

3.1.4. Erosion, accretion and extent area from 1990 to 2020

In the selected 30 years, the accretion rate is higher than the erosion and unchanged river (Fig. 5). The data of erosion, accretion and unchanged area are shown in the given table:

Table 2: Erosion, accretion and unchanged area from 1990 to 2020.

Years	Erosion (km)	Accretion (km)	Unchanged (km)
1990-2000	9.54752	6.21362	12.35574
2000-2010	6.599806	11.140894	11.969552
2010-2020	7.263552	22.854355	15.846894
1990-2020	6.63239	23.430379	15.27087

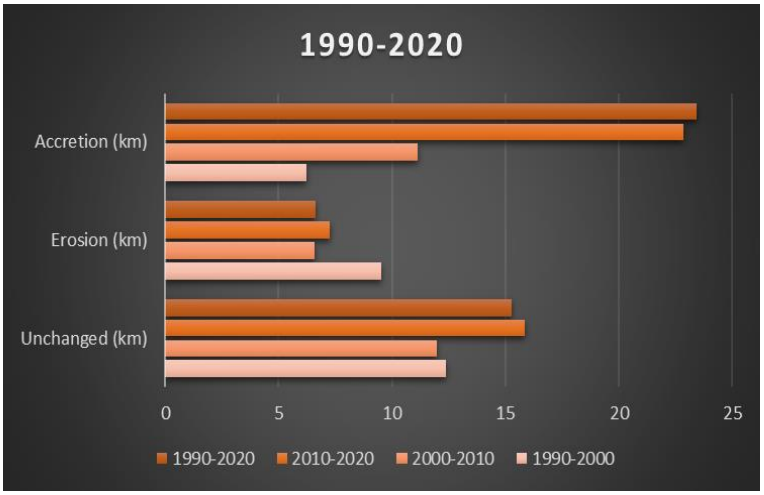

Fig. 4. Erosion, accretion and unchanged between 1990 and 2020.

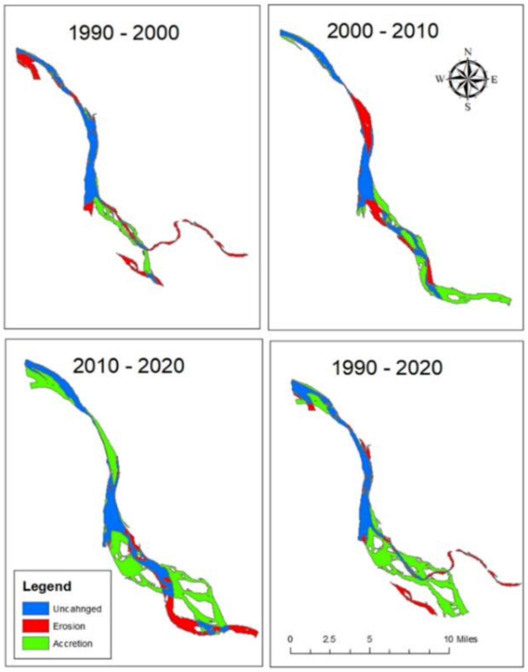

Fig. 5. Maps of Erosion, accretion and unchanged between 1990 and 2020.

The total erosion rate from 1990 to 2020 is 6.63239 km, and the accretion rate is 23.430379 km. The unchanged river area is 15.27087 km. On average, the erosion rate is so high. That means when a flood occurs, the erosion is high. For this reason, in the last era of the last century (1990s), the erosion rate was high, but after then, the erosion rate was not high as before and for that accretion rate started to increase slowly.

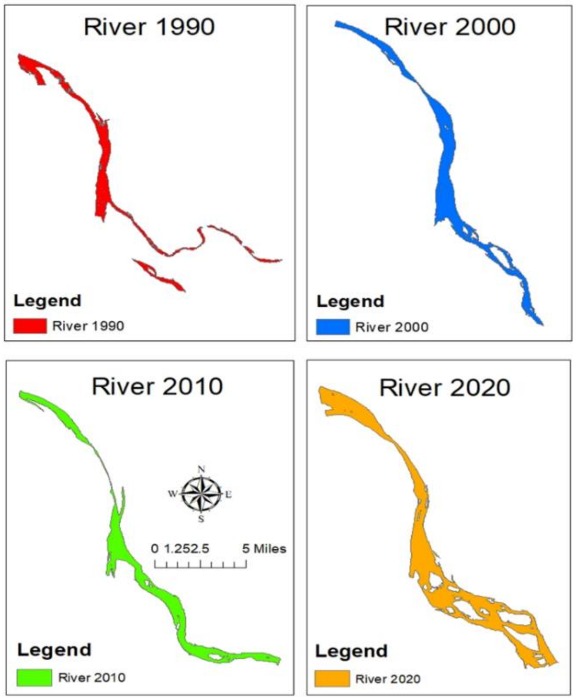

Fig. 6. Spatial and temporal bank line changes

3.2. Spatial and temporal bank line changes

Both the left bank (adjacent to Bangladesh) and the right bank (adjacent to India) of the Padma River experience bank erosion and accretion, respectively (Fig. 6). This study specifically focuses on the left bank, which has been consistently showing frequent and aggressive erosion trends in recent years. In 1990, erosion was observed along Yusufpur, Sardah, and Charghat unions, as well as the southern end of the Gargari Union in Bagha Upazila, resulting in approximately 586 hectares of eroded bank lines. Comparing the 1990 and 2020 maps, we can see significant widening of the river at Pakuria and Gargari due to erosion. Similarly, at Charghat, there was intense erosion in 2000, followed by accretion in 2010, and changes in the bank line continued. The lowest erosion during this period accounted for only 8% of the total erosion in the study. However, the erosion process continued, and by 2020, approximately 1319 hectares of new bank lines had been eroded, indicating a slow but persistent erosion pattern over the 30-year period. Notably, the eroded bank areas at Manigram, Pakuria, and Gargari unions of Bagha Upazila did not exist in 1975.

The trend is indicating a shift or the formation of a new channel from the Manigram Union through the Pakuria Union towards the Gargari Union. A recent research paper also confirms the north-eastward shifting pattern of the channel at this particular point of the Padma River. Bank erosion was particularly evident and extensive adjacent to Yusufpur and Gargari unions, significantly encroaching on the surrounding area. The change detection analysis of the bank line erosion in the left bank of the Padma River during 2020 highlights a significant threat to Pakuria and Gargari Unions. The trend of shifting the Padma River's new course has become even more pronounced in both unions.

A substantial number of Padma Riverbank lines have been submerged under the river course, with the majority of erosions occurring in this part of the study area, totaling 5392 hectares. This accounts for 74% of the detected erosion during this period, making it the highest in the study. Over the ten years since 2010, the erosion process has become significantly more active and rapid, posing an extreme risk to the inhabitants of Pakuria and Gargari. Change detection revealed that approximately 7297 hectares or 72.97 sq. km of bank areas have undergone erosion over the past 30 years. The river's encroachment has already caused extensive destruction of human settlements and agricultural land, resulting in a large number of displaced individuals. The future trend of erosion indicates aggression towards both unions, necessitating urgent measures to protect them from this disaster.

3.3. Vulnerability of physical and human assets

The physical assets of the people encompass housing and shelter, private land, access to adequate water and sanitation, energy, and information. Often, these physical assets are interrelated, and access to shared social infrastructure, such as roads, shelters, embankments, and utility services, is also considered a form of physical asset for the community. Living in a riverbank area, the inhabitants of Charghat Upazila have endured numerous floods throughout their lives, and both floods and riverbank erosion stand as significant factors driving migration. In a country like Bangladesh, where rural communities are closely interdependent, many individuals prefer not to leave their own village or home district but instead migrate to nearby areas.

3.4. Impact of riverbank erosion on social and economic status

As a consequence of Padma riverbank erosion, villagers have experienced the loss of their houses and agricultural land. One interviewee, Lotif, made this statement when asked about the extent of his land and the amount he lost due to bank erosion. He replied, *"I am empty. I lost everything, now I have nothing to lose but my life"*. The majority of the villagers lost their primary croplands, and they held on to the hope that the land would eventually resurface, allowing them to reclaim their lost assets.

In that case, one of the interviewees said, *"About 60 bigha of my land is lying in the river due to river erosion. It has been like this for 15 years, but I am paying rent. If ever Char floats, I will use that land again. The central government had stopped the tax. Now it is restarting again."*

People who lost their lands now land less and earn their livelihood by cultivating others' land. However, they have to pay taxes for those lost lands.

In the study area, people face the displacement of their houses approximately every 2 or 3 years due to river erosion, which significantly disrupts their way of life. The most profound impact of bank erosion is the loss of their homes. Rebuilding a house after erosion becomes a major challenge as it is impossible to retrieve all belongings lost during the erosion event. Constructing a new house requires a considerable amount of money, leading many individuals to take loans and work tirelessly to save enough funds for the construction. Building a house costs a minimum of BDT 30,000, but there is no government support provided for this purpose.

The economic repercussions of Padma riverbank erosion have led to significant changes in the villagers' way of life. With the loss of their agricultural land, they have become reliant on others for their livelihoods. Around 70% of the villagers now work as day laborers on others' lands, earning a meager income of only 200 to 250 taka per day. Additionally, they do not have steady employment, with work opportunities being more prevalent during the agricultural season and scarce during other times, often leaving them with little or nothing to do.

"What is more painful than this? During the rice season, when the rice is ripe, I will cut the rice; just at that time, everything has sunk in the river bed; this happened once," Hasan Ali said with

tears in his eye. He spent all his money to grow rice, and all his lands full of ripe crops went under the Padma at the cutting time.

In addition, they are unable to save a substantial amount of money after meeting their daily necessities. Whatever little they manage to save is often required to construct new houses following displacement caused by bank erosion. At times, they are compelled to sell their livestock to fund the construction, while acquiring new land or renting land for relocation proves to be a more intricate and costly process. The overall economic condition of the study area is found to be distressing due to bank erosion. Building a house becomes the primary focus for everyone, as they rely on work, savings, land acquisition, and house construction to rebuild their lives.

Poor Akkas Sikder uncovered a sad story *"16 years ago, and he went to a friend's house. There, 300 families drowned in the water simultaneously, and no one could say anything because of the river break. Almost all of the 300 families died in the sudden river break"*. Bank erosion significantly influences the social and cultural dynamics of riverbank areas. The close-knit communities in villages feel a stronger attachment to their neighbors compared to those in towns. The sudden displacement caused by erosion is a painful experience for them. Continuous movement and migration force people to adapt to new cultures and ways of life. Some villagers relocate to Dhaka in search of jobs for survival. In general, the impacts of bank erosion are predominantly detrimental to the residents living along the banks. We found many other impacts of bank erosion in the study area. These upazilas are not developed yet for continuous bank erosion and cannot afford modern transport facilities, thus, transportation problems exist in those upazilas. Only vans and motorbikes are used here for movement.

The primary reason for inadequate transportation in the study area is the lack of constructed roads. Approximately 80% of the roads in the region are kutcha roads, characterized by their uneven and precarious nature, making vehicle movements risky. Due to these road conditions, the economic development of the upazilas' residents is hindered, and they face difficulties in making progress. Additionally, the continuous occurrence of bank erosion diverts the government's attention away from addressing other pressing needs and problems in the area.

A significant number of villagers are illiterate as they began working in the fields to earn money at a young age. Additionally, the lack of sufficient schools and colleges nearby hinders proper educational facilities. If they wish to send their children to school, they must walk a considerable distance. In this village, it was noticed that 90 percent of the guardians are illiterate, and the children's school attendance is irregular due to the absence of government initiatives. The prevailing food shortage situation motivates everyone to work diligently.

The soil quality in areas affected by bank erosion differs from other regions in the country. As a result of this soil variation, the main crops cultivated in these areas are onions, rice, and some vegetables. Due to the impact of erosion on agricultural land, people often have to purchase vegetables from neighboring villages or districts to meet their needs.

3.5. Riverbank erosion and migration: a new version of life and livelihoods

Building a house became the most prominent problem after the river erosion. It is impossible to bring all the belongings of the previous house along with the river erosion time. It costs a lot of money to build a new house. Many people take loans for this and work for a long time and save money to build a house. It takes at least 30000 BDT to build a house. There is no support from the government to build houses.

After being displaced by river erosion, individuals who wish to construct a new house must first find a suitable location and then purchase the land. However, the challenge lies in finding available land, as it is not easily accessible. Generally, people are hesitant to sell their land, and convincing them to do so can be a lengthy and complex process. Nevertheless, some eventually agree to offer their land, and in such cases, the transaction is often settled through the court.

To build a house, everyone becomes dependent on work, saves money, buys land, and builds a house first. For that, they need a large amount of money. Moreover, they do not get any kind of loan to gather the money. One of the respondents said, *"No, I have never borrowed from any NGO or government institution. It is not very easy to repay a loan after taking the loan. I see many people like this, so I never have a loan."*

By working on other people's land, collecting money, and selling some cows and calves, sometimes relatives help a lot to collect the money to migrate to a new place and build a new house.

They move near a place not so far from the previous house. They cannot migrate to town; they are emotionally attached to the area. However, the primary reason for migrating near places is their agricultural land under the river. They are hoping and waiting for the rising of their land.

A few people moved to Dhaka or town for a better life. However, not all the members of that family moved to Dhaka. Only The head of the family came to Dhaka to earn a livelihood for his family. Moreover, the rest of his family moved to near after building a new house.

An interviewee said, *"I wish Padma took me with her one night, and I do not have to suffer this displacement again and again"*. After that, his wife added, *"I cannot sleep at night for the last week because the nearest house to the bank is mine. I am scared that if bank erosion occurred at night, none of my family members could survive if I slept. I do not sleep to inform them if any accident happens"*. These statements provide insight into the pain and enduring suffering experienced by the affected individuals due to the bank erosion in the study area. The residents have already begun relocating their homes to safer places in an effort to avoid further accidents.

The people of Charghat and Bagha Upazila are not settled permanently for the continuous bank erosion of that area, and they have to keep moving for the displacement of their houses. When they were asked why they are not moved to another district or far from the Padma, why are they still building their house near the bank again and again after experiencing bank erosion and losing their house repeatedly? They answered, *"Where will we go? My family and my neighbours are here. Respect, love and help I get here from my childhood. I cannot get from another place at this age. Moreover, my lands are here under the Padma. I know one day it will rise, and I can see them again. I want to close my eyes here."*

The majority of the people choose to stay in the area due to their attachment to their lands and community ties, leading them to construct new houses near their old ones. Additionally, they have come to terms with these effects and have learned how to cope with such circumstances.

4. Conclusion

This study aimed to examine the changes in Padma Riverbank erosion, accretion, and unchanged areas in the study region from 1990 to 2020. Over this 30-year period, the total erosion rate was measured at 6.63239 km, while the total accretion rate was 23.430379 km. The unchanged river area covered 15.27087 km during this timeframe. Notably, the erosion rate was highest between 1990 and 2000 but decreased significantly from 2010 to 2020. Conversely, the accretion rate was highest between 2000 and 2010 and lowest between 1990 and 2000. The years between 2010 and 2020 saw the most stable river area. The diagrams presented in earlier sections visually illustrates the differences in erosion and accretion rates across various years.

This research employed a combination of remote sensing and socioeconomic data to analyze the spatial distribution of riverbank erosion and its impacts. Utilizing temporal Landsat imageries and social survey information, the study found that Pakuria and Gargari Unions faced the highest levels of erosion and posed a severe risk of further erosion. If the current erosion pattern persists, there is a possibility of the main river channel shifting towards the left bank areas of both unions, leading to the destruction of human settlements and agricultural lands. Such erosion disasters could also result in the collapse of the socio-economic situation in the region. Human mobility is significantly driven by bank erosion, forcing populations to relocate and disrupting their way of life. Finally, this research would help formulate any erosion-related management and policy implications that will mitigate the erosion. At the same time, the findings of this research could help to better understand river induced displacement and associated socioeconomic challenges.

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