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Assessing the Climatic Influence on River in Bangladesh: in Perspective of Morphology and Discharge of Surma River

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ABSTRACT

Bangladesh is a region that is vulnerable to climate change. In this study, the influence of rainfall on river morphology and river discharges was investigated. The morphological analysis of the Surma River was carried out using GIS. Rainfall of Sylhet over 44 years (1972–2016) was analyzed. Annually 434.099 mm rainfall precipitated in Sylhet. The mean annual rainfall from 1972-to 2016 shows a little decreasing trend. 845.99 M3/s of water was discharged on average from the Surma river annually. Over these 44 years, erosion and deposition show a very decreasing rate with a very steep slope. The sinuosity index of the Surma River varies from 1.32 to 2.29. The total erosion is strongly related to annual mean rainfall (r=0.939), which greatly affects the total river erosion. 88% of erosion depends on the annual mean rainfall (r2=0.88). The r between mean annual rainfall and total deposition is 0.919, which presents a very strong positive relationship. More than 80% of the erosion can be explained by rainfall. According to the percentage of r2, about 89.8% of variables of deposition can be explained by rainfall if other factors remain constant. The river deposition and erosion are very highly dependent on river discharge. The Surma river's annual mean discharge and rainfall are strongly correlated (r = 0.69), which indicates that the discharge of the Surma river is highly dependent on the surrounding area's rainfall. To conclude, it can be noted that the Sylhet rainfall decreased from 1972 to 2016, which had affected the Surma river's morphology directly due to climate change.

INTRODUCTION

The magnitude of erosion and sediment yield is highly controlled by Climate (e.g., Hicks et al. ¬1996, Glade 1998, 2011; Crozier 1997). In response to global warming, soil erosion rates are commonly expected to rise (e.g., Ministry of the Environment (MfE),2008) through a number of mechanisms, including improvements in (1) rainfall erosion, (2) slope stability of soil water, (3) plant biomass, (4) wind and drought frequency, and (5) land use required to adapt to climate change. (Nearing et al. 2004; Crozier 2010). Due to climate change, the frequency and severity of natural calamities (droughts, floods, storms, and cyclones) have been changed. (Fowler & Hennessey 1995;MfE,2008).Over the past centuries, human beings have had a multitude of impacts on fluvial structures, either directly (such as dam and embankment construction) or indirectly (such as changes in the land cove) (Goudie, 2006). Climate change impact studies concentrate on changes in river discharge and aspects of its temporal variability and season for individual drainage basins (Howlader, 2021, Kundzewicz et al., 2007). There are still few global reports on the impact of climate change on river flow regimes (e.g., Milly et al. 2002, Döll and Zhang 2010, Hirabayashi et al. 2008). The strength of rainfall is a major factor in regulating phenomena such as floods, soil erosion levels, and mass movements (Sidle and Dhakal 2002).

In their third Assessment Report, South Asia is declared the most significantly affected climate change area by IPCC (Chowdhury, 2021, McCarthy et al., 2001). Due to several socio-economic and hydro-geological factors, Bangladesh is the most vulnerable to climate-prone areas. The main reasons for its vulnerability are its geographical location in South Asia, its low-lying floodplain topography, and its intense climate is driven by monsoons resulting in severe water distribution. The population density of Bangladesh is also very high, leading to the occurrence of poverty. The Bangladesh government has taken many steps to obtain sustainable development goals, but they face significant challenges in sustaining its development due to climate change (Ahmed and Haque, 2002). Bangladesh is on the list of the world's prominent climate change vulnerable countries (IPCC, 2007).

In Asia, the impact of global climate change is seen mostly in the hydrologic sector (Organization for Economic Co-operation and Development, 2003). Bangladesh's rainfall pattern will change along with a steady increase in temperature due to climate change (IPCC, 2007). The overall objective of this study is to analyze the impacts of climatic change on the Surma River, analyzing its morphology and discharge with respect to rainfall.

The specific elements of the objectives of this research have been set as follows:

I. To identify the Morphological (Historical course, quantity of accretion and deposition, the sinuosity index, width, length) change of Surma river.

II. To analyze the impact of climate change on river morphology and discharge of Surma River.

Materials and methods

"Research methodology is a way to systematically solve the research problem" (Kothari, 2004). It comprises the steps and methods of research that have been done and

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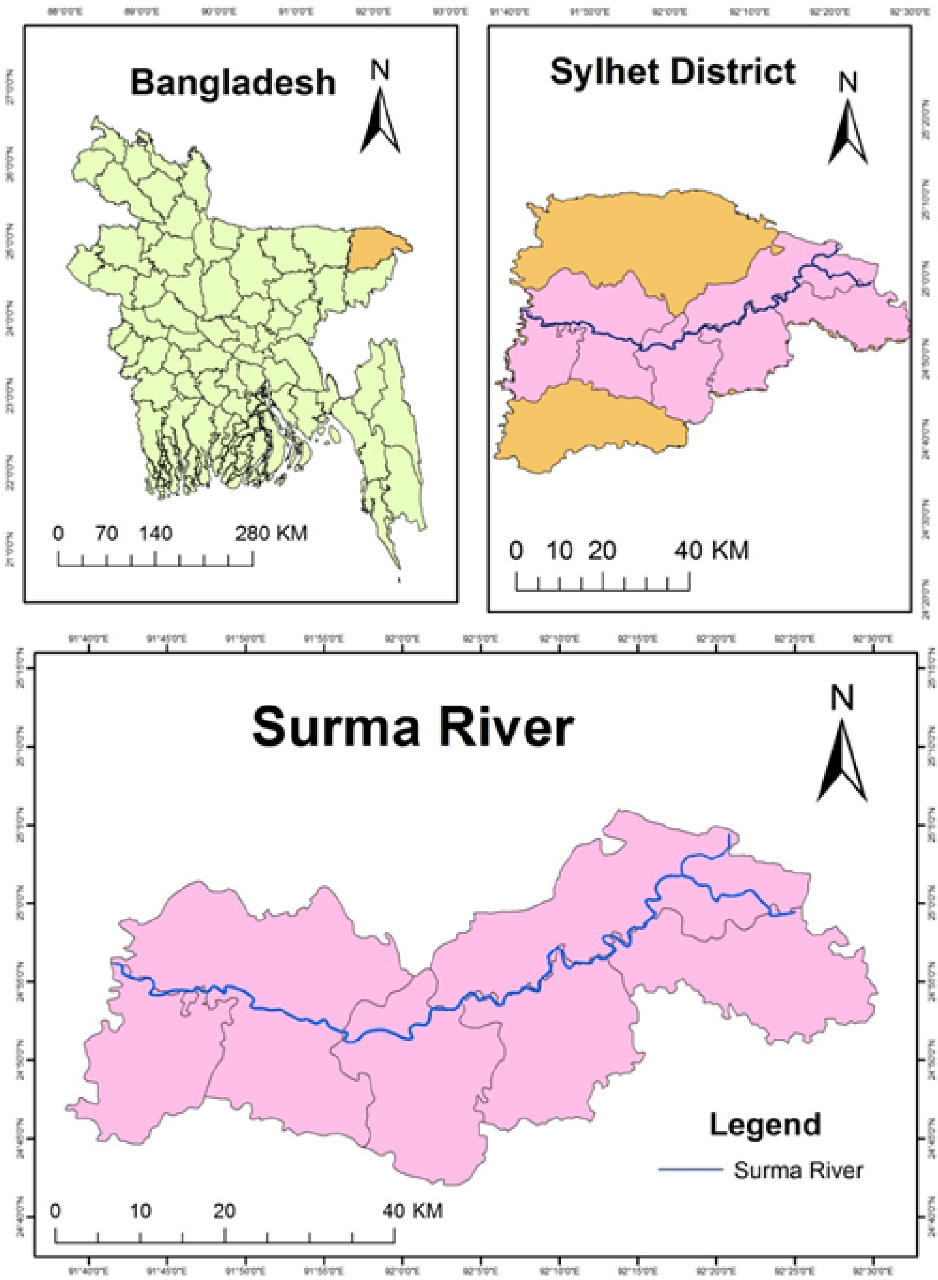
applied. In short, a methodology is a study or description of methods (Baskerville, 1991). Surma River in Sylhet District was the study area of this research work. Surma River is the longest river in Bangladesh; it runs through the northeastern part of Bangladesh (Rahman,2018). This is the cloudiest part of Bangladesh (Rashid, 1991). The highest precipitation falls in this area; for this reason, this river is chosen to determine rainfall's impact on its morphology and discharge (Akter, 2019). Two types of numeric data (mean discharge and rainfall) have been analyzed. To determine the relationship between the variables, the linear regression method is applied.

Description of Study area

The Surma Basin, which covers the eastern parts of Bangladesh, is home to at least 8 million people, making it a populated geographical region of Bangladesh. Surma Basin depends on these peoples for its household, industrial, and other purposes. Sylhet is a major metropolis located on the banks of the Surma River in northeastern Surma River ascends like the Barak on the



Khasi and Tripura

Naga-Manipur watershed's southern slopes. The Barak splits up branches within the Assam district of Cachhar in India. The northern department of Surma flows west, after which to Sylhet town in the southwest. It flows beyond Sylhet to Sunamganj town northwest and west; from there southwest to Madna, where it meets the kushiyara, the Barak's alternative branch.

Climatic variable (rainfall) and River Discharge data collection

In this study, to find out the climatic trend, one variable of climate, which is rainfall, was considered. But a fact is that from origin to meet up Kushiyara river in Ajmiriganj, Surma river travel between Sylhet and Sunamganj, But in Sunamganj do not have any meteorological observation post, for this purpose only from Sylhet Station the climatic variables (rainfall) records accumulated. Daily discharge data at Sylhet station were collected from the Water Resources Planning Organization of Bangladesh from 1972 to 2006, and observed discharge data in a certain interval from 2007 to 2016 have been analyzed here

Satellite images collection

This study is based on secondary data (river discharge, rainfall), and Landsat image was used as secondary data.

Table 1: Details of acquired Satellite Images

Spacecraft ID	Sensor Id	Acquisition Data	Path/Row	Resolution	Cloud cover	Image Quality
LANDSAT 1	MSS	1972-12-27	146/43	60	0.00	0
LANDSAT 2	MSS	1976-12-15	146/43	60	0.00	0
LANDSAT 3	MSS	1980-02-01	146/43	60	1.00	0
LANDSAT 5	TM	1988-11-10	136/43	30	1.00	9
LANDSAT 5	TM	1992-12-7	136/43	30	7.00	9
LANDSAT 5	TM	1996-01-30	136/43	30	0.00	9
LANDSAT 7	ETM	2000-11-17	136/43	30	0.00	9
LANDSAT 5	TM	2004-02-26	136/43	30	3.00	7
LANDSAT 5	TM	2008-11-17	136/43	30	0.00	9
LANDSAT 7	ETM	2012-02-22	136/43	30	1.00	9
LANDSAT 8	OLI-TIRS	2016-12-09	136/43	30	0.00	9

In order to assess the effect of climate change on river morphology, eleven satellite images of 1972, 1976, 1980, 1988, 1992, 1996, 2000, 2004, 2008, 2012, and 2016 were downloaded from the United States Geological Survey (USGS). The total time span was divided by a 4-year time interval. Satellite data of the same time interval is quite impossible to acquire, so there is some lapse in the interval. Examples of the Satellite images obtained are shown in table 1. A list of steps is made to get an appropriate output. To correct the errors, Radiometric and Geometric corrections were done in many steps. The radiometric correction and atmospheric correction were performed for all the bands of each image.

The correction procedure of the Landsat 8 image is different from the correction procedure of other Landsat images. The image was processed using the formula provided in the Landsat 8 handbook.

Dark object Subtraction is a very simple image-based method of atmospheric correction. ENVI 5 was used to do Dark object Subtraction.

The Normalized Difference Water Index (NDWI) method is a common approach to detecting water bodies. The following formula was used for the NDWI index. But the formula varies with Landsat sensor. For Landsat 4 TM, the following formula was used for the NDWI index.

$$\text{MNDWI} = \frac{Green - MIR}{Green - MIR}$$

MNDWI means Modified Normalized Difference Water Index, where MIR is a middle infrared band, and Green presents the pixel value of the green band.

The collected satellite images from USGS were subset using the shapefile of the study area in ERDAS Imagine.

RESULT AND DISCUSSION

A sequence of Landsat images of four years intervals, including 1972, 1976, 1980, 1988, 1992, 1996, 2000, 2004, 2008, 2012, and 2016 reveal the yearly erosion and deposition rate.

Erosion and deposition have occurred at different places in different periods. Table 2 represents the erosion and deposition scenario of the Surma River. Over the period of these 44 years in Surma, River deposition was higher than erosion. The highest deposition and erosion took place in the time interval 1980 to 1988. During these time intervals, the rainfall and river discharge were also very high (Table 2).

In the period 1972 to 1976, total accretion was 828.813 acres, and the accretion rate was 207.20 acres/year (table 2). The total erosion was 681.1 acres, and the erosion rate was 170.27 acres/year (table 2). Land deposited more than the eroded, a total of 147.713 acres of land added to the bank of Surma River (table 2).

In the period 1976 to 1980, total accretion was 1276.87 acres, and the accretion rate was 319.27 acres/year (table 2). The total erosion was 680.56 acres, and the erosion rate was 170.14 acres/year. Land deposited quite worn, a total of 596.31 acres of land superimposed within the bank of Surma stream (table 2). This period of the deposition was from 1972 to 1976 (table 2). The deposition rate was conjointly beyond erosion.

Due to the unavailable Landsat image from 1981 to 1987, 1984 image could not get to go with a sequence of 4 years time interval. The image had taken in 1988 for analysis. In the period 1980 to 1988, total accretion was 2634.29 acres, and the accretion rate was 329.28 acres/year (table 2). The total erosion was 1873.61 acres, and the erosion rate was 234.2 acres/year (table 2). Land deposited more than eroded land; a total of 760.68 acres of land was added to the bank of the Surma River (table 2). A very high amount of land was eroded and deposited in these eight years time intervals (table 2).

Total accretion was 1084.23 acres, and the accretion rate was 271.05 acres/year from 1988 to 1992 (table 2). The total erosion was 774.29 acres, and the erosion rate was

193.57 acres/year (table 2). The land deposition was higher than erosion, with a total of 309.94 acres of land added to the bank of the Surma River (table 2).

In the period 1992 to 1996, total accretion was 964.35 acres, and the accretion rate was 241.08 acres/year (table 2). The total erosion was 486.29 acres, and the erosion rate was 121.57 acres/year. Land deposited more than eroded land; a total of 478.06 acres of land was added to the bank of the Surma River.

In the period 1996 to 2000, total accretion was 645.85 acres, and the accretion rate was 161.46 acres/year (table 2). The total erosion was 482.896 acres, and the erosion rate was 120.724 acres/year (table 2). Land deposited more than eroded land; a total of 162.95 acres of land was added to the bank of the Surma River (table 2).

In the period 2000 to 2004, total accretion was 304.062 acres, and the accretion rate was 76.01 acres/year (table 2). The total erosion was 292.8 acres, and the erosion rate was 73.2 acres/year (table 2). Land deposited more than eroded land; a total of 89.37 acres of land was added to the bank of the Surma River (table 2).

Twelve bends from the selected reach of the Surma river were shown in the following figure 1, which are selected These river bends were selected on the basis of the historical imagery of Google Earth Pro and the reconnaissance survey. Surma River is the longest river in Bangladesh. From upstream to downstream, 12 bends are selected for the analysis. Significant changes took place along with these 12 selected reaches.

In the period 2004 to 2008, total accretion was 267.934 acres, and the accretion rate was 66.98 acres/year (table 2). The total erosion was 178.56 acres, and the erosion rate was 44.64 acres/year (table 2). Land deposited more than eroded land; a total of 89.37 acres of land was added to the bank of the Surma River (table 2).

Table 2: Erosion and deposition scenario of Surma River from 1972 to 2016.

Period	Accretion rate (Acres/year)	Total Accretion (Acres	Erosion Rate (Acres/year)	Total Erosion (Acres)	Difference (Acres)
1972-1976	207.20	828.813	170.27	681.1	147.713
1976-1980	319.27	1276.87	170.14	680.56	596.31
1980-1988	329.28	2634.29	234.2	1873.61	760.68
1988-1992	271.05	1084.23	193.57	774.29	309.94
1992-1996	241.08	964.35	121.57	486.29	478.06
1996-2000	161.46	645.85	120.724	482.896	162.95
2000-2004	76.01	304.062	73.2	292.8	11.26
2004-2008	66.98	267.934	44.64	178.56	89.37
2008-2012	38.17	152.7	25.76	103.05	49.65
2012-2016	26.89	107.98	19.07	76.287	31.69
Total	173.739	8267.079	117.3144	5629.443	2637.623
1972-2016	75.51	6457.34	24.4	4930.93	1526.41

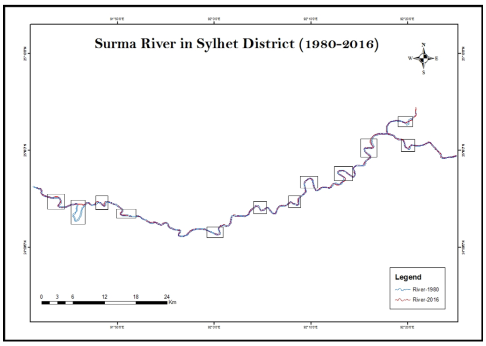


Figure 1: Selected reach of Surma River.

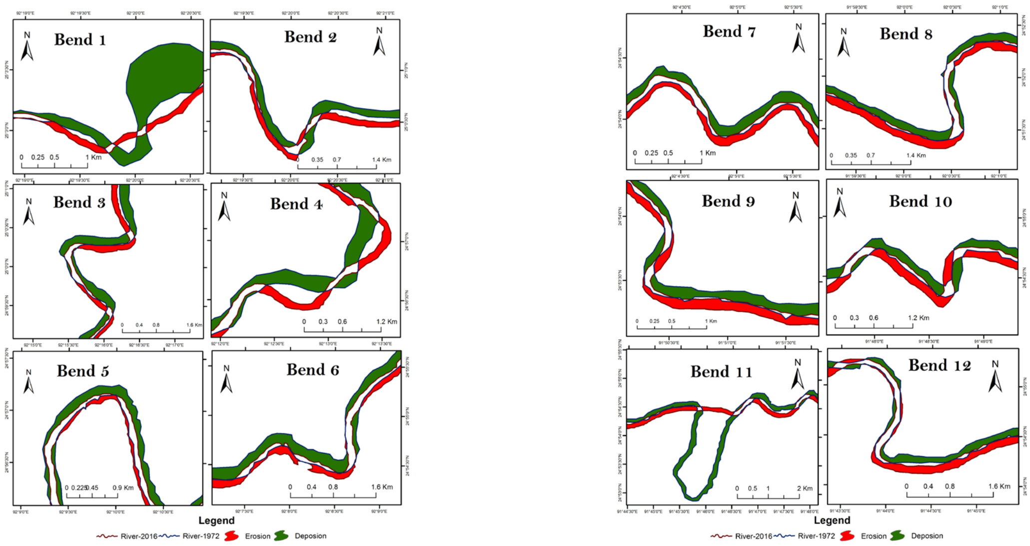


Figure 2: Erosion and Deposition inbend 1-12 from 1972-2016

In the period 2004 to 2008, total accretion was 267.934 acres, and the accretion rate was 66.98 acres/year (table 2). The total erosion was 178.56 acres, and the erosion rate was 44.64 acres/year (table 2). Land deposited more than eroded land; a total of 89.37 acres of land was added to the bank of the Surma River (table 2).

In the period 2008 to 2012, total accretion was 152.7 acres, and the accretion rate was 38.17 acres/year (table 2). The total erosion was 103.05 acres, and the erosion rate was 25.76 acres/year (table 2). Land deposited more than eroded land; a total of 49.65 acres of land was added to the bank of the Surma River (table 2).

Total accretion was 107.98 acres, and the accretion rate was 26.89 acres/year in the time of 2012 to 2016 (table 2). The total erosion was 76.287 acres, and the erosion rate was 19.07 acres/year (table 2). Land deposited more than an eroded total of 31.69 acres of land added to the bank of the Surma River (table 2).

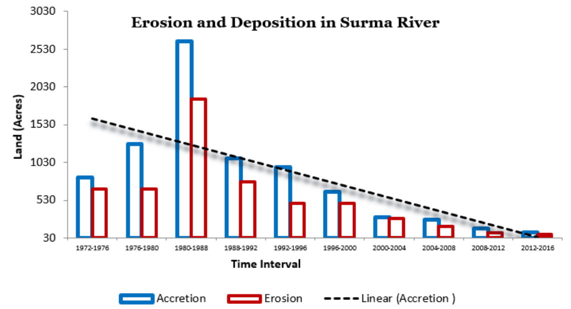


Figure 3: Total Erosion and Deposition in Surma River from 1972-2016.

Figure 3 exhibits total Erosion and Deposition in the Surma River from 1972-to 2016. The erosion and deposition were higher from 1980-to 1988 (figure 3). Over these 44 years, erosion and deposition show a very decreasing rate with a very steep slope. The rainfall in Sylhet also shows a decreasing trend. The discharge of Surma River is showing a decreasing rate. The relationship of river morphology with river discharge and rainfall will be discussed later in this paper.

Analysis of channel widening in Surma River

The width of each bend is the average width of this corresponding bend. Figure 4 represents the width of the Surma River at a different point from 1972 to 2016. The width of the Surma River shows a decreasing trend over the period of time. From 1972 to 1980, the river width was the highest (figure 4). After 1980 the river width started decreasing because of the deposition of sediment on the bank. The deposition of the Surma River was much higher than erosion, which is caused by a decrease in the river width (table 2).

The maximum width of the river was in 1972, and after that, the width fluctuated with increasing time. On average, the river width is higher in the middle stream than upstream, 130.71 m (figure 4). The average width downstream is 122.34 m. The lowest width found in Upstream is 116.75 m. Day by the Surma River width decreases.

Analysis of sinuosity index of Surma River

The river channel is straight when the sinuosity is less

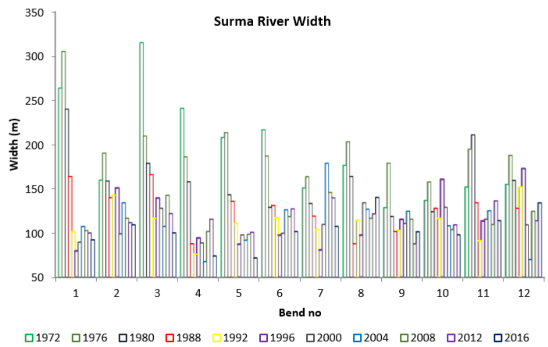


Figure 4: River width at a different location from 1972-to 2016.

than 1.05; the river pattern is seen as sinuous when it is between 1.05 and 1.50and if it is greater than 1.5, the river meander (Brice, 1984).

Surma River is a meandering river. The sinuosity of the Surma River changes over time. The highest sinuosity found in 1976 which 2.29 (table 3). The sinuosity index of the Surma River varies from 1.32 to 2.29. The highest sinuosity was found in bend eleven in 1976, which was 2.3. the lowest sinuosity was found in bend two, which was 1.33.

After 1980 the sinuosity of the Surma River started to decrease due to the cut off in bend eleven and the straightening of the river channel (figure 2). The river meander Surma River ups and down with time. In 1988, 1996, and 2000 the river characteristics were sinuous (table 2). In the years 1976 and 1980, the river was meandering (table 3).

Table 3: Sinuosity Index of Surma River from 1972 and 2016.

Year	Curvilinear length (m)	Linear length (m)	SI	Characteristics
1972	142486.79	73,763.36	1.93	Meandering
1976	169607.01	73,820.26	2.29	Meandering
1980	152598.22	73,807.38	2.06	Meandering
1988	109227.30	73,320.26	1.49	Sinuous
1992	116288.03	73,057.34	1.59	Meandering
1996	100595	73,222.65	1.37	Sinuous
2000	96718.97	73,210.26	1.32	Sinuous
2004	114767.87	73,407.38	1.56	Meandering
2008	109227.30	73,232.65	1.5	Meandering
2012	121652.12	73,216.26	1.62	Meandering
2016	117767.87	73,817.38	1.59	Meandering

Patterns of average Rainfall in Sylhet

Figure 5 shows the average rainfall from 1972-to 2016. Average rainfall in Sylhet decreased throughout the study period (figure 5). The rainfall pattern fluctuated over this period. More than 450 mm of rainfall was precipitated at the beginning of 1972. Suddenly, the amount of rainfall increased with a moderate margin in the following two years, above 550 mm. In the middle of the study period (1975-1981), the amount of rain fell moderately, and it continued. In Sylhet, the total rainfall increased moderately in the following four years (1988-1992) at a moderate rate.

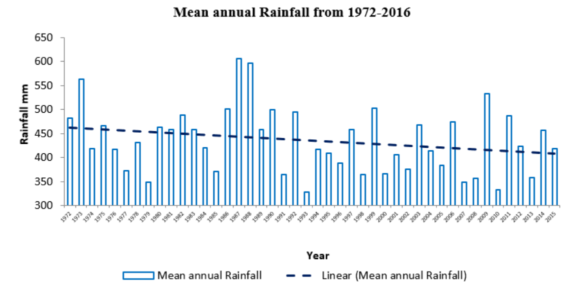


Figure 5: Mean Annual Rainfall from 1972-2016

In recent days, the rainfall in Sylhet decreased, causing many impacts on the environment and the economy. Due to this rainfall change, there must be some disorder in the discharge pattern of the Surma River.

Effects of Climate Change on river morphology

In the event of climate change, when the quantity and seasonal distribution of the water discharge increases, both sediment supply, and sediment transport are subject to change. Changes in the quantity of water will induce changes in the discharge of rivers; in particular, the likelihood of serious hydrological events will increase. This may contribute to improvements in the river channels' flooding, sedimentation, and sediment transport. It can be due to a lack of physically grounded river channel structure and sediment transport models, leading to little faith in projections of the effect of climate change on river channels (IPCC, 2007). In addition, the estimation of improvements in sediment transport shows a great reliance on the predicted greenhouse gas emission scenario. Below we analyzed the impact of climate change on the Surma River.

Relation among annual mean rainfall, total erosion, and deposition in 1972-2016

Erosion is mainly caused due to the flowing water in the river. The fast river discharge erodes rocks and soil. When a vast amount of rainfall drains in a certain area, the rainwater falls into the river, and the discharge increases.

The water flow is highly dependent on the landslope, where the slope is very steep, and the water flows faster. The amount of discharge in the river is another cause of river erosion; when the discharge is high, it flows very faster than when it is dry.

Table 4 represents the correlation of mean rainfall, river erosion, and deposition from 1972-to 2016. The erosion of the Surma river depends on annual mean rainfall (Table 4). The r between them is 0.939, indicating a very strong positive relationship and significance (table 4). It is shown from multiple r2 that 88% of erosion is influenced by annual mean rainfall (Table 4). If the rainfall increases, the erosion will increase; if the rainfall decreases, the erosion will also decrease.

The rainfall of Sylhet highly influences the deposition in Surma River; the r between them is 0.919, which indicates a very strong positive relation (table 4). It is seen that r2 square is 0.84, which means 84% of deposition depends on the annual mean rainfall (Table 4). The river deposition is very highly dependent on river discharge. The higher amount of rainfall increases the total river discharge. This leads to an increase in the erosion of the river and the eroded sediments deposited in other parts of the river.

Table 4: Correlation of mean rainfall, river erosion and deposition in 1972-2016

Independent Variable	Dependent Variable	r-value	P.E (r)	r^2	r^2 in %	Significance
Annual Mean Rainfall (1972-2016)	Total Erosion (1972-2016)	0.939	0.025	0.88	88%	Significant
Annual Mean Rainfall (1972-2016)	Total Deposition (1972-2016)	0.919	0.035	0.84	84%	Significant

r= Coefficient of correlation, P.E. = Probable Error, r^2= Coefficient of determination

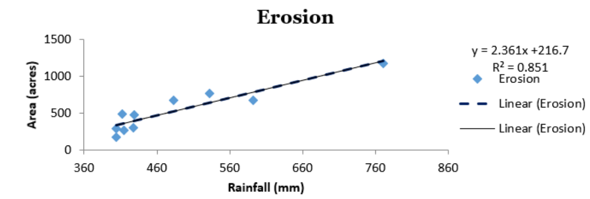


Figure 5: Scatter plotting of mean annual rainfall and erosion.

Figure 5 exhibits a scatter plotting of mean annual rainfall and erosion. The linear regression between rainfall and erosion shows a very meaningful result. Here, rainfall is considered a predictor or independent variable, while erosion is considered a dependent variable. The r2 value shows a very strong relationship between rainfall and erosion. More than 80% of the erosion can be explained by rainfall. The regression coefficient reveals that a one-unit change in rainfall may cause a change of 2.361unit of erosion (figure 5). The intercept of regression means that if the change in rainfall remains constant, the erosion would be 216.7. The direction of the trend line also shows a very strong positive relationship between these two variables. In short, it can be concluded that increasing (or decreasing) rainfall can cause increment (or decrement) in erosion.

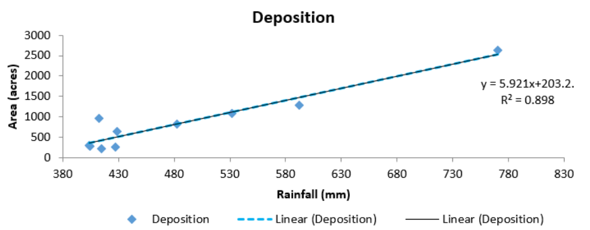


Figure 6: Scatter plotting of mean annual rainfall and deposition

To measure the association between deposition and rainfall, a linear regression model has been applied, considering rainfall as an independent variable and deposition as the dependent variable. The value of r2 reveals a very strong relationship between these two variables (figure 6). According to the percentage of r2, about 89.8% of the variables of deposition can be explained by rainfall if other factors remain constant. 89.8% of deposition depends on rainfall (Table 4). Changes in rainfall impact the change in deposition proportionally. For example, one-unit increment (or decrement) of rainfall can cause a 5.921-unit decrement (or increment) in deposition (Table 4). In short, rainfall and deposition are strongly related to each other.

Relation among annual mean Discharge, total erosion, and deposition in 1972-2016

Table 5 represents the correlation between mean discharge, river erosion, and deposition from 1972-to 2016. The Coefficient of correlation r of annual mean discharge and total erosion is 0.786, indicating a strong positive relation (table 5). Multiple r square is 0.617which means 61.7% of erosion depends on the annual mean discharge. The total amount of erosion is highly dependent on discharge. If the discharge increases, the deposition amount will increase; if the discharge decreases, the deposition will also decrease.

Table 5: Correlation of mean discharge, river erosion and deposition in 1972-2016.

Independent Variable	Dependent Variable	r-value	P.E (r)	r^2	r^2 in %	Significance
Annual Mean Rainfall (1972-2016)	Total Erosion (1972-2016)	0.786	0.081	0.617	61.7%	Significant
Annual Mean Rainfall (1972-2016)	Total Deposition (1972-2016)	0.749	0.093	0.561	56.1%	Significant

r= Coefficient of correlation, P.E. = Probable Error, r^2= Coefficient of determination

The r between mean annual discharge and total deposition is 0.749, presenting a very strong positive relation (table 5). Multiple r square is 0.561, meaning 56.1% of deposition depends on the annual mean discharge (table 5). The relationship between deposition and discharge is very high. The river deposition is very highly dependent on river discharge. The higher amount of rainfall increases the total river discharge. This leads to an increase in the deposition of the river and the eroded sediments deposited in other parts of the river.

CONCLUSION

At present, global climate change has become a huge issue of concern. In the setting of global climate change, the regional and local climate is additionally evolving. The climate in Northeastern parts of Bangladesh is likewise evolving with time. This climate change is affecting the rivers. Both the river morphology and river discharge are altered due to climate change. Climate change affects river hydrology.

The rainfall in Sylhet shows a decreasing rate, which alters the morphology of the Surma River. The rainfall of the study area can explain more than 80% of river erosion and deposition. Both river erosion and deposition are strongly positively correlated with rainfall. The change in rainfall alters river discharge, leading to the change in river width, erosion, and deposition.

From 1972 to 2016, the rainfall in Sylhet decreased, which altered the river discharge. The river discharge also lessened with the decline of rainfall. More than 55% of river erosion and deposition can be explained by discharge. River discharge has a strong positive impact on river erosion and deposition. The diminishing discharge changed the river morphology. Reducing discharge lessened the river flow, which affected the river morphology. The erosion and deposition shrank with the decline of discharge. The river width and sinuosity were also reduced. The river morphology is more correlated with rainfall than discharge.

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