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The rainfall and discharge trends of Surma River area in North-eastern part of Bangladesh: an approach for understanding the impacts of climatic change

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Abstract

Background: Bangladesh is known as a deltaic plain at the confluence of the Ganges, Brahmaputra and Meghna River Basins (GBM) and their tributaries. The rainfall pattern of northeastern part of Bangladesh is changing along with the discharge pattern of Surma River. In this study, the changes in precipitation of Sylhet and river discharge of Surma River and the relationship between them were investigated. The study emphasizes on the influence of climatic component (rainfall) on the hydro-characteristics of river. The time series data from 1973 to 2016 (44 years) of rainfall and river discharge of Surma River were collected and analyzed. The basic hydro-characteristics, including arithmetic mean, variability, skewness, distribution type, persistence, dependence, trend, and correlation have been studied through various statistical methods, including coefficient of variation, Mann–Kendall test, Sen's slope estimator, and Pearson's coefficient of correlation.

Results: The rainfall trend shows moderate year-to year variability although there is an indication of declining rainfall trend. As with rainfall, the river discharges show moderate year to year variations that are related to the variability in rainfall. The decreasing rate is 1.53 mm for rainfall and − 1.51 m^3/s for discharge (Mann–Kendall test). The rainfall was increasing from 1973 to 1989 but after 1990 it is reduced. The mean discharge of Surma River was 845.99 M^3/s. The rainfall started to fall down extremely from 1990 to 2016 but before that the rainfall showed an increasing trend with modest slope. It is possible that the declining trend in rainfall observed in Sylhet is a result of climate change which causes the declining of Surma River discharge. Over these 44 years analysis, the rainfall and discharge shows a very decreasing trend and both rainfall and discharge were highly related for most of the time.

Conclusion: In conclusion, it can be noticed that the rainfall in Sylhet has been reduced from the time 1973 to 2016 which directly affects the discharge of Surma River. Consequently, this result might be the indication about the effect of climatic change in the local as well as global level.

Keywords: Surma River, Rainfall pattern, Trend detection, Discharge pattern, Climate change

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Introduction

Bangladesh is located in South Asia. It extends from 20°34′N to 26°38′N latitude and from 88°01′E to 92°41′E longitude. Bangladesh has got about 700 rivers. Due to the presence of a large number of rivers, Bangladesh is called a riverine country (Alam 2007). River is a topographical feature. The natural and anthropogenic influences force the geographical feature, e.g. river to a frequent change (Khublaryan 2009; Spencer and Thomas 1987). The source of the water drains by the river is precipitation, melting of glaciers, baseflow from groundwater, etc. (Raghunath 2006). The rivers of Bangladesh are morphologically dynamic characterized by erosion and sedimentation (Habibullah 1987). River discharge varies over space and time. In fact, the climate change impact studies for individual drainage basins mostly focus on changes of river discharge (Lahmer et al. 2001). Global-scale studies on the impact of climate change on river flow regimes are still rare (D¨oll and Zhang 2010; Hirabayashi et al. 2008; Mitchell et al. 1966). In many regions, the changing precipitation or melting of snow and ice is altering hydrological systems, affecting water resources in terms of quantity and quality (Jiménez et al. 2014). The potential impacts of climate change and variability have received a great deal of attention from researchers in a variety of fields. Reviews of related work include (Kundzewicz et al. 2007) and the Inter-governmental panel on climate change (IPCC 2007). From these works, a range of potential impacts on the hydrologic regime for various geographic areas has been hypothesized. Many researchers analyzed the trend of discharge change of different country and regions. Monthly mean discharge in Canada for most months decreased, with the strongest decrease in summer and autumn months (Zhang et al. 2006). There is an upward discharge trend pattern at United States with the exception of a small number of downtrends concentrated in the Northwest, Florida, and coastal Georgia (Lettenmaier et al. 1994). The trend of 26 basins in Turkey showed in general downward trend (Kahyaa and Kalayci 2004). The annual maximum discharge and water level (WL) of Yangtzee river in China has downward trend at upper stream while at middle and lower stream has upward trend (Zhang et al. 2006). In short, streamflow characteristics are changing all over the world. Parajuli (Parajuli et al. 2015) deals with the river discharge and rainfall pattern of Marshyangdi River Basin. Croitoru and Minea (2015) try to assess the impact of climate changes on rivers discharge in Eastern Romania. Billah et al. (2015) focused on the impact of climate change on the river flows in Southwest region of Bangladesh. However, many studied have been conducted on the quality of water of Surma River for example (Alam 2007; Ahmed et al. 2010; Islam 2016 and so on). According to the Third Assessment Report of IPCC, South Asia is the most vulnerable region of the world to climate change impacts (McCarthy 2001). The international community also recognizes that Bangladesh ranks high in the list of most vulnerable countries on earth. Hydrologic changes are the most significant potential impacts of global climate change in Bangladesh (Organization for Economic Co-operation and Development 2003). It has been predicted that due to climate change, there will be a steady increase in temperature and change in rainfall pattern of Bangladesh (IPCC 2007). According to IPCC (2007), an increase in average global temperature will lead to changes in precipitation, atmospheric moisture due to the changes in atmospheric circulation, and increase in evaporation and water vapor. The rainfall in North-eastern Bangladesh have a downward or decreasing trend (Begum and Alam 2013; Basak et al. 2013). So, it is expected that there must be a change in stream flow of the Surma River with the change in rainfall pattern. Thus this research aims to investigate the change in rainfall and discharge pattern, and their relation to imply the future impact on water resources and environment of this river. This study is a very innovative one with respect to this area because no one done this kind of research before within this study area. The result of this study will help the people to understand the possible impact of climate change on river discharge of Surma River. It will also help the policy maker to make proper management plan. Many studies, projects and programs have taken before but effects of climate change on Surma River are rare. As Climate change cause many damage in river but this kind of study is very rarely seen. The Surma River discharge is decreasing but no study was done before to see the cause of this decrease.

Therefore, the main aims and objectives of this study are:

- To analyze the trends in discharge of Surma River along with the rainfall pattern of Sylhet.
- To measure and discuss the effects of climate change on discharge of Surma River.

Study Area and the characteristics of Surma River

Sylhet is the major city in the North-eastern Bangladesh, located on the banks of the Surma River (Fig. 1). This area is surrounded by the Jaintia, Khasi, and Tripura hills. The Surma Basin, covered the eastern parts of the Bangladesh, and encompasses about 8 million peoples making it a populous river basin in Bangladesh. Most of these peoples depend on the Surma Basin for their domestic, manufacturing and other purposes. The Surma River is a branch of the Barak

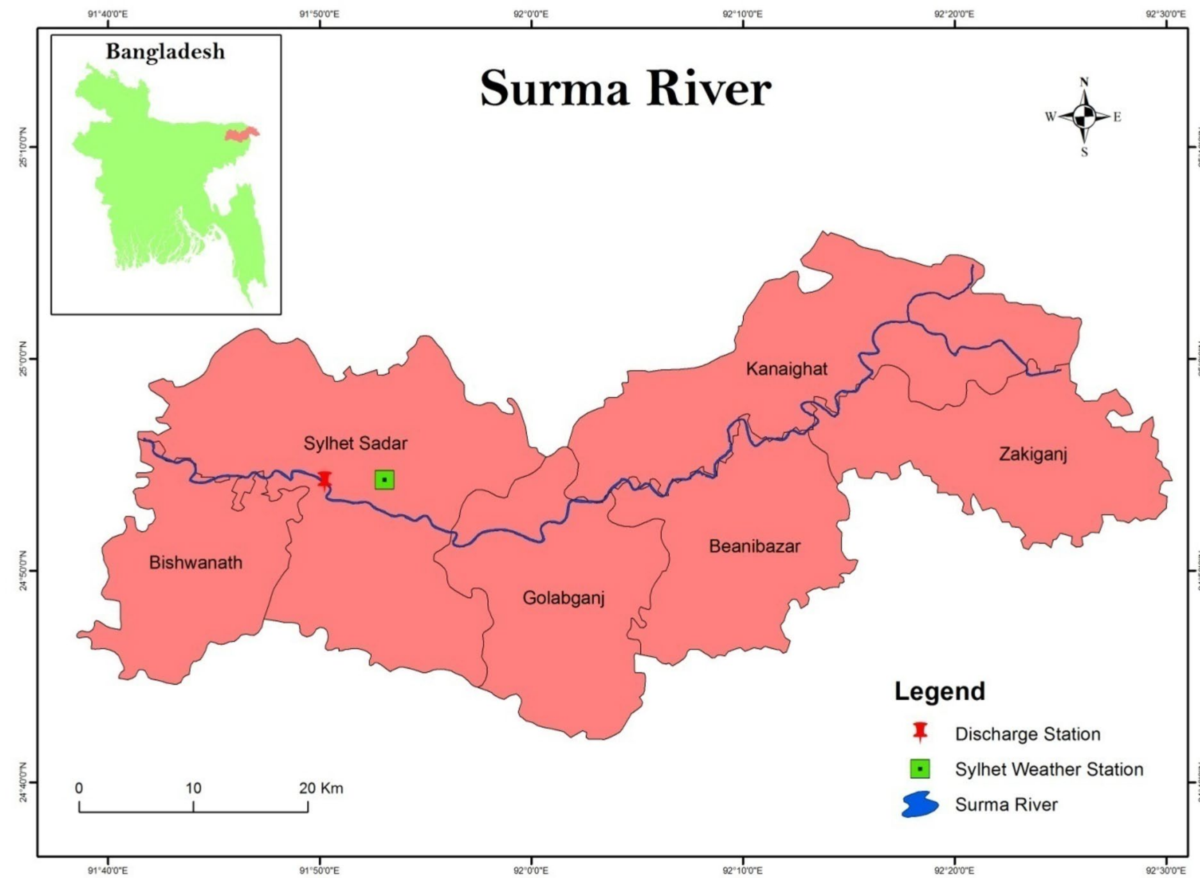

Fig. 1 Location of the Surma River, Bangladesh

River which is developed from the southern slopes of the Naga-Manipur watershed. The Barak splits into two branches in the Cachhar district of Assam in India. In fact Surma is the northern branch of Barak, flows west and then southwest to Sylhet town. Beyond the Sylhet, it flows northwest and west to Sunamganj town. From there to southwest, and then south to Madna, where it meets with the kushiyara river, the other branch of the Barak. It receives a variety of rivers and streams flowing south from the Meghalaya Plateau. From east to west, they are the Lubha, Hari (Kushia), Goyain Gang (ChengarKhal), piyain, Bogapani, Jadukata, Shomeshwari and kangsa. However, the characteristics of the River are consisted of two major subdivisions such as hydrological and geomorphological characteristics. The hydrological characteristics include the mean rate of water flow, flood stage, discharge trend, and so on (McMahon 1982). Whereas, the geomorphological features comprise the erosional and depositional activities, the shape of the channel, river bed, sedimentation, etc. (Singh 1998).

Methodology

Data and methods

The Surma River flows between Sylhet and Sunamganj district. But there is no weather station in Sunamganj. For this reason, the rainfall data was collected only from the Sylhet Station. For this study, the rainfall data was collected from WARPO (from 1972 to 2013). The latest data were collected from BMD (from 2014 to 2016). The daily time series discharge data from 1973 to 2006 and observed discharge data in a certain interval from 2007 to 2016 in Sylhet station have been collected and analyzed in this study. Total period of discharge data is 44 years (from 1973 to 2016). Yearly mean, seasonal mean, annual peak, annual minimum data set were produced from these time series and observed data set. Originally, the Discharge data is recorded by Bangladesh Water Development Board (BWDB). The period of discharge data, and climatic variable data is 44 years. However, the data for more than 30 years of period is considered as standard data period for trend analysis. Various statistical methods have been operated to derive the hydro-characteristics of

Surma River. Two types of data, mean discharge and rainfall, have been analyzed. Collected data set from BMD and WARPO was daily time series data. This data set are computed and prepared by software application. Collected time series data has some missing. Missing value is interpolated during data processing. In case of temperature, rainfall and discharge, the value on 1 month is closely related to the value on the previous and following month. So, when gaps in the record are short, not more than 2 month, it may be acceptably accurate to use linear interpolation between the last value before the gap and the first value after it. Following formula is used to apply linear interpolation (Aziz 2008).

$$Y = Y_1 + \frac{(X - X_1) \times (Y_2 - Y_1)}{(X_2 - X_1)}$$

Here, Y = New discharge/rainfall; Y_1 = Previous discharge/rainfall value; Y_2 = Discharge/rainfall value of following day(s); X = New year; X_1 = Previous year; X_2 = Following year.

During periods of variable flow or in longer gaps, simple interpolation should not be used and relation/regression equations may be applied to fill in missing data. Regression relations may be obtained for annual, monthly or daily series. Longer gaps of discharge data have been interpolated by regression method. The following regression formula is used.

$$y = bx + a$$

Here, y = discharge/rainfall value (dependent); x = time period/year (independent); b = Regression coefficient or changing rate for one unit change in 'x'; a = intercept.

The median is the number at which half your measurements are more than that number and half are less than that number. The median is actually a better measure of centrality than the mean if your data are skewed, meaning lopsided. The mean is just the average. It is the sum of all your measurements, divided by the number of measurements. This is the most used measure of central tendency, because of its mathematical qualities. It works best if the data is distributed very evenly across the range, or is distributed in the form of a normal or bell-shaped curve. The range is the measure from the smallest measurement to the largest one. This is the simplest measure of statistical dispersion or "spread."

The standard deviation is the "average" degree to which scores deviate from the mean. More precisely, you measure how far all the measurements are from the mean, square each one, and add them all up. The result is called the variance.

Prior to applying MK tests to identify precipitation trends over the time series from selected stations, data were tested according to the tests' requirements. The magnitude of the slope in time series data was calculated using Sen's slope method. The Mann–Kendall (MK) test (Mitchell et al. 1966; Kendall 1975; Mann 1945; Gilbert 1987; Helsel and Hirsch 1992) has widely used in hydrological studies. This test evaluates whether outcome values tend to increase or decrease over time. The magnitude of trend is estimated by the Sen's estimator (Sen 1968; Islam 2016). The regression between two variables is called linear regression. The linear regression between the dependent variable y and independent variable x can be written as equation of a straight line.

$$Y = bx + a + e$$

where, a is the intercept, b is the regression coefficient or shape and e are random error components. Positive (negative) value of b indicated upward (downward) trend. b is the slope of trend line. a shows the point where trend line intersects the y axis.

The Coefficient of correlation is a numerical measure of the correlation between two fluctuating series, and is denoted by r, it is used to assess the relation between rainfall and discharge. When $r = +1$, there exists perfect positive correlation, the $r = -1$, there exists perfect negative correlation and when $r = 0$, there is no correlation. The coefficient of determination is the square term of coefficient of correlation (r). It is usually denoted by r^2 that indicates the proportion of the variance in the dependent variable that is predictable from the independent variable (Aziz 2008; Howladar et al. 2014; Howladar and Rahman 2016; Howladar et al. 2017; Numanbakth et al. 2019). It applies to determine the fitting the observed values with the outcomes values. The probable error (Aziz 2008; Islam 2016; Howladar et al. 2019) is used to find out the reliability or significance of the value of Pearson's coefficient of correlation. The Skewness has been measured to understand the asymmetry or departure from symmetry of a distribution of the data.

Results and discussions

The characteristics of discharge and rainfall features in the study area

The preliminary analysis for this study included the mean, standard deviation, coefficient of skewness, coefficient of kurtosis, and coefficient of variation for understanding the annual precipitation time series for each station.

The measured coefficient of skewness of the annual mean rainfall at Sylhet is 0.62 that means the distributions are positively skewed and not symmetrical (Table 1). The Tails on the right side of the shapes are longer than left sided tail. The mean of the distributions is higher than the median. It revealed that, smaller values than mean flow is concentrated at the left side. Most

Table 1 Annual mean rainfall and Discharge Scenario of Sylhet

Indicator	Rainfall (mm)	Discharge (m^3/s)
Mean	434.09	845.99
Median	419.55	851.52
Standard deviation	67.96	282.67
Skewness	0.62	0.62
Range	277.77	1046.91
Lowest annual mean	328.66 (1994)	343.55 (2014)
Highest annual mean	606.44 (1988)	1390.47 (1991)
Highest monthly peak	1394 (2004-July)	3310.96 (1990-June)
Lowest monthly peak	0	1.77 (2014-April)
Highest monthly mean	797.61 (June)	2176.87 (August)
Lowest monthly mean	9.48 (December)	19.00 (January)

of the smaller values of mean annual flow have been occurred in later years. The Lowest and highest annual mean found in 1994 and 1988 which was 328.66 mm and 606.44 mm respectively (Table 1). The range of rainfall in Sylhet is 277.77 mm (Table 1). The Highest monthly peak rainfall was 1394 mm in July of 2004 (Table 1). The Lowest monthly rainfall was 0 mm that means in many times there was no rainfall in January, November and December. The highest and lowest rainfall was in June and December which is 797.61 mm and 9.48 mm respectively (Table 1).

Collected data from 1973 to 2016 from Sylhet gauging Station is taken into consideration. The mean discharge and median of Surma River is 845.99 M^3/sand 851.52 M^3/s respectively which indicates that half of discharge measurements are more than 851.52 M^3/sand half is less than 851.52 M^3/s (Table 1). The Standard Deviation is 282.67 M^3/s represented that the mean discharge of Surma River is not consistent, it is fluctuating over time with a very high rate (Table 1). The discharge distributions are positively skewed and not symmetrical because the measured coefficient of skewness of annual mean discharge at Sylhet is 0.62 which means the right side of the shapes are longer than left sided tail. The mean of the distributions is higher than the median which means smaller values than mean flow are concentrated at the left side. Most of the smaller values of mean annual flow have been occurred in later years. In additional, maximum of larger values has been occurred in earlier years. The Lowest and highest annual mean found in 2014 and 1991 respectively which was 343.55 M^3/sand 1390.47 M^3/s (Table 1). The range of discharge in Surma River is 1046.91 M^3/s (Table 1). The highest monthly peak flow was 3310.96 M^3/s in June of 1990 (Table 1). On the contrary, the lowest monthly peak flow was 1.77 M^3/s in April of 2014 (Table 1). The peak discharge occurs in August which is 2176.87 M^3/s and lowest discharge occurs in January which is 19.00 M^3/s (Table 1).

Monthly trend analysis

The average monthly rainfall and discharge from 1973 to 2016 are depicted in Fig. 2. The maximum rainfall is seen in June and it is 797.61 mm (Fig. 2). In January Surma River gets the lowest Discharge which is 9.48 mm. Though November to February winter season in these months very poor amount of precipitation fall. Monsoon

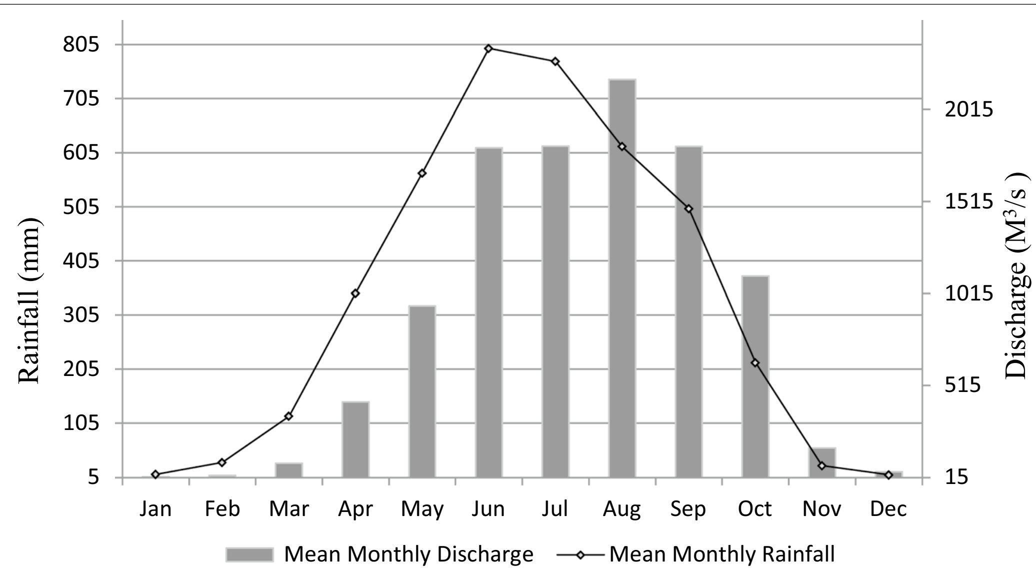

Fig. 2 Mean monthly rainfall and discharge from 1973 to 16

is the season of rain which is from July to August these 4 months the highest amount rainfall is available.

The average discharge from 1973 to 2016 was not consistent monthly. The premier discharge is seen in August which is 2176.87 M^3/s though it lies in monsoon season. In January Surma River gets the poor amount of discharge which is 19.00 M^3/s which means the river is almost dry because it is lies in winter season.

Trends in seasonal mean discharge of Surma River

Four distinct seasons (Rashid 1991) have taken into consideration. They are: Winter (December–February), Pre-monsoon (March–May), Monsoon (June–September) and the last one is Post-monsoon (October–November). Winter is considered as a dry season while the other three seasons are considered as wet season.

Discharge of winter is calculated from December of previous year to February of the following year. Feasibility of parametric trend has been studied by normality test. As a normality test, Kolmogorov–Smirnov test shows that the seasonal value of the discharge is not normally distributed. The seasonal mean discharge of Surma River from 1973 to 16 are presents a line graph in Fig. 3. Monsoon season drains tremendous amount of water rather than the other season. Winter season drains the lowest amount of water (Fig. 3). Both pre-monsoon and monsoon drains a moderate amount of water. Discharge in winter is extremely lower than the other three seasons.

Trends in seasonal mean rainfall in Sylhet

The seasonal mean rainfall from 1973 to 2016 are depicted in a line graphs in Fig. 4. The mean rainfall in pre-monsoon is declining over the period of time within a slower rate. The highest and lowest rainfall in Pre-monsoon season occurred in 2016 and 1979 respectively which were 599 mm and 177.7 mm. The rainfall in pre-monsoon season is not consistent; it shows lots of ups and downs.

In the monsoon season the highest rainfall gets and in July it is highest in Sylhet. In recent year the rainfall of Monsoon season is decreasing with a moderate rate. In 1989 rainfall was 989.5 mm which was highest in Monsoon season among the study period. However the lowest rainfall was seen in 1980 which was 341.75 mm. In this season the rainfall was not in a consistent form it was changing over time to time. In the middle of the study periods (1981 to 1993) the rainfall showed increasing pattern but after 1993 it started to fall down. Whereas, in recent year the rainfall again falling down in a moderate rate.

In recent years the rainfall of Post-monsoon season is showing a decreasing trend where in this season gets moderate rainfall. In Post-monsoon season the rainfall was highest in 1986 which was 280 mm whereas the lowest rainfall found in 1982 which was 17.76 mm. The rainfall in Pre-monsoon season is not consistent; it shows lots of fluctuations. In the middle period from 1983 to 1990, the rainfall was increasing in Monsoon within a

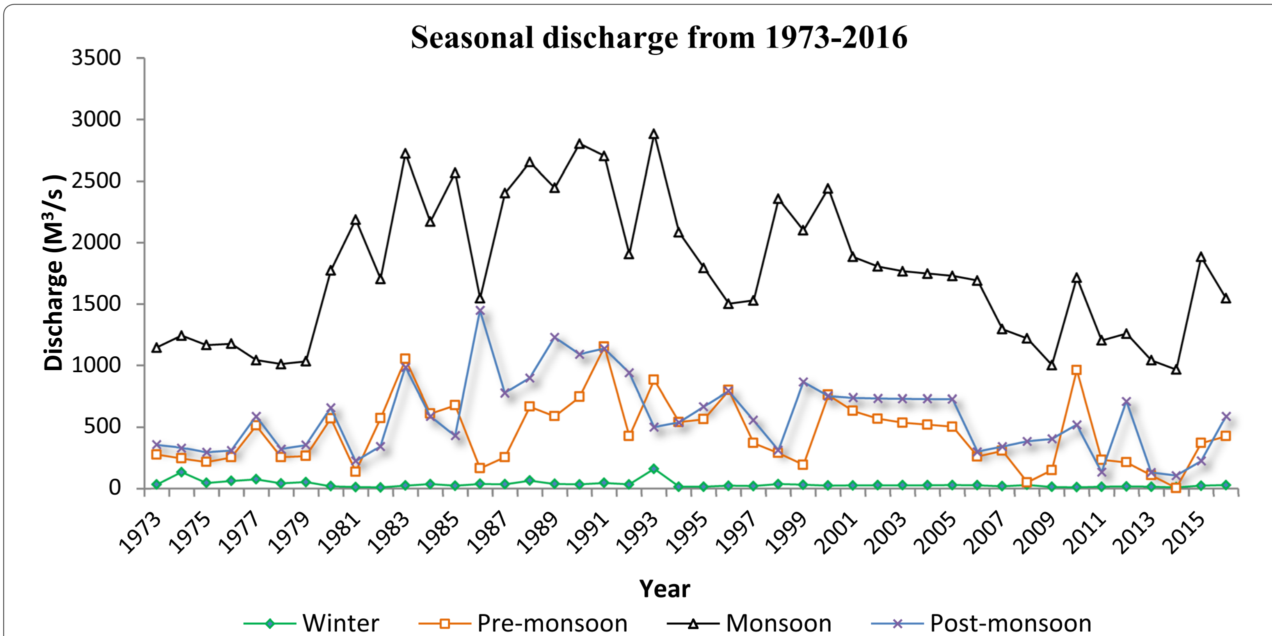

Fig. 3 Seasonal discharge from 1973 to 16

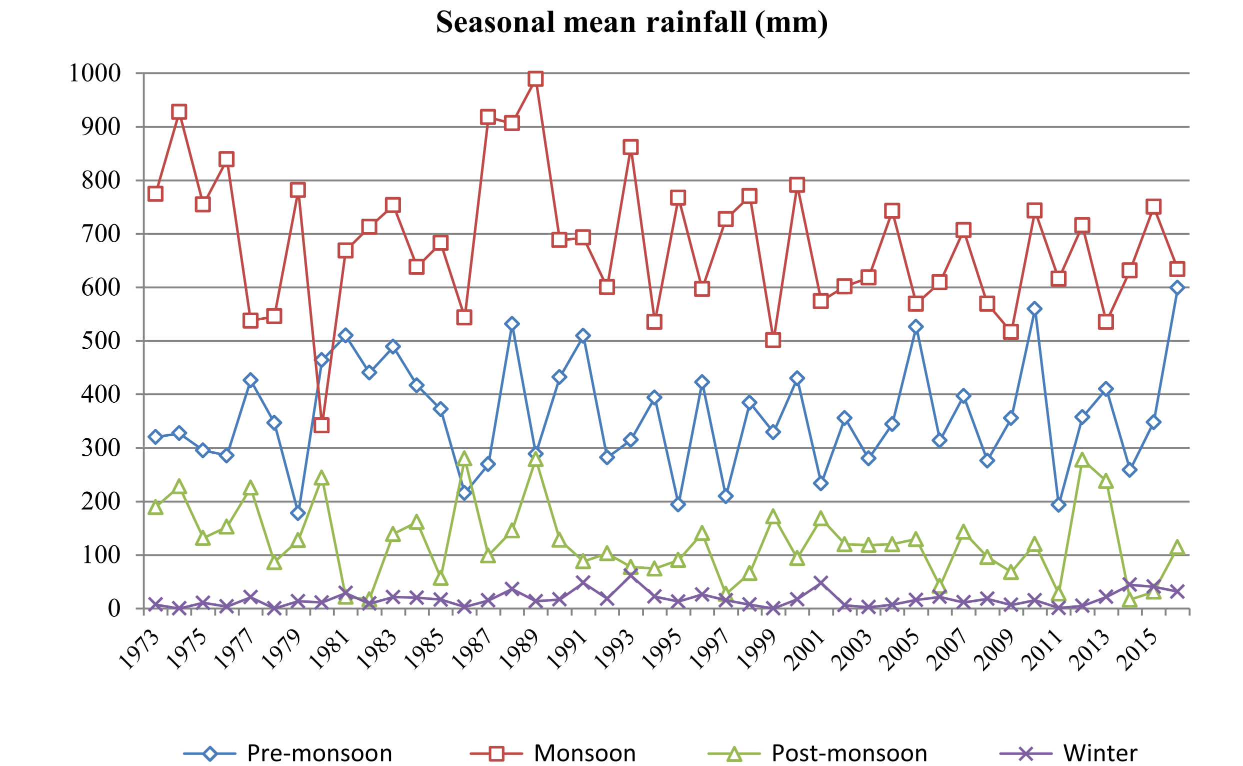

Fig. 4 Mean seasonal rainfall from 1973 to 2016

moderate rate. After 1990 the trend of rainfall in Monsoon started to fall down. In recent year the rainfall in Monsoon season showing a little decreasing trend with a moderate slope. In winter, the lowest rainfall exhibits.

In the winter season the rainfall is very low and in recent years the rainfall of winter season is declining moderately (Fig. 4). The highest rainfall in winter season occurred in 2001 which was 47.34 mm (Fig. 4). On the contrary, in the Year 1974 and 1978 no rainfall exhibits in winter season in Sylhet. The rainfall in winter season is not consistent. It shows a notable anomaly (Fig. 4). In the middle period from 1987 to 1996, the rainfall in winter session was slightly higher than the rest of time period (Fig. 4) whereas after 1990 the rainfall in Monsoon started to fall down (Fig. 4). In recent year, the rainfall in Monsoon started to decline moderately (Fig. 4).

Relation between the Annual and seasonal rainfall and discharge trends in the study meteorological station

Variation of yearly rainfall at Sylhet has been depicted from the study period 1973 to 2016 (Fig. 5). The mean rainfall in pre-monsoon shows a little decreasing rate over the period of time. The highest rainfall in Pre-monsoon season occurred in 2016 which was 599 mm (Fig. 4). On the other hand, the lowest rainfall occurred in 1979 which was 177.7 mm (Fig. 4). In the monsoon season the highest rainfall gets (Fig. 4). In June the highest monthly rainfall exhibits in Sylhet (Fig. 2). In recent year the rainfall of Monsoon season is showing a decreasing trend (Fig. 4). The highest and lowest rainfall in Monsoon season occurred in years 1989 and 1980 which was 989.5 mm and 341.75 mm respectively (Fig. 4). In recent years the rainfall of Post-monsoon declining moderately (Fig. 4). The highest rainfall in Post-monsoon season occurred in 1986 which was 280 mm (Fig. 4). The lowest rainfall in Post-monsoon season occurred in 1982 which was 17.76 mm (Fig. 4). Along with the rainfall of Sylhet district the discharge of Surma River also shows a decreasing trend in all season.

Figure 5 shows the mean annual rainfall from 1973 to 2016 and it is declining. The mean annual rainfall in this period is not consistent. From the graph it is seen that from the very beginning of 1973 the rainfall was above 450 mm, in the following year in 1974 the rainfall increased a lot which was above 550 mm (Fig. 5). Than in 1975 again the mean annual rainfall decreased (Fig. 5). In the period of 1975 to 1981, the rainfall shows a decreasing trend (Fig. 5). From 1982 to 1987 the mean annual rainfall was moderate (Fig. 5). From 1988 to 1992, the mean rainfall shows a very increasing trend (Fig. 5). In

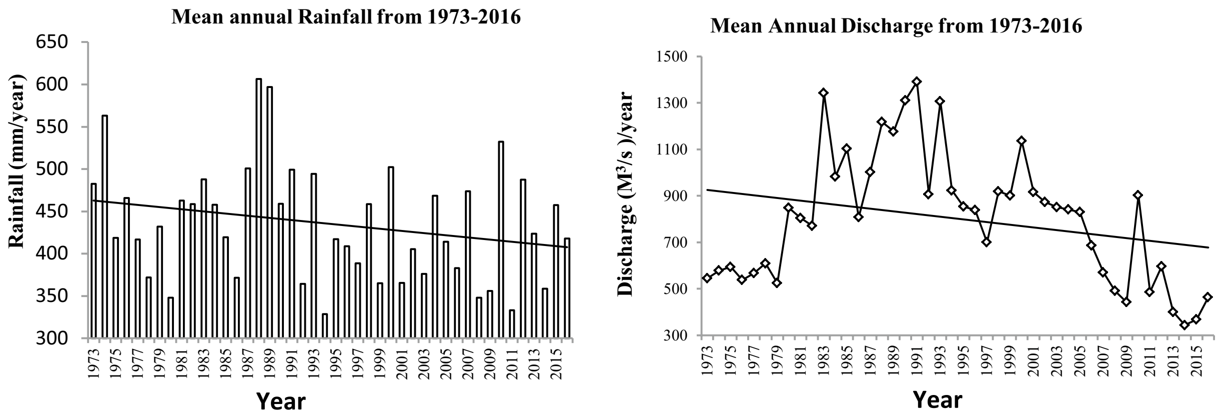

Fig. 5 Variation of yearly rainfall and discharge at Sylhet station from 1973 to 2016

the year 1988 the highest mean annual rainfall occurred (Fig. 5). From 1993 to 2016 the mean annual rainfall shows a decreasing trend. There was little anomaly in the rainfall pattern. In the year 2010 the mean annual rainfall was above 500 mm (Fig. 5). From 1973 to 2016 overall the mean annual rainfall shows a decreasing trend (Fig. 5). In recent, the rainfall in Sylhet decreased causing many effects on environment and economy. Due to the change of rainfall, the discharge pattern of Surma River might be changed. Consequently, the flow of water and the morphological structure of the river is reshaping with time. The mean annual discharge from 1973 to 2016 is showing decreasing trend (Fig. 5).

Pre monsoon and post monsoon characteristics

The rainfall and discharge of Surma River in March in these 44 years were analyzed to get a brief explanation of the dependency of discharge on rainfall. March is considered as a represents of Pre monsoon season, like this the Rainfall and discharge of July months also analyzed. July month is considered for monsoon season.

The above figure from 6 shows means rainfall and discharge from 1980 to 2016 in March. The discharge and rainfall in March is shown pretty similar change when the rainfall was low the discharge on that year was also very poor. In 1994 both rainfall and discharge was very high in March (Fig. 6). On the other hand in some years like 1984, 1986, 1999, 2007 both the rainfall and discharge was very poor (Fig. 6). Some anomalies also presented here, in 1995 and 2005 rainfall was high but the discharge was not that satisfactory (Fig. 6) this may be happened due to less runoff and more penetration of rainfall in soil. Therefore some different case also detected, in 1985, 1993 and 2010 the discharge was high where the rainfall was not that satisfactory in Sylhet that might be the cause of rainfall in the upstream (Meghalaya—India). The rainfall

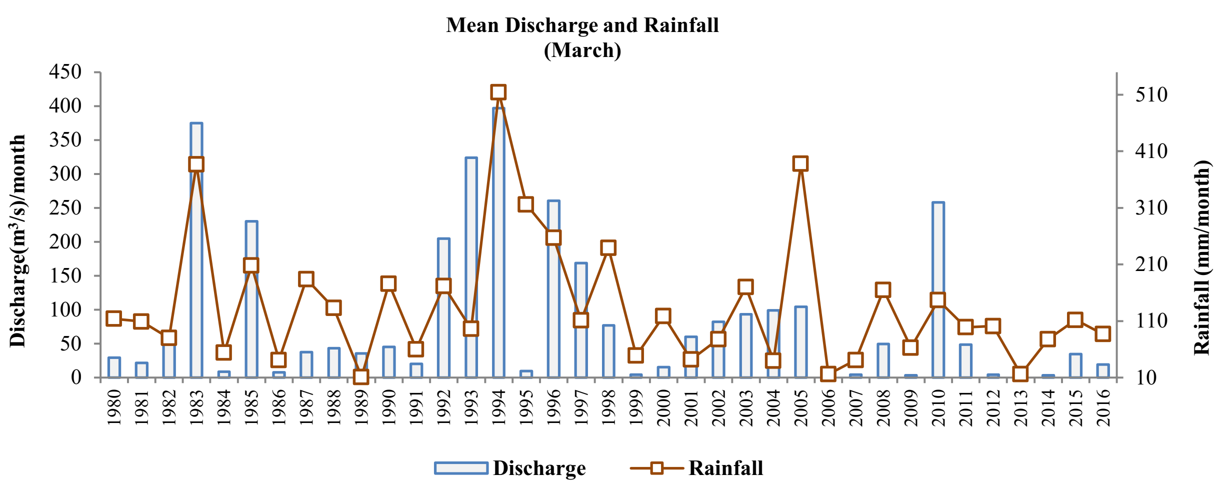

Fig. 6 Mean discharge and rainfall in March (1980 to 16)

in Meghalaya has some direct influence in the river discharge of Surma River because the Barak river originate from the Lusai hill in Assam and Surma is a branch of Barak river. It would be more valuable if the climatic data of upstream (Meghalaya- India) could analyze and detect the relation with the discharge of the river. It was one of the limitations of this study that the upstream climatic data was not purchasable to the researcher.

The above figure represents mean rainfall and discharge from 1980 to 2016 in July. From those figure it is seen that the discharge and rainfall is decreasing in recent years. Both rainfall and discharge is showing a decreasing trend (Fig. 7). The relation between rainfall and discharge within these years was almost similar but some differentiation also found. From 1980 to 1994 both the rainfall and discharge was high but in the following years both starting decreasing. Though the rainfall presented some anomalies but the discharge pattern was almost same. In 1999, 2002, 2005 and 2007 rainfall was much higher than the previous years but the case of discharge was different. From 2000 to 2008 the amount of discharge in July was almost similar. In 2009 discharge decreased a lot but then the following three consecutive years (2010–2012) discharge increased. Again from 2013 it stared decreasing.

Trend analysis

Table 2 shows the statistical result of Mann–Kendall Test and Sen's Slope of annual mean rainfall, total rainfall and discharge. The mean annual rainfall and the total rainfall both are showing a decreasing trend. At 95% significant level ($\alpha = 0.05$), above α value trend is not significant. If the p value is less than α value than the MK trend is significant.

Table 2 Mann–Kendall test and Sen's slope statistics of mean rainfall and discharge

Variable	*P* value	Sen's slope	Significant	Trend
Mean annual rainfall	0.03	− 1.53 (mm)	*Yes*	*Downward*
Total-rainfall	0.04	− 13.77 (mm)	*Yes*	*Downward*
Discharge	0.03	− 1.51 (m^3/s)	*Yes*	*Downward*

For Both trends is significant at 95% significant level. Sen's Slope measure the magnitude of the trend. How far the mean rainfall of Sylhet is deviate from the trend line per year is given by the Sen's Slope Estimate value. Negative values of Sen's Slope Estimate indicate the downward trend. Sen's slope for both mean annual rainfall and total rainfall are − 1.53 mm and − 13.77 mm (Table 2). From table the values of MK Test and Sen's Slope Estimate the mean Discharge of Surma River shows a downward trend. Here, Slope of trend of Surma River is − 1.51 (Table 2). Both the MK Test and Sen's Slope shows the decreasing trend (Table 2). It can be concluded that the mean Discharge of Surma River is decreasing with a little moderate rate (Table 2).

Table 3 shows the statistical result of Mann–Kendall Test and Sen's Slope of seasonal mean Discharge. In winter and post-monsoon MK test value was not significant at 95% significant level. In Pre-monsoon and monsoon discharge of Surma River shows a downward trend and the trend is significant at 95% significant level. According to Sen's Slope estimate, changes in mean Discharge of Surma River in

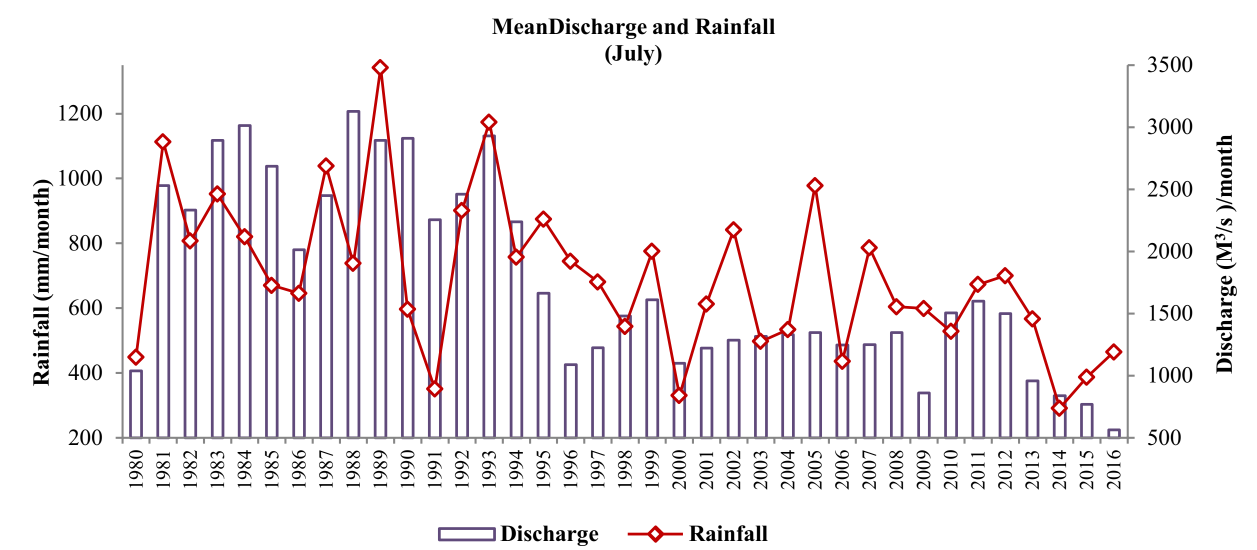

Fig. 7 Mean discharge and rainfall in July (1980 to 16)

Table 3 Mann–Kendall test and Sen's Slope Statistics of seasonal mean discharge

Season	Mann–Kendall test		Sen's slope	Significance	Trend
	Test statistics Z	P-value			
Winter	−1.06	0.14	−0.34	No	Downward
Pre-monsoon	−1.11	0.006	−1.28	*Yes*	*Downward*
Monsoon	−1.50	0.06	−1.86	*Yes*	*Downward*
Post-monsoon	−1.21	0.13	−1.04	No	Downward

Table 4 Mann–Kendall test and Sen's slope statistics of seasonal mean rainfall

Variable	P-value	Sen's slope (mm)	Significant	Trend
Pre-monsoon	0.02	−11.56	*Yes*	*Decreasing*
Monsoon	0.02	−5.19	*Yes*	*Decreasing*
Post-monsoon	0.03	−1.84	*Yes*	*Decreasing*
Winter	0.15	−0.85	No	Decreasing

pre-monsoon and monsoon are, −1.28, and −1.86 respectively (Table 3). In monsoon season the decreasing rate was higher than the pre-monsoon season.

The statistical result of Mann–Kendall Test and Sen's Slope of seasonal mean rainfall is presented in Table 4. Among four seasons the Pre-monsoon, Post-monsoon and Monsoon trend is significant at 95% significant level. According to Sen's Slope estimate, changes in mean seasonal rainfall in Sylhet in pre-monsoon, post-monsoon and monsoon are −11.56, −1.84 and −5.19 respectively (Table 4). In pre-monsoon season the change of rainfall in per year was highest. In winter season the change of rainfall per year is lowest.

Effects of climate change on river discharge

The impacts of climate and hydrological changes cover all spatial scales, from local to global (Lahmer et al. 2001; Coulthard et al. 2005). There is now substantial evidence indicating that over the most recent decades, the global hydrological cycle has already been responding to observed global warming (Bates et al. 2008), which includes an increasing atmospheric water vapor content and changing precipitation pattern. In many regions, the changing precipitation or melting of snow and ice is altering hydrological systems, affecting water resources in terms of quantity and quality (Jiménez et al. 2014). In context with global climate change the climate of Bangladesh is also changing. With respect to climate change the hydrology and morphology of river is also changing. In Statistics, a relation is any involvement between two measured quantities that renders them statistically dependent (Upton and Cook 2006). The behavior of river hydrology is closely related to rainfall. Rainfall is a key constituent of climate. To understand the effects of climate on river discharge 44 years' time series data of discharge and rainfall are analyzed together. Correlation and regression method was used to determine the impact of climate change on river discharge. The rainfall of Sylhet trend shows normal year-to year decreasing trend although there is an indication of declining rainfall trend. As with rainfall, the river discharges show normal year to year variations that are related to the variability in rainfall. Table 5 presents the Pearson's coefficient of correlation between annual mean rainfall and annual mean discharge of different season.

The Coefficient of correlation r of annual mean discharge and annual mean rainfall is 0.69 is close to +1 which indicates a strong positive relation between them. It is also seen in the Fig. 5 that the changes in rainfall and discharge are very similar. The discharge of Surma River was declining along with declining of rainfall in Sylhet (Fig. 5) On the other hand the P.E. of r between them is 0.053 (Table 5). The Coefficient of correlation r is six times more than the P.E of r which indicates the Coefficient of correlation r is significant. Multiple R square is 47.61 which means 47.61% of annual mean discharge depend on the annual mean rainfall (Table 5), the rest of discharge might gets from the rainfall in upstream region (Meghalaya). The positive value of regression coefficient means that changes in rainfall positively impacts the change in discharge (Table 5) which is seen in Fig. 5.

The r between winter rainfall and discharge is 0.49 which presents a moderate positive relation (Table 6). On the

Table 5 Correlation between mean discharge and mean rainfall from 1973 to 2016

Independent variable	Dependent variable	r-value	P.E (r)	R^2	R^2 in %	Significance
Annual mean rainfall	Annual mean discharge	0.69	0.053	0.4761	47.61	*Significant*

Table 6 Correlation between seasonal mean discharge and mean rainfall from 1973 to 16

Independent variable (rainfall)	Dependent variable (discharge)	r-value	P.E (r)	R^2	R^2 in %	Significance
Winter	Winter	0.49	0.07	0.24	24.01	*Significant*
Pre-monsoon	Pre-monsoon	0.57	0.06	0.32	31.49	*Significant*
Monsoon	Monsoon	0.61	0.63	0.37	37.21	Insignificant
Post-monsoon	Post-monsoon	0.64	0.06	0.40	40.96	*Significant*

other hand the P.E. of r between them is 0.077 (Table 6). The Coefficient of correlation r is six times more than the P.E of r which indicates the Coefficient of correlation r is significant. Multiple R square is 24.01 which means 24.01% of annual mean discharge depend on the annual mean rainfall (Table 6). The r between pre-monsoon rainfall and discharge is 0.57 which presents a moderate positive relation which is also. On the other hand the P.E. of r between them is 0.06 (Table 6). The Coefficient of correlation r is six times more than the P.E of r which indicates the Coefficient of correlation r is significant. Multiple R square is 31.49 which means 31.49% of annual mean discharge depend on the annual mean rainfall (Table 6). The r between Post-monsoon rainfall and discharge is 0.64 which presents a strong positive relation (Table 6). On the other hand, the P.E. of r between them is 0.06. The Coefficient of correlation r is six times more than the P.E of r which indicates the Coefficient of correlation r is significant. Multiple R square is 40.96 which means 40.96% of annual mean discharge depend on the annual mean rainfall (Table 6). A very good amount of discharge depends on the rainfall. It can say, the values indicate that the strength of association between the variables is very high ($r = 0.64$), and that the correlation coefficient is very highly significantly different from zero ($P < 0.001$) (Table 6). Also, we can say that 40.96% (0.4096) of the variation in discharge is explained by rainfall (Table 6).

Conclusion

The mean discharge of Surma River is 845.99 M^3/s. The Standard Deviation is 282.67 M^3/s which is far from the annual mean of 845.99 M^3/s that the mean discharge of Surma River is not consistent and fluctuating over time. The Highest annual mean discharge found in 1991 which was 1390.47 M^3/s. The Sen's slope for both mean and annual rainfall and total rainfall are −1.53 mm and −13.77 mm, respectively which indicates a decreasing trend. The discharge of Surma River shows a moderate positive relation with rainfall. When the rainfall decreases the discharge of Surma River is also decreases. When the rainfall increases, discharge is also increases. About 50% of discharge can be explained by rainfall in Sylhet. In addition, due to the change of rainfall, the discharge pattern of Surma River might be changed. Consequently, the flow of water and the morphological structure of the river is reshaping with time. At the end, the overall scenarios of fluctuations of the river from 1973 to 2016 is obvious which might be the indication of the climatic change in local as well as globally.

Abbreviations

GBM: Meghna River Basins; IPCC: inter-governmental panel on climate change; WL: water level; BMD: Bangladesh Meteorology Department; BWDB: Bangladesh Water Development Board; MK: Mann–Kendall; r: coefficient of correlation (r); mm: millimeter.

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Authors' contributions

MFH contributed to conception, design, and the supervision of the acquisition of data, data analysis and interpretation of data. SA participated to acquisition of data, data analysis and interpretation of data as well as involved in drafting the primary manuscript. ZA and TRC made a contribution to drafting, checking graphs, and revising the manuscript critically for final submission of the manuscript. All authors read and approved the final manuscript.

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