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HYDROLOGICAL CHARACTERISTICS ANALYSIS OF SURMA RIVER IN NORTHEASTERN BANGLADESH: A QUANTITATIVE APPROACH

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Abstract: *This article presents the quantitative analysis of hydrological characteristics of the Surma River in northeastern Bangladesh. Time series data from two hydrologic gauging stations named Kanaighat and Sylhet have been studied. Two kinds of data series, annual mean flow and annual peak discharge, have been considered for analysis. 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, skewness, Kolmogorov-Smirnov test, lag-1 serial correlation, Mann-Kendall test, Sen's slope estimator, and Pearson's coefficient of correlation. Results revealed that, annual mean flow is more consistent at Kanaighat than Sylhet. Peak discharge at both stations shows a low degree of variation. Distributions of peak discharge and mean flow are positively skewed at two stations. Presence of serial correlations in annual mean flow at both stations is statistically not significant. Both the annual mean flow and peak discharge have a downward trend at two stations. Trends at Kanaighat are insignificant, while trends at Sylhet are significant. Annual mean flows at the two stations are highly correlated to each other. The findings of the study express the current status of river and provide guidance for maintenance of surface water resources.*

Keywords: *Hydrological Characteristics, Mean Discharge, Peak Discharge, Surma River, Sylhet.*

1. Introduction

Rivers are the veins of the earth carrying the liquid water, which is essential for natural and artificial environment. The water carried by the river is called surface water [1]. Other containers of surface water are lake, pond, stream or reservoir. River provides the life generating-fuel to ecology. It is also a determinant of prosperity of human civilization. Many of the prominent ancient civilizations were developed on the bank of any river [2]. The livelihood pattern of human being largely depends on the river. River serves the humanity with different purposes. Many sectors of human society, including economy, culture, politics, transportation and agricultural characteristics have been influenced by river for thousands of years. River is a geographical feature. Natural and anthropogenic factors force the geographical feature, e.g. river to a continual change. The origin of the water drains by the river is precipitation, melting of glaciers, baseflow from groundwater, etc. [3]. Now, climatological elements have changed with time. With that change, river characteristics are also changing.

River characteristics can be divided into two classes. They are geomorphological and hydrological. Geomorphological characteristic covers the shape of the channel, river bed, meandering, sedimentation, erosional and depositional activities, etc. [4]. In other hands, hydrological characteristics, mainly covers mean rate of water flow, peak flow, flood stage, minimum flow, variability, skewness, discharge trend, correlations between different parts of stream etc. [5]. This study confined its scope within the analysis of basic hydrological characteristics. The study area of this research is the Surma River in northeastern Bangladesh. The Surma is one of the main rivers of the Surma-Meghna River System. This river is situated in the Meghna basin that covers the vast area of eastern India and eastern and northeastern Bangladesh. Hydrological data from two gauging

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stations have been analyzed here. They are Kanaighat station, which is located on upper stream, and Sylhet station, which is located on middle stream. There is another station named Sunamganj station located on the downstream. But discharge data are not available at that station. Therefore, Kanaighat and Sylhet station has been considered as the study area of this work.

Hydrological characteristics of the Surma River have been analyzed by quantitative method. Quantitative method includes various mathematical, statistical or computational methods. Different statistical methods have applied in this study. The main purpose to find out the hydrological characteristics is to determine the present situation of the river with a different perspective on the basis of historical data series. This knowledge can be helpful to predict the future status of the river. Water is considered as a precious element by human and other life being. Cause without fresh water life can't be sustained. Total volume of liquid fresh water in rivers is 2,120 km^3 which is 0.006% of total fresh water and 2.03% of total liquid fresh water [6]. Although the total amount of water on earth is generally assumed to have remained virtually constant, the rapid growth of population, irrigated agriculture, industrialization, urbanization, isstressing the quantity and quality aspects ofthe natural system e.g. river [7]. As a result, the necessity for a comprehensive policy of rational management of water resources has become important. To create and execute such kind of policy need the information on hydrological characteristics of the river. This study can provide that information in case of Surma River. In the earlier period, there was not any research on the Surma River with this topic.

There have been found a few papers dealing with the hydrological characteristics of vast areas like continental or world scale. Kalinin [8] studied the global hydrology. In this, he deals with quantitative aspects of the hydrological cycle in general, as well as particular space-time variations of hydrological elements. Yevdjevich [9] studied total 140 streams; most of them are located in the United States and Europe. He analyzed annual flow characteristics and flow volumes. McMahon [10] studied the 126 rivers of the world. He studied annual flow and peak flow. By reviewing those papers, this study also determined to analyze the annual flow and annual peak discharge.

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

(i) To analyze the basic statistical characteristics of annual mean flow and

(ii) To analyze the basic statistical characteristics of annual peak discharge of Surma River.

2. Study Area

The Surma is one of the major rivers in Meghna basin. The area covered by the Meghna basin is 82,000 square kilometers. Bangladesh contains 42.7% of the Meghna basin. The Surma River originated from Barak River, another river of the basin in Indian part. Near Bangladesh boundary, Barak is bifurcated into Surma and Kushiyara River. After streaming as separate channels, Surma and Kushiyara are joined to form the Meghna River, which ended at Bay of Bengal. Kanaighat and Sylhet stations are located on the upper and middle course of the Surma. Location of Kanaighat station is 25.00°N and 92.27°E, and location of Sylhet station is 24.89°N and 91.85°E. Both stations are situated in Sylhet district in northeastern Bangladesh. Figure 1 shows the Map of study area, including two hydrologic gauging stations and river portion confined within Sylhet district boundary.

3. Materials and Method

3.1 Materials

Daily discharge data series of Kanaighat and Sylhet station of the Surma River have been collected from Water Resource Planning Organization (WARPO) and Bangladesh Water Development Board (BWDB). Total period of collected data is 42 years (from 1973 to 2014). Among them, daily discharge data from 1973 to 2006 was collected from WARPO. And observed discharge data from 2007 to 2014 was collected from BWDB. Then, the annual mean flow from 1973 to 2014 have been derived from collected daily and observed data series. And annual peak discharge data has been derived from daily time series from 1973 to 2006. Therefore, period of annual mean data series and annual peak data series is 42 and 34 years respectively.

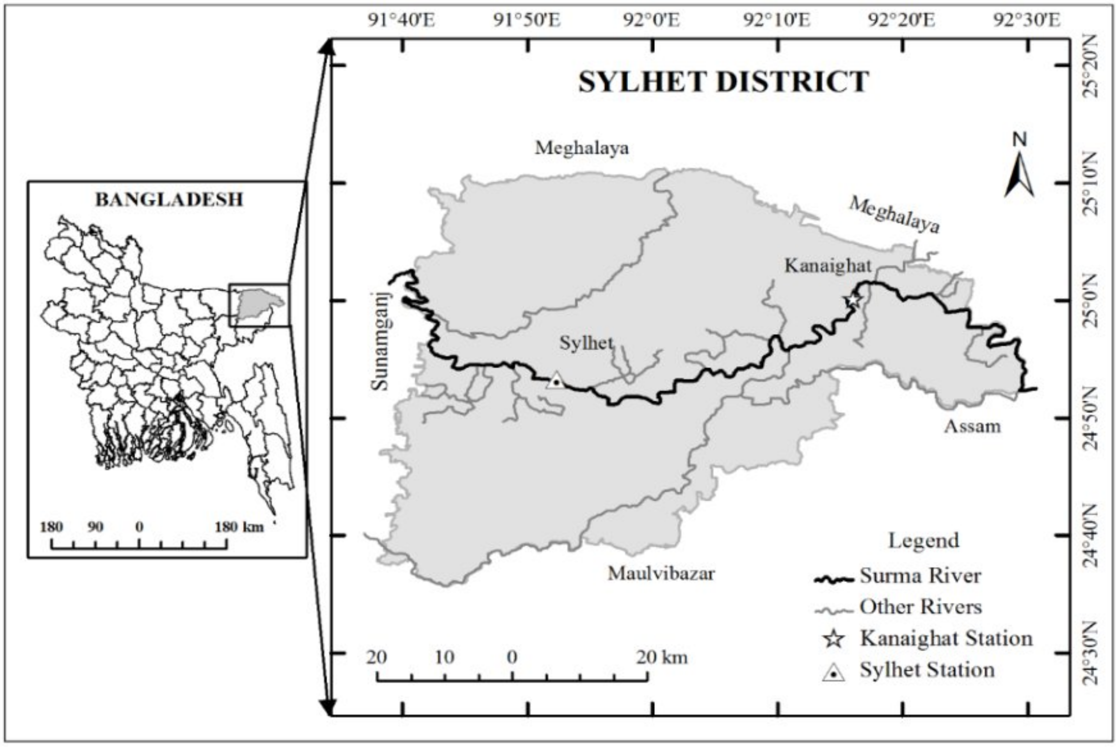

Figure 1: Location of studied gauging stations

3.2 Method

In the natural sciences and social sciences, quantitative research is the systematic empirical investigation of observable phenomena via statistical, mathematical or computational techniques [11]. Various statistical methods have been operated to derive the hydro-characteristics of Surma River. Two types of data, annual mean flow and annual peak discharge, have been analyzed. The applied statistical methods are briefly described below:

3.2.1 Coefficient of Variation

Coefficient of Variation (CV) represents the ratio of the standard deviation to the mean. It is widely used to measure the degree of variation or variability of any distribution. It measures the consistency of time series data. CV can be computed by following equation:

$$CV = \frac{\sigma}{\mu} \quad (1)$$

Here, σ = Standard Deviation, and

μ = Mean

3.2.2 Skewness

Skewness is the degree of asymmetry or departure from symmetry of a distribution. That is, it means lack of symmetry or the degree of distribution from symmetry. The following equation is used to calculate the coefficient of skewness:

$$S_k = \frac{n}{(n-1)(n-2)} \sum \left(\frac{x_i - \overline{x}}{s} \right)^3 \quad (2)$$

Here, n = Sample size, and s = Sample standard deviation. Coefficient of skewness can be positive or negative. If positive, the distribution is to be called positively skewed. The tail of the shape at the right side is longer. If negative, the distribution is to be called as negatively skewed. The tail of the shape at the left side is longer.

3.2.3 Kolmogorov-Smirnov Test

The Kolmogorov-Smirnov test [12] is used to decide if a time series is normally distributed. KS-test is defined by two hypotheses:

H_O: The data follow a normal distribution

H_1: The data do not follow a normal distribution

For testing of hypothesis, calculated p-value of KS-test is compared with the value of 'α'; at 95% significance which is 0.05. If a p-value is greater than 0.05, then the data set is normally distributed. If a p-value is less than 0.05, then the data set is not normally distributed.

3.2.4 Pearson's Coefficient of Correlation

Coefficient of correlation is a numerical measure of the correlation between two fluctuating series, and is denoted by r. It is the numerical expression of the degree of correlation existing between two variables.

Let, $x_1,x_2,\ldots\ldots,x_n$ and $y_1,y_2,\ldots\ldots\ldots,y_n$ be two data sets. Coefficient of correlation between two data sets can be expressed as:

$$r = \frac{\sum_i (x_i - \bar{x})(y_i - \bar{y})}{\sqrt{\sum_i (x_i - \bar{x})^2} \times \sqrt{\sum_i (y_i - \bar{y})^2}}$$

(3)

3.2.5 Serial Correlation

The relationship between a given variable and itself over various time intervals. Serial correlations are often found in repeating patterns when the level of a variable affects its future level. Serial correlation can be measured at different lag period. In this study, lag-1 serial correlation has been calculated. To estimate the lag one serial correlation, following equation is used:

$$r_k = \frac{\sum_{i=1}^{N-k} (x_i - \bar{x})(x_{i+k} - \bar{x})}{\sum_{i=1}^{N} (x_i - \bar{x})^2} \quad (4)$$

The quantity r_k is called the serial correlation coefficient at lag *k*.

3.2.6 Sen's Slope Estimator

The magnitude of trend is estimated by the Sen's estimator [13]. Here, the slope (T_i) of all data is computed as:

$$T_i = \frac{x_j - x_k}{j - k} \quad \text{For } i = 1,2,\ldots\ldots,N \quad (5)$$

Where, x_j and x_k are considered as data value at time j and k (j>k) correspondingly. The median of these N values of T_i is represented as Sen's estimator of slope which is given as:

$$Q_i = \begin{cases} T_{\frac{N+1}{2}} & N \text{ is odd} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+1}{2}}\right) & N \text{ is even} \end{cases} \quad (6)$$

Sen's estimator is computed as $Q_{med} = T_{(N+1)/2}$ if N appears odd, and it is considered as $Q_{med} = [T_{N/2}+T_{(N+2)/2}]/2$ if N appears even. At the end, Q_{med} is computed by a two sided test at 100 (1-α) % confidence interval and then a true slope can be obtained by the non-parametric test. Here, α denotes level of significance which is 0.05 (at 5% level of significance and 95% confidence level). That implies that we are 95% confident about the significance of the decision and there is 5% chance to occur a type 1 error. Positive value of Q_i indicates upward or increasing trend and a negative value of Q_i gives a downward or decreasing trend in the time series

3.2.7Mann-Kendall Test

The Mann-Kendall (MK) test [14,15] is a non-parametric test for identifying trends in time series data. The test compares the relative magnitudes of sample data rather than the data values themselves [16]. One benefit of this test is that the data need not conform to any particular distribution. No assumption of normality is required [17].

This test has been widely used in hydrological studies. This test evaluates whether outcome values tend to increase or decrease over time. It is highly recommended for general use by the World Meteorological Organization [18]. The hypotheses of Mann and Kendall's trend test are written below.

H_O: Time series values are independent and identically distributed, i.e. there is no trend.

H_1: There is a monotonic (not necessarily linear) trend

So, it is a two-tailed test. The test statistic, S is than computed as:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sign(y_j - y_i) \quad (7)$$

Where, $sign(y_j - y_i)$ is equal to +1, 0 or -1, n is the total number of observations. It has been documented that when n >= 8, the statistic S is approximately normally distributed with the mean.

$$E(S) = 0$$

The variance statistic is given as:

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{j=1}^{m} t_1(i)(i-1)(2i+5)}{18(8)}$$

Where, t_i is considered as the number of ties up sample i. The test statistics Z_c is computed as:

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} \\ 0, S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, S < 0 \end{cases} \quad (9)$$

Z_c here follows a standard normal distribution. A positive (negative) value of Z signifies an upward (downward) trend. A significance level α is also utilized for testing either an upward or downward monotonic trend (a two-tailed test). Here, the value of α is 0.05 at5% level of significance. If Z_c appears greater than $Z_{\alpha/2}$ where α depicts the significance level, then the trend is considered as significant

3.2.8 Probable Error

The probable error is used to find out the reliability or the significance of the value of Pearson's coefficient of correlation. It is obtained as:

$$P.E\ (r) = 0.6745 \times \frac{1 - r^2}{\sqrt{n}} \quad (10)$$

Where, r = Coefficient of correlation, n = Number of pairs (x, y), and 0.6745 is a constant.If the value of r is less than P.E, then r is not significant. If the value of r is greater than 6 times of P.E, then r is significant [19].

3.2.8 Coefficient of Determination

The coefficient of determination is the square term of the coefficient of correlation (r). It is usually denoted by r^2 (or R^2). It expresses the proportion of the total variation of the dependent variable has been explained by the independent variable [20].

4. Results and Discussion

4.1 Annual Flows

Mean annual flow is obtained by dividing the sum of all the individual daily flows by the number of daily flows recorded for the years. Arithmetic mean, variability, skewness, distribution type, persistence, trend, and correlation between two stations have been calculated and discussed below.

4.1.1 Mean Annual Flow

The mean annual flow of the Surma River over 42 years (from 1973 to 2014) has been calculated. Upper and middle stream shows a tiny difference in mean annual flow. The mean annual flow through Kanaighat station is 545.92m^3/s. At Sylhet station, it is 542.06m^3/s. Water flow in Kanaighat is higher that Sylhet; though the difference is very small. This difference indicates the water withdrawal between upper and lower stream of the river.

4.1.2 Variability

Variability of hydrologic events of the Surma River has been calculated by the coefficient of variation (CV). CV is the most influential method to measure variability. CV measures the consistency of variables of any time series. In this study, variability of annual mean flow in Kanaighat and Sylhet station is measured by CV method. The measured values of CV in Kanaighat and Sylhet are 0.23 and 0.16 respectively. The lower value of variability indicates the distributions are more consistent. Annual mean flow at Sylhet is more consistent than Kanaighat station. Distribution of annual mean flow at Kanaighat is more dispersed than Sylhet.

4.1.3 Skewness

The measure of mean and variability provides the information about the characteristics of a set of values; but they can't determine the shape characteristics of the set of values (or distribution). Shape characteristics mean the asymmetry of the set of values. The measured coefficient of skewness of annual mean flow at Kanaighat and Sylhet is 0.76 and 0.62. Both values are positive. That means the distributions are positively skewed and not symmetrical. Tails on the right side of the shapes are longer than left sided tail. Mass of larger values than mean value is concentrated on the left side of the shape. The mean of the distributions is higher than the median. It revealed that, smaller values than mean flow are concentrated at the left side. Therefore, most of the smaller values of mean annual flow have been occurred in later years. In other hand, maximum of larger values has been occurred in earlier years.

4.1.4 Distribution Types

Distribution types are determined by normality test. Normality test is a test which determines whether the distribution is normally or not normally distributed. Kolmogorov-Smirnov (KS) method is applied to detect the normality of discharge data series in this study. The P-value of KS test is <0.01 and 0.04 at Kanaighat and Sylhet respectively. These values are less than α (= 0.05). Therefore, annual mean flows at both stations are not normally distributed at 5% significance level. Normal distribution follows a symmetrical shape. And not normal distribution is asymmetrical distribution. The degree and direction of asymmetry can be detected by skewness. Skewness is measured in paragraph 4.1.3. Though skewness already indicated that, distributions are not symmetric which determined the distributions as not normal. The Kolmogorov-Smirnov test is conducted to determine the normality more precisely at the5% level of significance.

4.1.5Persistence

Persistence is an important characteristic of hydrological variables. Persistence is the effect of one event on following event of a time series. If there is a significant amount of soil moisture in a basin carried over from one year to the following year, such that the flows in the second year are larger than they otherwise would be, then this effect is regarded as persistent [21]. Persistent can be measured by serial correlation or autocorrelation. Here, lag one serial correlation is measured for annual mean flow of Kanaighat and Sylhet station. Coefficient of correlation at Kanaighat and Sylhet is 0.21 and -0.11 respectively. The reliability of these correlation values has been tested by student's t-test. At the5% level of significance, t-test revealed that, serial correlations are not significant at both of the Kanaighat and Sylhet stations. The main consequence of presence of serial correlation is that, it influences the trend and prediction of time series. According to the t-test, the presence of such type of correlation in annual mean flow has not strong evidence.

Table 1 Trend test statistics of annual mean flow

Variable	Z	P-value	Q	Trend
Annual Mean flow at Kanaighat	-0.694	0.244	-0.938	Downward
Annual Mean flow at Sylhet	-1.864	0.031	-1.510	Downward

Z = MK test statistic; Q = Sen's slope

4.1.6 Trend

The trend is a pattern of gradual change in a condition, output, or process, or an average or general tendency of a series of data points to move in a certain direction over time, represented by a line or curve on a graph. The trend shows the general direction that a group of points seem to be heading. Non-parametric Mann-Kendall (MK) test has been applied to detect trends of annual mean discharge at both stations. Fluctuation rate or slope of the trend has been calculated by the Sen's slope estimator. Annual mean flows at both of Kanaighat and Sylhet stations show downward trend (Table 1). Cause values of Z are negative. P-value at Kanaighat is greater than 0.05; so, the trend is insignificant at 95% significance level. In other hand, p-value at Sylhet is less than 0.05; therefore, the trend at Sylhet is significant. Sen's slope (Q) revealed that, Annual mean flow at Kanaighat is changing at a rate of -0.938m^3/s per year. While, the changing rate at Sylhet is -1.51m^3/s per year. The negative sign of Q indicates the downward trend.

Table 2 Correlation statistics of annual mean flow at two stations

Independent Variable	Dependent Variable	r	P.E	r^2	r^2 in %
Annual Mean flow at Kanaighat Station	Annual Mean flow at Sylhet Station	0.86	0.027	0.7396	73.96

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

4.1.7 Relation between Two Stations

The hydrological variability of lower stream depends on the hydrologic status of upper stream. Kanaighat station is situated atupstream of Sylhet station. Therefore, there might be positive, strong relations between two stations. Pearson's coefficient of correlation method is used to detect the relations. Table 2 shows the correlation statistics. The value of correlation is 0.86 which interpret a strong positive relation between two stations. P.E has been calculated to determine the reliability of the correlation. According to the value of P.E, correlation is significant. r^2 is the coefficient of determination. It expresses the proportion of the total variation of the dependent variable has been explained by the independent variable [22]. 73.96% variables of the annual mean flow at Sylhet can be explained by annual mean flow at Kanaighat. The rest of the 26.04% variables of annual mean discharge at Sylhet station are not directly related to flow from Kanaighat station. These may be originated from run-off or baseflow from groundwater.

4.2 Peak Discharge

Annual peak discharge means the highest rate of flow among the recorded data during a year through a certain point. Like annual mean flow, Kanaighat and Sylhet station is considered to analyze peak discharge. The results of different statistical operations in annual peak discharge have been discussed below.

4.2.1 Mean Annual Peak Discharge

The mean annual peak discharges of thirty-five years are 2085.70m^3/s and 1850.74m^3/s at Kanaighat and Sylhet respectively. Annual peak discharge at Kanaighat varied from 1580 to 2810m^3/s. In other hand, at Sylhet station, annual peak discharge varied from 1350.96 to 2480m^3/s.

4.2.2 Variability and Skewness

Firstly, variability has been measured by the coefficient of variation method (CV). The values of CV for annual peak discharge at Kanaighat and Sylhet is 0.16 and 0.15 respectively. Two values are quite close to each other. The lower value of CV indicates the more consistency of the distribution. If the value of CV is zero, then there is no variation among distribution. Hence, the variables of annual peak discharge are not highly varied. McMahon [23] calculated the CV of peak discharge of world's major rivers. The mean value of the CV of the rivers of different climatic zone is: 0.13 (Tropical), 0.15 (Semi-arid), 0.17 (Temperate), and 0.15 (Cold). The Surma River is situated in tropical zone. The CV of Surma is close to the value of tropical zone's rivers, which indicates the close relationship of Surma with other rivers of this zone.

Secondly, degree of asymmetry of the standard symmetrical shape of distribution is calculated by skewness. The value of skewness of annual peak discharge at Kanaighat and Sylhet is 0.43 and 0.34 respectively. Positive value of skewness indicates the longer tail of shape on the right side of the distributions. Mass of higher values than the mean is concentrated on the left side of the shape. The mean is greater than the median. Mass of lower values than the mean is concentrated on the right side of the shape. That means most of lower values than mean occurred in recent or later years out of total period of years. Earlier years have most of higher values than the mean.

4.2.3 Dependence

The dependence of following year on the previous year is tested by serial correlation. Lag-1 serial correlation shows the variables of annual peak discharge are not independent. Coefficient of correlation at Kanaighat and Sylhet is 0.39 and 0.52 respectively. Serial correlation at Kanaighat is not significant, while the correlation at Sylhet is significant at the 10% level of significance (α=0.10). Mean value of the lag one serial correlation coefficient of the major rivers was found to be 0.13 [24]. In case of

Surma River, these values are indeed higher. Generally, during analysis of peak discharges, they are assumed to be independent. Serial correlation showed that, peak discharge of the Surma River has dependency on the previous year's value. Though, according to the value of serial correlation, this dependency or relation is not very strong.

4.2.4 Trend

Statistical trend has been measured to detect the general direction of the changes of annual peak discharges at both stations of Kanaighat and Sylhet. Non parametric MK test has been applied to detect the trend. Results of the MK test revealed that, at both stations, annual peak discharge has downward or decreasing trend (Table 3). According to p-value, trend at Kanaighat is not statistically significant at 95% significance level. While at Sylhet station, the trend is statistically significant. According to Sen's slope, the annual fluctuation rate is -8.26m^3/s and -14.9m^3/s at Kanaighat and Sylhet respectively. This fluctuation rate does not indicate the decreasing rate. Peak discharge has both of increment and decrement in different and consecutive years. Slope of the trend refers to the average changes or fluctuations. Negative sign of the value of slope directs the direction of fluctuation which is downward.

Table 3 Trend test statistics of annual peak discharge

Variable	Z	P-value	Q	Trend
Annual Peak Discharge at Kanaighat	-1.05	0.15	-8.26	Downward
Annual Peak Discharge at Sylhet	-2.62	0.004	-14.9	Downward

Z = MK test statistic; Q = Sen's slope statistic

5. Conclusion

The objective of this research was to analyze the characteristics of annual mean flow and annual peak flow by statistical approach. The results of the statistical operation gave some significant results. Some corollaries can be taken from the results of various statistical tests. Skewness shows the distribution's tail is rightly longer. This means small values have more surpluses in later years. It makes a sense that; annual mean and peak discharge are decreasing. This corollary is further investigated by trend test. Both the annual mean and peak discharge showed negative trend. So the findings of statistical test have an adjustment and harmonization. This study concentrated on the basic characteristics of Surma River. The results of this research can be a gateway for further research and helpful for policy makers to understand the river situation and upcoming consequences.

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