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Detection of Trend in Hydrologic Variables Using Non-Parametric Test: A Study on Surma River in Northeastern Bangladesh

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Abstract

An initiative has been taken to investigate the trends in discharge and water level (WL) of the Surma River in northeastern Bangladesh. The daily time series data of discharge and WL from two stations named Kanairghat and Sylhet with a period of 42 years (1973 – 2014) and 35 years (1980 – 2014) respectively have been analyzed. Non parametric Mann-Kendall Test has been applied to detect the trend and Sen's slope estimator is used to measure the slope of the trends. In Kanairghat station, annual mean WL has significant trend (*P*: 0.03); while, annual mean discharge, mean monsoon discharge, annual maximum discharge, mean monsoon WL, and annual maximum WL shows insignificant trend (*P*: 0.24, 0.46, 0.14, 0.05, and 0.12). In Sylhet station, annual mean discharge, annual maximum discharge, and annual mean WL have significant trend (*P*: 0.03, 0.004, and 0.02). On the other hand, mean monsoon discharge, mean monsoon WL, and annual maximum WL in Sylhet station has insignificant trend (*P*: 0.46, 0.13, and 0.21). According to Sen's slope statistics, all of the detected trends, except annual maximum WL at Sylhet station, are downward. This study recommends a comprehensive water management scheme should be taken to ensure sustainable use of the river water.

Keywords: Trend; Discharge; Water Level; Surma River; Non-parametric; Sylhet.

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1. Introduction

Surface water is the life generating fuel for civilizations. The main sources of surface water are lakes and rivers. People and life on earth consume water to meet their everyday needs of water from these surface water resources. Total volume of waters in rivers is 2,120 km^3 which is 0.006% of total fresh water and 2.03% of total liquid fresh water [1]. Rivers contain only a small amount of fresh water. But this is where humans get a large portion of their water from. The pattern of water flow in the stream is

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changing all over the world. Water is linked with various climatic variables, e.g. temperature, precipitation, evaporation etc. Studies have found that ecumenical surface warming is occurring at a rate of 0.74 ± 0.18°C from 1906 to 2005 [2]. In association with temperature change; there must be a change in precipitation. Perceptions demonstrate that progressions are happening in the amount, intensity, frequency, and types of precipitation [2]. The observed long-term trend over the century (from 1900 to 2005) shows spatial variations across the earth, such as: significantly wetter in eastern North and South America, northern Europe and northern and central Asia, but drier in the Sahel, southern Africa, the Mediterranean and southern Asia [2]. Effect of climate change in the future is very extreme as given by IPCC reports which imply that there will be diminishment in the freshwater accessibility on account of climate change [3]. This has likewise been uncovered that by the center of 21st century, diminishing in yearly mean runoff and accessibility of water will extend up to 10 – 30% [4]. So, there may have a change in river flow.

Many researchers analyzed the trend of streamflow change of different countries and regions. Month to month mean stream-flow in Canada for most months diminished, with the most grounded abatement in summer and autumn months, and there was no river basin displaying upward pattern or trend [5]. There is an upward streamflow trend pattern at USA except for a little number of downward trends gathered in the Northwest, Florida, and beach front Georgia [6]. The trend of 26 basins in Turkey showed in general downward trend [7]. In China, in case of Yangtze River, annual maximum discharge and water level has downward trend at upper stream while at middle and lower stream has upward trend [8]. In short, streamflow characteristics are changing all over the world.

Bangladesh is situated at the drainage outlet of Ganges, Brahmaputra and Meghan River system. Therefore, Bangladesh is known as a riverine country with a network of many rivers. Out of those, Surma River is one of the principal streams in the country. Climate has no boundary and change at one place can influence the changing factors of another place. While, climatic variables and the surface water situation are changing all over the world, Bangladesh is not isolated from these phenomena. Fourth assessment report of IPCC [2] showed that, long term trend analysis of precipitation from 1900 to 2005 found a drier situation in southern Asia. Hence, streamflow at Bangladesh must have a change. Surma River is situated at north-eastern part of the country. It has been found in previous studies that, rainfall in north-eastern Bangladesh has a downward or decreasing trend [9]. Monsoon rain has a strong impact on river flow. Monsoon rainfall in north-eastern Bangladesh also showed slightly decreasing trend [10]. So, it is expected that, there must be a change in streamflow of Surma River. Therefore, this study made an attempt to investigate the trend of discharge and water level of the Surma River over a certain period of time. Out of total river course, the upper and middle course has been selected as the study area. There are two hydrologic gauging stations at the concerned portion of the river – Kanairghat station (at upper stream) and Sylhet station (at middle stream). Annual mean, mean monsoon and annual maximum discharge and water level have been analyzed. There are three distinct seasons in Bangladesh [11]. They are, summer (March - May), monsoon (June - October) and winter (November - February). The Surma River drains around 77% of its annual discharge in monsoon. Therefore, out of three seasons, this study only considered the monsoon season. This study has not any initiative to build relationships between precipitation change and streamflow change. To investigate the trend status is the only purpose of this research.

The specific objectives of the study are the following:

i. To investigate the trend status of annual mean, mean monsoon and annual maximum discharge of the Surma River in Bangladesh.

ii. To investigate the trend status of annual mean, mean monsoon and annual maximum water level of the Surma River in Bangladesh.

1.1. *Study area*

The Surma River is one of the main rivers of Meghna basin. The Meghna basin covers a total catchment area of 82,000 km^2 in India and Bangladesh. Bangladesh contains 42.68% of the basin, which covers an area of 35,000 km^2. It extends along the eastern and north-eastern part of Bangladesh. The study area of this research is the upper and middle courses of Surma which are confined within Sylhet district boundary. Two hydrologic gauging stations named Kanairghat and Sylhet stations from upper and middle stream of the river have been selected for trend analysis. Fig. 1 shows the locations of the two studied stations.

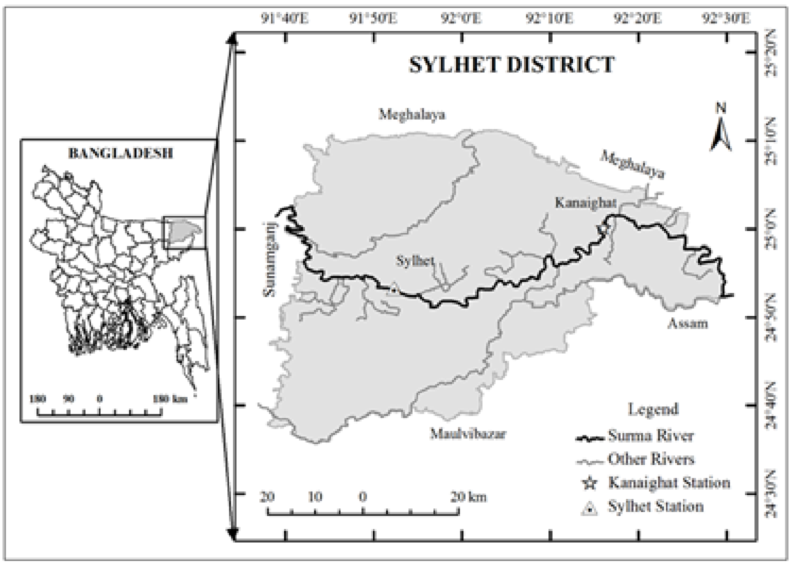

Fig. 1. Map of the study area.

2. Materials and Methods

2.1. *Materials*

Two prominent hydrologic elements of river, discharge and water level, have been analyzed to detect the hydrologic trend of the river. The discharge and water level data have been collected from two government organizations named Water Resource Planning Organization (WARPO) and Bangladesh Water Development Board (BWDB). Total period of discharge data is 42 years (from 1973 to 2014), while period of water level data is 35 years (from 1980 to 2014).

2.2. *Methods*

To detect the trend of annual and seasonal discharge and water level of Surma River, non-parametric Mann-Kendall test (hereafter MK test) has been used. Non-parametric test is a distribution free test. It has no need to assume the time series as a normal distribution. It can dodge the issue energized by data skew [12]. MK test is a factual technique which is being utilized for contemplating the spatial variety and fleeting patterns of hydro-climatic arrangement [3]. This test had been formulated by Mann [13] and test statistic distribution had been given by Kendall [14]. It assimilates the relative sizes of sample data instead of the data values themselves [15]. MK test is normally utilized technique to survey the noteworthiness of monotonic patterns in hydro-meteorological data. It is exceedingly suggested for general use by the World Meteorological Organization [16].
The hypotheses of Mann and Kendall's trend test are:
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 then computed as:

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

Where, $sign\ (y_j - y_i)$ is equal to +1, 0 or -1, n is the total number of observations. It has been noted that when $n >= 8$, the measurement S is roughly ordinarily circulated with the mean.
$E(S) = 0$
The variance statistic is given as:

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

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

$$Z_c = \begin{cases} \frac{S-1}{\sqrt{Var(S)}} \\ 0, S = 0 \\ \frac{S+1}{\sqrt{Var(S)}}, S < 0 \end{cases} \quad (3)$$

Z_c here takes after a standard ordinary circulation. A positive (negative) estimation of Z connotes an upward (descending) pattern. A significance level α is likewise used for testing either an upward or descending monotone pattern (a two-tailed test). In the event that Z_c seems more noteworthy than $Z\alpha/2$ where α portrays the centrality level, then the pattern is considered as critical or significant. In this study, 95% significance level is used where $\alpha = 0.05$. P value has been calculated for testing the significance of the trend. P values greater than α indicate an insignificant trend, while a P value less than α indicates a significant trend.

The magnitude of the trend is estimated by the Sen's estimator [17]. Here, the slope (T_i) of all data is computed as:

$$T_i = \frac{x_j - x_k}{j-k} \quad \text{For i = 1, 2……, N} \quad (4)$$

Where, x_j and x_k are considered as a 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:

$$Q_i = \begin{cases} T_{\frac{N+1}{2}} & N \text{ is odd} \\ \frac{1}{2}\left(T_{\frac{N}{2}} + T_{\frac{N+1}{2}}\right) & N \text{ is even} \end{cases} \quad (5)$$

Sen's estimator is processed as $Q_{med} = T_{(N+1)/2}$ if N seems odd, and it is considered as $Q_{med} = [T_{N/2}+T_{(N+2)/2}]/2$ if N seems even. Toward the end, Q_{med} is registered by a two sided test at 100 (1-α)% certainty interim and after that a genuine slant can be acquired by the non-parametric test. Positive estimation of Q_i demonstrates upward or expanding pattern and a negative estimation of Q_i gives a descending or diminishing pattern in the time series.

3. Results and Discussion

3.1. *Trends in discharge*

Table 1 shows the trend test results of annual mean, mean monsoon, and annual maximum discharge of Sylhet and Kanairghat station. Out of six discharge data series in two stations, all of them are showing a downward trend. P value reveals that, two trends out of six, annual mean and annual maximum discharge in Sylhet are significant at the 5% level of significance. The rest of the discharge trends are insignificant. The slopes of the discharge trend (Q) vary from 0.938 cumec to 14.9 cumec. Maximum annual discharge shows a larger slope in both of the stations. This implies that, the extremity of the river has larger fluctuations than mean flow.

Table 1. Trend test statistics of discharge at Kanairghat and Sylhet station.

Variables	Z	*P* value	Q (m^3/s)	Trend
Annual Mean Discharge at Kanairghat	-0.694	0.24	-0.938	Downward
Annual Mean Discharge at Sylhet	-1.864	0.03*	-1.510	Downward
Mean Monsoon Discharge at Kanairghat	-0.09	0.46	-0.180	Downward
Mean Monsoon Discharge at Sylhet	-1.50	0.06	-1.867	Downward
Annual Maximum Discharge at Kanairghat	-1.05	0.14	-8.26	Downward
Annual Maximum Discharge at Sylhet	-2.62	0.004*	-14.9	Downward

*Note: Z = MK test statistic, Q = Sen's slope, *P value less than 0.05 indicates significant trend*

The findings of the present study are relevant to previous research findings on global climatic phenomena. As we stated, IPCC [2] found a drier trend of precipitation in southern Asia, while Mondal *et al*. [3] concluded that there is a possibility of diminishing fresh water on the basis of global climatic change. The downward trend of the Surma River reflects the findings of those studies. Some neighboring south Asian rivers, such as the Jhelum River of northwestern India and eastern Pakistan also showed a downward trend in annual and seasonal discharge [18]. The downward discharge trend has also relevancy with local scale precipitation change. Decreasing trend has been found in annual precipitation and monsoon precipitation in Sylhet region in previous studies [9,10]. It clearly explains the results of the present study. Moreover, Nury *et al*. [19] analyzed the discharge trend of Kushiyara River – another major river of the Meghna basin, which is originates from the same source of Surma River. They found a significant downward trend of discharge (*P* : 0.03). Therefore, the global and local rainfall trend as well as discharge trend of adjacent river of the same basin strengthens the acceptance of the downward trend of Surma River.

3.2. *Trends in water level*

Table 2 shows the results of trend analysis of water level at both stations. All of the water level data series, except annual maximum water level at Sylhet, shows a downward trend. According to *P* value, the mean annual water level at both stations has significant downward trend at 5% significance level. On the other hands, the rest of the downward trends of water level are insignificant. The only detected positive trend, annual maximum water level at Sylhet, is also insignificant. The slope of the trends varies from 0.01 to 0.02 meters for downward trends. Increasing trend's slope of maximum water level at Sylhet is very small (0.004 m).

The downward trend has also been found in some Asian rivers in previous studies. Delgado *et al*. [20] analyzed the trends of the Mekong River by MK test, where negative trend was found. On the other hand, Zang *et al*. [8] analyzed the annual maximum water level of the Yangtze River in China. The Yangtze River shows an upward trend of maximum water level during the same period considered for this research. In this study, Sylhet station has also showed an upward trend of maximum water level. Therefore, the findings of the present study has relevancy with other rivers of the same continent. Maximum water level indicates the extremity of flood. Therefore, the extreme flood level is increasing in the Sylhet region. In other words, flood severity is decreasing in upper stream (Kanairghat station) and increasing in middle stream (Sylhet station) of the Surma River.

Downward trend of discharge and water level might have some consequences on ecosystem, agriculture, and naval transportation of concerned area. The agricultural sector will suffer from lack of surface water for irrigation purpose. As a result, farmers will be more dependent on ground water extraction, which eventually will create a shortage of drinking water. Reduction of ground water will also affect the streamflow at dry season. Decreasing of streamflow will increase the concentration of pollutants and turbidity, which is very harmful for aquatic organisms. There are some heavy industries on the bank of Surma River. They transport raw materials and products by using naval transportation facilities on the river. It will be difficult to operate naval vessels due to decreasing of river flow. In short, immense damages on the sector of agriculture, trade and commerce will occur if the river dries out. Local and national economy will be damaged.

Table 2. Trend test statistics of water level at Kanairghat and Sylhet station.

Variables	Z	*P* value	Q (mPWD)	Trend
Annual Mean WL at Kanairghat	-1.96	0.03*	-0.015	Downward
Annual Mean WL at Sylhet	-2.16	0.02*	-0.015	Downward
Mean Monsoon WL at Kanairghat	-1.56	0.05	-0.02	Downward
Mean Monsoon WL at Sylhet	-1.11	0.13	-0.01	Downward
Annual Maximum WL at Kanairghat	-1.16	0.12	-0.013	Downward
Annual Maximum WL at Sylhet	0.78	0.21	0.004	Upward

*Note: Z = MK test statistic, Q = Sen's slope, *P value less than 0.05 indicates significant trend, mPWD = Meter from Public Works Datum*

4. Conclusion

The objective of this study was to find out the trend status of hydrological variables (discharge and water level) of the Surma River; especially at upper and middle course. The results of the analysis showed some meaningful findings. At both of the upper and middle stream of the river, the annual mean water level is decreasing significantly. In case of discharge, significantly decreasing at middle stream, but insignificantly decreasing at upper stream. In short, water level and discharge both are decreasing. These phenomena of hydro-variables of the river might have an impact on physical and human environment of the river basin area. The study of monsoon trend also revealed downward trend. Annual maximum water level of Sylhet showed an increasing trend. Though it is not significant trend, but it gives some concept of future flood scenarios at middle Surma. Concerned authorities must be given attention on this issue. A further comprehensive study on the impact of decreasing trend of streamflow and water level can reveal the detail consequences. This study might be helpful and gateway for that kind of initiatives.

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