International Research Journal of Earth Sciences E-ISSN 2321–2527
Vol. **4(6),** 1-16, June **(2016)** *Int. Res. J. Earth Sci.*

Capturing Stream Flow Regime of Punarbhaba River of Indo-Bangladesh

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Available online at: www.isca.in, www.isca.me
Received 17th Feburary 2016, revised 24th June 2016, accepted 25th June 2016

Abstract

This work mainly concentrates on detecting trend of stream flow since 1978 to 2014 in Punarbhaba river of Indo Bangladesh. For detecting trend and change, Pettitt test, standard normal homogeneity test (SNHT), Mann-Kendall test, Spearman's rank correlation methods have been used. It is observed that within this spectrum of study period, 1992 is detected as yard mark for change in flow regime. In pre and post change point phases, water levels have reduced by 10.22%, 18.22%, 15.42% and 12.48% during pre monsoon, monsoon, post monsoon and winter periods respectively. Significant trend is detected in mean, maximum and minimum flow character as indicated by Kendall's tau value of MK test e.g. -0.57, -0.62 and -0.48 in the respective parameters. After change point phase water level is reduced but variability of flow is increased from 2.24% to 6.61% for mean flow level, 1.54% to 6.45% for maximum flow level and 3.24% to 5.78% for minimum flow level. This sort of flow attenuation has fur flung impact on downstream habitat and ecosystem characters.

Keywords: Change point detection, flow regime, flow trend, Mann-Kendall Test and Pettit's test.

Introduction

Climate change, human intervention on river flow etc. are some burning issues impacting flow characters. Mix responses are recorded in this issue of flow alteration. One group established that flow modification has stabilized flow and other group responded that instability is the penultimate of flow modification. For investigating it properly, it is essential to detect the trend of flow regime. Gradual and catastrophic change speaks about the vectors of change responsible for it. Adeloye et al. documented that consistent and trend free are two ideal conditions for hydrological time series in water resource planning[1]. According to Xiong and Gao Consistency means hydrological variable always behaving or performing in a similar way, while trend free means there is no significant association between the variables[2]. But consistency and trend free hydrological variables are never observed in reality. Many studies documented that there is exists significant non-consistency or non-stationary in many hydrological regions because of the effect of climatic change and large scale anthropogenic activities upon water resource. Perreault have documented the presence of change point in their work[3]. Douglas have detected the trend exist in stream flow data[4].

Hydrological variables (water level, discharge) frequently experienced variability over time and this may be cyclical with the seasons, steadily (a trend), abruptly (a step-change) or some other types variation over time[1]. In time series data set, detecting abrupt changes from a sequence of observation is called change point detection and it has attracted researchers from several disciplines for decades. There are several parametric and non-parametric methods for detection of change point. The non-parametric Pettitt test and standard normal homogeneity test (SNHT) are used to detect occurrence of the abrupt change in a time series hydrological data set[5-6]. Trend analysis of hydrological regimes focuses on whether variables are increasing or decreasing over time[1]. There are many researchers worldwide have been used recently different non-parametric and parametric statistical tests to assess trend in hydro-meteorological time series data sets[7-10]. Mann-Kendall test and Spearman's rank correlation have widely been used in stream flow trend analysis[11-13]. Xuefei analyzed the data using Pettitt test and standard normal homogeneity test, with the results exhibit the change point located in 1977 for minimum water level, but did not find change point for maximum water level (Pettitt test) and 1981(standard normal homogeneity test)[14]. Vezzoli performed SNHT tests on minimum and maximum annual discharge with a confidence level of 5%[15]. Yeh analyzed the data using Pettit test and cumulative deviation test, with the results show that change points existed only in Ximen Bridge Station among the 12 gauging stations in the study area. The change point of the Ximen Bridge Station occurred in 2001[16]. Zheng documented that annual stream flow in four headwater catchment of the Yellow River experienced no significant change in trend during 1956-2000[17]. Li (2007) analyzed the data for annual stream flow during 1972-1997 in Wuding River and reported a significant downward trend in the beginning of 1972[18]. Zhang used MK test in their study and reported decreasing trend for annual maximum stream flow in the upper portion of Yangtze River. The middle and lower portion of Yangtze River has featured significant positive trend[19]. Rougé documented application of Mann-Kendall and Pettit test (1979) on 1217 data sets of hydrological time series (rainfall, river flows) in the United States during 1910–2009 for detection trend and step-change[20].

The Mann-Kendall test exhibits significant trend in a sequence of observations. But, it cannot be estimate the magnitude of the upward or downward trend. So, Theil-Sen estimator is used to calculate trend slope in conjunction with MK test. MK test and Theil-Sen estimator are used together.

The present paper investigates whether the water level data of the Punarbhaba River since 1978 to 2014 show evidence of change point in the data set i.e. to investigate is there any significant climate change impact on flow character or any other intervention. This paper also attempts to find out is there any significant trend of mean, minimum and maximum water level in pre and post change points condition if change regime does exist.

Study area: Punarbhaba River (length: 160 km, width of valley: 3 to 8 km) basin, covering an area 5265.93 sq. km, is a tributary of Mahananda River located upstream in Dinajpur, Thakurgaon district of Bangladesh and downstream in South Dinajpur, Malda district of India and Nawabganj district in Bangladesh where it join with Mahananda River. Elevation of this basin ranges from 89 meter (at the source region) to 12 meter (at the confluence). Total annual rainfall is 154cm. and out of total rainfall 83% rainfall concentrates on monsoon months (June to September) and therefore post monsoon (October to December) and pre monsoon (March to May) agriculture depends on either river water or subsurface water.

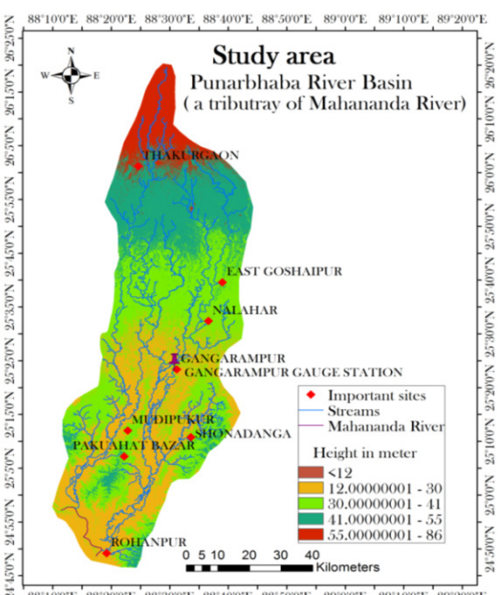

Figure 1
Punarbhaba River Basin

Materials and Methods

Data collection: The present study is totally based on secondary data. But the major shortcoming of this study is related to the lack of proper data regarding hydrological variables. Though the data were found and obtained from Gangarampur gauge station, Irrigation and Waterways Department and North Bengal Planning Division, Malda and District Irrigation Department, Balurghat[21]. Monthly discharge and water level data were obtained from 1978 to 2014. Gangarampur Gauge station has following characteristics is represented in Table-1.

Change point detection: A number of methods can be applied to determine change points of a time series. In present study, the non-parametric Pettitt test, standard normal homogeneity test are used to detect occurrence of the abrupt change in a time series data set. Alexandersson test can be applied to the testing of homogeneity in the time series, which is also known as SNHT (standard normal homogeneity test). Alexandersson test have used to detect change in a data set. A statistic $T(y)$ is used to relate the mean of first y year with the last of (n-y) year[22].

$$Ty = \bar{y}z_1 + (n-y)\overline{z_1}, y = 1,2,\dots,n$$

Where, $\overline{z_1} = \frac{1}{y}\sum_{i=1}^{n}\frac{(y_i-\overline{y})}{s}$ and $\overline{z_1} = \frac{1}{n-y}\sum_{i=y+1}^{n}\frac{(y_i-\bar{y})}{s}$

Where, $\bar{y}$ denotes mean and s denotes the standard deviation of the sample data. To determine the most probable break point of the data series the following equation is followed:

$$T_0 = maxT_y, 1 \le y < n$$

When T_0 attains extreme value in the data series that point is called change point. It is assumed that, y_i have same mean under null and alternative hypothesis, h, SNHT test detects change point, i.e., when Ty has a extreme value in year $y = A$, it is means that is located in year A a probable change (deviation). At what time Ty has small values to all y years the null hypothesis will be valid, besides when Ty takes greater values it will be more probable the alternative hypothesis. The null hypothesis will be rejected when T_0 be above a specified level, which is dependent on the sample size.

Another method, Pettit test is a non-parametric rank based test, has applied to detect the homogeneity and finding the changing point that exists in a sequence of observation when the exact time is unknown [23]. Pettit test can be defined as follows: it uses the version of the Mann-Whitney statistic Ut, considering a time series variable (X1, X2,., Xt), which have a change point at t. As a result, the dataset is divided into two intervals from same population, first is (X1, X2,..., Xt) and second is (Xt+1, Xt+2,..., Xn) The Ut statistic is derived from the following equation:

$$Ut = \sum_{i=1}^{t}\sum_{j=t+1}^{n} sgn(x_i - x_j)$$

Where,

$$sgn(x_i - x_j) = \begin{pmatrix} 1 & if\ (x_i - x_j) & > 1 \\ 0 & if\ (x_i - x_j) & = 0 \\ -1 & if\ (x_i - x_j) & < 1 \end{pmatrix}$$

Table-1
Gauge station and its characteristics

Stream gauge	River	Location of the Gauge station		Characteristics of gauge station		
		Latitude	Longitude	P.D.L	D.L.	E.D.L
Haripur, Malda	Punarbhaba	24°53'24"N	88°19'16"E	25.22	25.82	26.42

However, Ut value has plotted against time t in a time series with no change point. As a result, if |Ut| will continue to rise, no breaking point will be observed. But |Ut| will rise up to a particular point and started to decrease after that point and thus create breaking point, so it can be said that change point exists in time series. The most probable changing point is determine, if changing point exists there, by using following equation,

$$Kt = \max|ut|, 1 \leq t < n$$

Kt is the extreme value of |Ut|. Then the confidence level associated with Kt value is calculated by following equation,

$$p = 1 - \exp\left(\frac{-6k^2 t}{n^2 + n^3}\right)$$

The change point will statistically significant at time t with α level of significance, when probability (P) crosses (1-α).

Trend Analysis: Trend analysis can be defined as the measured value of hydrological variables describe the amount or rate of change, either upward or downward during a time period and the change may be deviation from some central value of the distribution such as mean or median[24]. In present study, trend analysis of the hydrological variables is carried out in two phases: First phase is related to trend detection, here two methods are used to detect trend in the hydrologic data series, namely, Mann-kendall and Spearman rank correlation coefficient method.

Trend estimation is the second phase of trend analysis. Sen's Estimator method is used for trend estimation and it estimates the magnitude of increasing and decreasing trend. Phase 1: Trend detection:

Mann-Kendall Test: Mann originally used this test and Kendall subsequently derived the test statistic distribution[11-12]. This non-parametric distribution free test is applied to assess the significance of monotonic trend in hydrological variables[17].

Mann Kendall test is done to considering the time series of n data points and Xi and Xj are the annual value in i and they are ranked as i = 1,2,3,…, n-1 and j = i+1, i+2, i+3, …, n. The data values are evaluated as an ordered time series. Each data value of Xi is compared with all subsequent data values of Xj. If a data value from a later time period is higher than a data value from an earlier time period, the statistic S is incremented by 1. On the other hand, if the data value from a later time period is lower than a data value sampled earlier, S is decremented by 1. The net result of all such increments and decrements yields the final value of S[25-26].

The MK test statistic is given by:

$$S = \sum_{i=1}^{n} \sum_{j=i+1}^{n} sgn(x_j - x_i)$$

Where,

$$sgn(x_i - x_j) = \begin{pmatrix} 1 & if\ (x_i - x_j) & > 1 \\ 0 & if\ (x_i - x_j) & = 0 \\ -1 & if\ (x_i - x_j) & < 1 \end{pmatrix}$$

Where, Xi and Xj are the annual values in years i and j, j›i respectively.

For Large samples (N›10), the statistical value S is assumed to be similar to a normal distribution with a mean of 0 and the variance of statistic S is computed as follows:

$$var(s) = \left[\frac{n(n-1)(2n+5) - \sum_{p=1}^{q}(t_p - 1)(2t_p + 5)}{18}\right]$$

Here *tp* is the number of data values in the pth group and q is the number of tied groups. The *Z* value can be used to determine whether the time series data exhibits a significant trend. The *Z* value is defined as:

$$Z = \begin{pmatrix} \frac{s-1}{\sqrt{var(s)}} & for & s > 0 \\ 0 & for & s = 0 \\ \frac{s+1}{\sqrt{var(s)}} & for & s < 0 \end{pmatrix}$$

If the normalized test statistic Z is equal to zero, the data are normally distributed, and the positive values of Z mean a rising trend and negative a decreasing trend.

Another statistic calculated using Mann-Kendall test is as Kendall's Tau, which measures the strength of the relationship between variable X and Y[24]. Kendall's Tau is done on the basis of rank of the data. The value of Kendall's Tau is ranges from -1 to +1. The positive correlation indicates that rank of the variables increases together and vice versa[27].

Mann-Kendall Tau is calculated as:

$$T = \frac{s}{n(n-1)/2}$$

Where: S=Mann- Kendall principle of statistic, n= total number of data in the time series.

Serial correlation: In the present study Trend free pre-whitening method is used to remove the presence of serial correlation in the time series dataset prior to application of Mann-Kendall trend test[28]. Pre-Whitening can remove some of the trend as well as serial correlation. The presence of serial correlation can complicate the identification of trends and presence of a positive serial correlation can increase the expected number of false positive outcomes for the Mann-Kendall test. When sample size and magnitude of trend are large enough, serial correlation no longer significantly affects the MK test statistics. In this study, before the MK test was applied, the series of annual, monthly, seasonally maximum and minimum and average water level of the Punarbhaba River were tested for persistence by the serial correlation analysis method. The equation for the calculation is as follows:

$$r_1 = \frac{\sum_{i=1}^{n-1}(x_i - \bar{x})(x_i + 1 - \overline{x})}{\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

Where N is the length of the time series, Xi is the value of the time series at time t, $\bar{x}$ is the overall mean of Xi and $x_i + 1$ is the same time series with a lag time of 1. 95% significance of r_1 can be estimated by using following equation:

$$r_k(95\%) = \frac{-1 \pm 1.96\sqrt{N-k-1}}{N-k}$$

Where k is the time lag and rk is the autocorrelation coefficients at the time lag of k.

Addinsoft's XLSTAT 2014 software is used for performing the Mann- Kendall test. The null hypothesis is tested at 95% confidence level.

Spearman's Rank correlation Coefficient (rho): Spearman's rank correlation coefficient or spearman's rho or rs is used in the present study for determining the degree of linear association or correlation between two independence variables[13].

$$r_s = \frac{1 - 6\sum_{i=1}^{n} d_i^2}{n^3 - n}$$

In rank correlation coefficient, each variable is ranked separately from lowest to highest such as 1,2,…,n and the difference between each data pair is calculated. If the data are correlated then the sum of the square of difference between ranks will be small. When there are no tied ranks, then there is simple equation that may be used to calculate the Spearman correlation coefficient:

Where: di is the difference between the ranks of Xi and Yi data pair and n is the number of the data pairs. If there are ties in the dataset, then the equation will be more complicated, but it will be appreciable differences if the number of tied data pairs are large. Then the equation of spearman's correlation coefficient will be:

$$r_s = \frac{\frac{(n^3-3)}{6} - \sum_{i=1}^{n} d_i^2 - \sum T_{x-}\sum T_y}{\sqrt{\left[\frac{(n^3-3)}{6} - 2\sum T_x\right]\left[\frac{(n^3-3)}{6} - 2\sum T_y\right]}}$$

Where, $\sum T_x = \frac{1\sum_{j=1}^{g}(t_j^3 - t_j)^2}{12}$ (For X value) and $\sum T_y = \frac{1\sum_{j=1}^{g}(t_j^3 - t_j)^2}{12}$ (for Y value)

r_s Value ranges from -1 to +1. Here 1 indicates perfect positive correlation between the variables and -1 denotes perfect negative correlation, while rs value 0 denotes there is no correlation between the variables.

The significance level of the r_s test statistic can be done in special tables when the value of n is small. For samples with more than 20 values a t statistic can be calculated using equation

$$t = {}^{r_s}\sqrt{\frac{n-2}{1-r_s^2}}$$

Which is distributed similar to Student's t distribution with $n - 2$ degrees of freedom (df). If P-value associated with that t statistic which is less than α, we reject the null hypothesis and vice versa.

Trend estimation: In this phase, Theil and Sen's estimator is used to estimate trend or magnitude of trend and it is introduced by Sen. When time series data represents linear trend, true slope can be calculated by this method. This method has great advantages that it is not influenced by extreme value as like linear regression analysis[16]. The formula for trend slope calculation is as follows:

$Ti = \frac{x_{j-}x_k}{j-k}$ Where i=1,2,…….n

Where *xj* and *xk* are the data values at time j and k (j>k) respectively. The Sen's slope estimator represents the median of these N values of Ti which is given as:

$$Q_1 = \left[\frac{1}{2}\begin{Bmatrix}\frac{Tn+2}{2} & \\ \frac{Tn}{2} + & \frac{Tn+2}{2}\end{Bmatrix}\right] \begin{matrix} N\ is\ odd \\ N\ is\ evem \end{matrix}$$

In the time series, the positive value of Qi indicated an upward or increasing trend and vice-versa.

The percentage change over a period: The percentage change can be estimated by using the median slope of Theil and sen's slope estimator[30]. It is calculated by multiplying median slope of Theil and sen's slope estimator with length of the period of time series data and then derived results are divided by the mean of the time series. It is calculated as follows:

$$Percentage\ change\ (\%)over\ period = \frac{Median\ slope\ \times Length\ of\ the\ period}{Mean}$$

Results and Discussion

Change point detection and serial correlation: The Pettitt's test and Standard normal homogeneity test (SNHT) are used to calculate the change point for the water level data**.** The results of change point detection for annual water level data series are presented in Table 2. The most probable change point is 1992 for water level data of Punarbhaba River for the entire study area over 37 year's period and the resultant change year by the both test are more reliable with each other. Both results are statistically significant at 0.01 levels presented in Table-1. The average annual stream flow for pre and post change point is 21.55 and 18.43 meter, respectively. After 1992, the average water level decreased by 3.12 meters.

Table – 2
Change point detection

Methods	Change point year	Significance level
Pettitt's test (Data)	**1992**	**
Standard normal homogeneity test (SNHT)	**1992**	**

** indicates 0.01%evel of significance.

Trend of annual stream flow regime: Table-2 displays the results of Mann-Kendall and Spearman's rho for the significance test of annual average, maximum and minimum stream flow. Variables those are significant at 95% levels of significance are shown in bold. Before change point (1978-1992), average, maximum and minimum water level does not have significant trend but experienced slight reduction of water level. But after change point (1993-2014) average (**-**0.5731 of MK test and **-**0.7764 of rho), maximum (**-**0.6206 and **-**0.8182) and minimum (-0.4783 and -0.6759) water level have documented significant declining trend and the result of both the trend test have same results.

Table-3 summarized the result of the calculation of Sen' slope estimator, where a trend slope greater than zero indicates an upward stream flow and vice versa. Relative percentage change is also calculated to show the amount of change of annual stream flow. Insignificant trend of decline in annual average, maximum and minimum water level has observed for pre-change point and it is significance for Post change point. The result of Sen's slope estimator and percentage change for the annual water level are: average (-0.1125 and -13.46%), maximum (-0.1261 and -14.38%) and minimum (-0.08 and -9.91%).

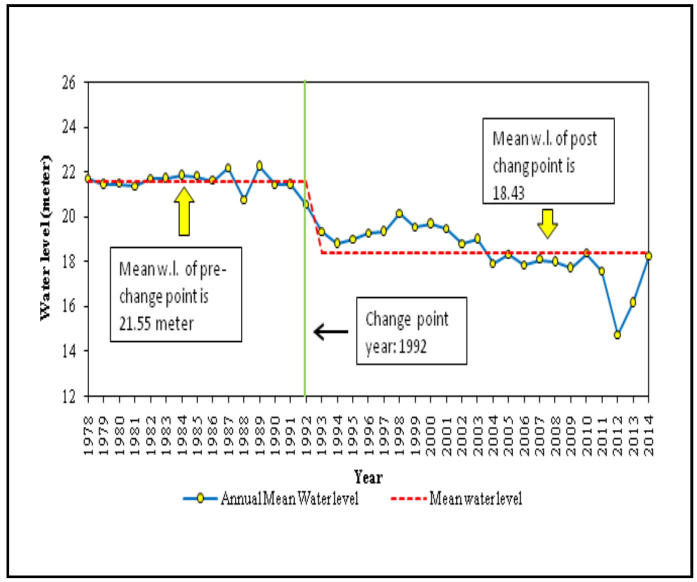

Figure 2
Change point detected at Haripur Gauge station over Punarbhaba River

Table-3
Trend of annual average, maximum and minimum water level using Mann-Kendall and Spearman's rho

Length of recorded data	Water level	Mann-Kendall test result	Sen's slope	Relative Change (%)	Spearman rank correlation	Remarks
		Kendall's tau				
Before Change point (1978-1992)	Average water level	-0.0476	-0.0026	-0.18095	-0.1571	Trend does not exist
	Maximum Water level	-0.1429	-0.0117	-0.78706	-0.2643	Trend does not exist
	Minimum Water level	-0.1429	-0.0313	-2.26823	-0.2286	Trend does not exist
After change point (1993-2015)	Average water level	**-0.5731**	-0.1125	-13.4577	**-0.7764**	Significant trend
	Maximum water level	**-0.6206**	-0.1261	-14.3819	**-0.8182**	Significant trend
	Minimum water level	-0.4783	-0.08	-9.91046	**-0.6759**	Significant trend for rho

Values in bold letter indicates significant (alpha=0.05)

Table-4
Monthly Average water level trend using Mann-Kendall test and Spearman rank correlation Method

	Month	Mann-Kendal test result		Relative change (%)	Spearman rank correlation	Remarks
		Kendall's tau	Sen's slope			
Before Change point	January	-0.3062	-0.066	-4.90228	-0.3771	Slightly negative trend exist
	February	-0.2297	-0.0983	-7.11929	-0.2431	Slightly negative trend exist
	March	-0.2488	-0.056	-4.15896	-0.2627	Slightly negative trend exist
	April	**-0.689**	-0.17	-12.8962	**-0.8561**	Significant trend
	May	**-0.6381**	-0.165	-12.4226	**-0.8179**	Significant trend
	June	0.3143	0.095	6.414296	0.4714	Slightly positive trend exist
	July	**0.4857**	0.2325	14.43143	**0.6571**	Significant trend
	August	0.181	0.073	4.528536	0.3214	Trend does not exist
	September	**0.4211**	0.08	5.046257	0.5147	Significant trend
	October	0.3333	0.093	6.235287	0.4857	Slightly positive trend exist
	November	-0.2762	-0.1667	-12.1869	-0.3250	Slightly negative trend exist
	December	-0.0095	-0.0025	-0.18197	-0.0214	Trend does not exist
After change point	January	-0.1619	-0.0304	-3.56748	-0.3052	Slightly negative trend exist
	February	-0.181	-0.035	-4.27951	-0.2636	Slightly negative trend exist
	March	**-0.6095**	-0.2396	-31.7847	**-0.7987**	Significant trend
	April	**-0.6286**	-0.1889	-25.4086	**-0.8273**	Significant trend
	May	**-0.6762**	-0.241	-33.0577	**-0.8597**	Significant trend
	June	-0.0048	-0.0025	-0.29312	-0.0883	Trend does not exist
	July	**-0.3143**	-0.135	-14.6161	**-0.4818**	Significant trend
	August	-0.2571	-0.1103	-11.9733	-0.3948	Slightly negative trend exist
	September	**-0.3238**	-0.1194	-12.8473	**-0.4818**	Significant trend
	October	**-0.4439**	-0.0976	-10.9455	**-0.6073**	Significant trend
	November	-0.2721	-0.0679	-8.05698	**-0.4521**	Significant trend
	December	**-0.3905**	-0.17	-21.4724	**-0.4987**	Significant trend

Values in bold letter indicates significant (alpha=0.05)

Based on the Mann–Kendall, Spearman, Sen's slope estimator, Pettitt's test and Standard normal homogeneity test (SNHT), it is found out that in 1992 significant inflection of flow reflecting anthropogenic control on stream flow because rainfall analysis does not show any such change point and no such trend of rainfall is detected even. So, from this flow pattern two flow regimes have been identified: 1) natural flow regime (1978-1992) and 2) regulated or anthropogenic flow regime (1993-2014). In the second phase water level is reduced in significant strength.

Trend of monthly stream flow regime: Table-4 displays monthly average water level trend by using Mann-Kendall test and Spearman's rank correlation at 5% levels of significance of the River has shown significant differences among the different months of pre and post change point condition. In pre-change point condition, the result of Mann-Kendall and Spearman's rho shows April (-0.689 and -0.856) and May (-0.6381 and -0.8179) months document negative trend and significant at 5% levels of significance. July (0.4857 and 0.6571) and September (0.4211 and 0.5147) months experienced positive trend and significant at 5% levels of significance.

Some months had slightly negative trend, they are: January (-0.31 and -0.3771), February (-0.23 and -0.2431), March (-0.25 and -0.2627) and November (-0.28 and -0.3250) and they are not significant at 5% levels of significance. June (0.31 and 0.4714) and October (0.33 and 0.4857) month had experienced positive trend.

After change point condition, negative trend have observed in all the months. The result of MK test and Spearman's rho show that March (-0.6095 and -0.7987), April (-0.6286 and -0.8273), May (-0.6762 and -0.8597), July (-0.3143 and -0.4818), September (-0.3238 and -0.4818), October (-0.4439 and -0.6073), November (-0.4521 for rho) and December (-0.3905 and -0.4987) have been experienced negative trend with significant at 5% levels of significance. Rest of the month observed slightly negative trend, but not significant at 5% levels of significance. To compare the results of pre and post change point condition, line graph have plotted using the results of pre and post change point condition achieved from application of MK test and Spearman's rho. However, figure 2 represents that there is featured big gap between pre and post change condition, especially during monsoon months (June, July, August, September, October and November). So frankly it can be said that after change point, the monthly trend of water level is decreasing. This form of validation is also noticed in the work of Yaseen et al.[21].

In the present study, Sen's slope estimator and relative change are used to measure the magnitude of slope and amount of change has been taken place from pre to post change point condition for all the months. Result shows that significant relative change and magnitude of the slope does not observed in the most of the month of pre-change point condition, only few month had faced significant changes, namely, April (-12.89 and -0.17) , May (-12.42 and -0.165) , July (14.43 and 0.23) and November (-12.186 and -0.1667). However, this image has been completely changed pre-change point to post change point. Result for post change point shows that March (-31.78 and -0.239), April (-25.408 and -0.188), May (-33.057 and -0.24), July (-14.616 and -0.135), August (-11.97 and -0.11), September (-12.847 and -0.119), October (-10.945 and -0.097) and December (-21.47 and -0.17) have experienced significant change.

Figure-3 displays the 5-year-running mean and trend line drawn based on the linear fit for the average monthly water level and presented the fact that overall trend of hydrological regime featured downward trend for all the months supports the results derived from MK test and Spearman's rho, although MK test and Spearman's rho applied on two half of the whole study period i.e. pre and post change point condition.

In the present study, Table-4 summarized the results of the MK test and Spearman's rho which have been applied on maximum and minimum monthly water level. Before change point, only May (-0.4286 and -0.5473) month had experienced significant negative trend at 5% level of significance. Rest of the month does not have significant trend. The Sen's slope estimator and relative change are also depicted similar result.

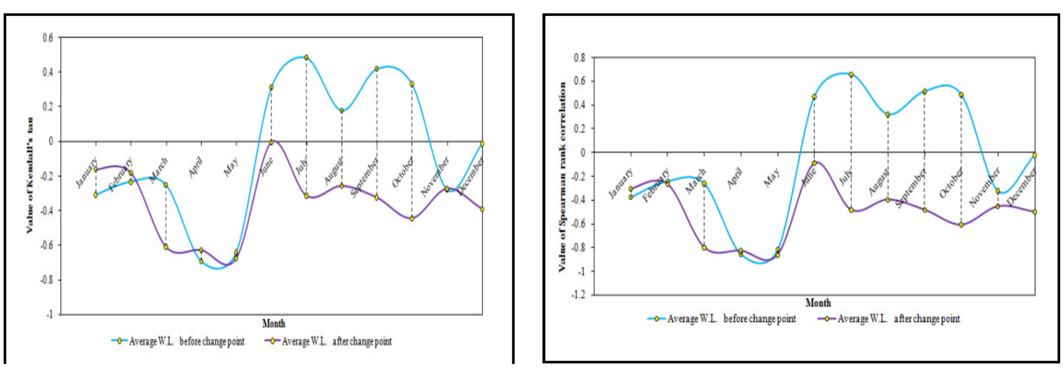

Figure 3
Comparison of Mann-Kendall's Tau with Spearman's rho for the monthly average water level of Pre and Post Change Point condition

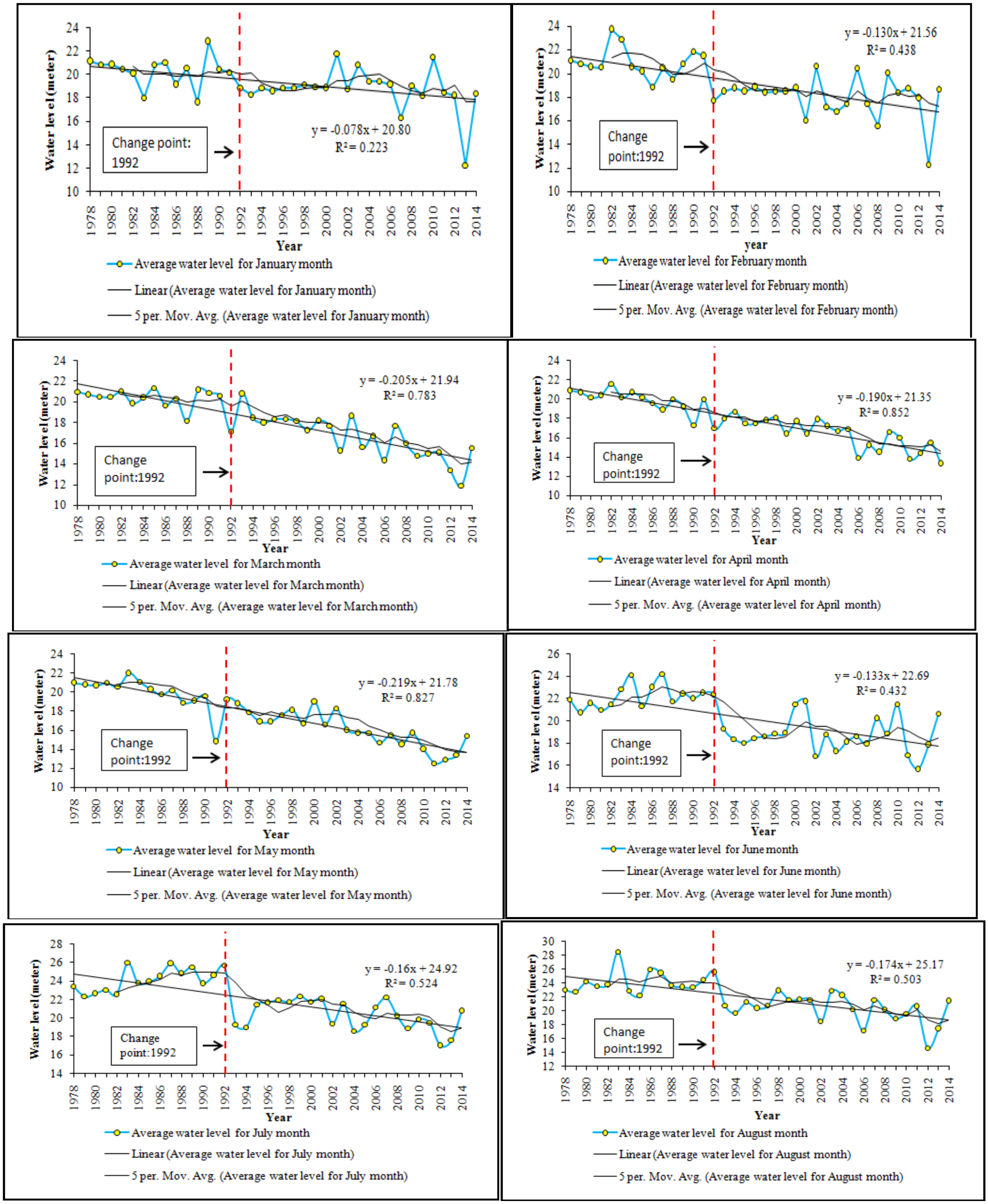

Figure-4A
The 5-year-running mean and linear regression for monthly average water level

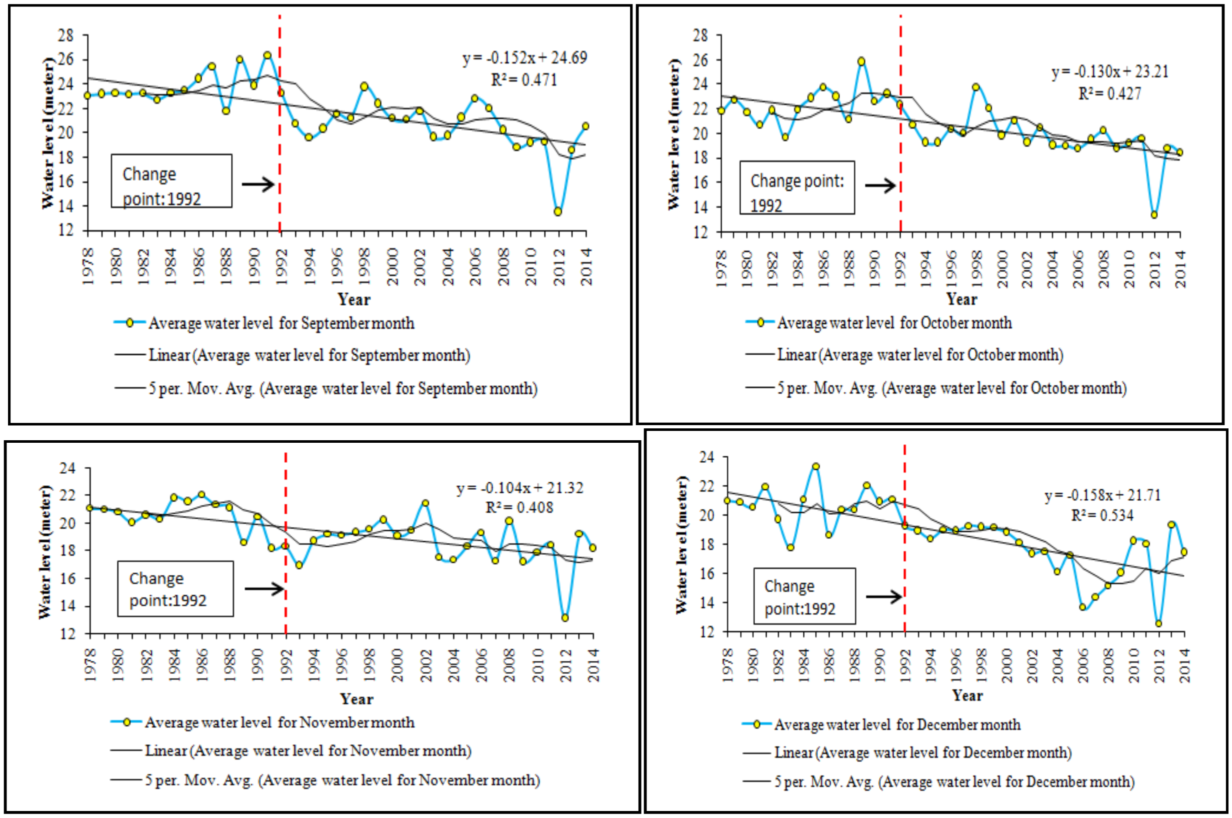

Figure-4 B
The 5-year-running mean and linear regression for monthly average water level

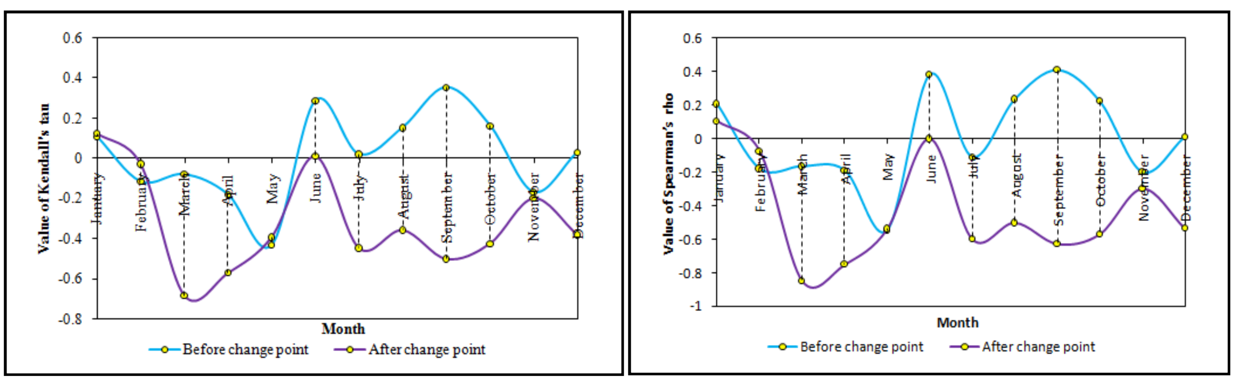

Figure-5
Comparison of Mann-Kendall's Tau with Spearman's rho for the monthly maximum water level of Pre and Post Change Point condition

Table-5 documented that the results obtained from both the models validated that the whole picture of all the months after change point are getting reverse. Results of MK test and Spearman's rho displays that March (-0.6826 and -0.8490), April (-0.5714 and -0.7506), May (-0.3923 and -0.5380), July (-0.4476 and -0.6000), August (-0.358 and -0.5015), September (-0.5012 and -0.6281), October (-0.4248 and -0.5697) and December (-0.381 and -0.5351) have documented negative trend at 5% level of significance. The results established that the hydrological regime significantly reduced from pre to post change point condition.

Figure-4 (A and B) represents that there is marked gap observed between pre and post change point condition. The figure revealed that the water level has reduced maximum in the month of June, July, August, September and October since pre to post change point condition. It clearly set up the fact that the behavior of monthly hydrological regime has reduced.

Table-5
Trend analysis of Monthly Maximum water level using Mann-Kendall test and Spearman rank correlation Method

	Month	Mann-Kendal test result		Relative Change (%)	Spearman rank correlation	Remarks
		Kendall's tau	Sen's slope:			
Before Change point	January	0.1105	0.0156	1.097112	0.2068	Trend does not exist
	February	-0.113	-0.0167	-1.2063	-0.1792	Trend does not exist
	March	-0.0769	-0.015	-1.10703	-0.1648	Trend does not exist
	April	-0.1768	-0.0325	-2.41122	-0.1892	Trend does not exist
	May	**-0.4286**	-0.102	-7.29243	**-0.5473**	Significant trend
	June	0.2873	0.0944	6.056286	0.3828	Slightly positive trend exist
	July	0.0221	0.0138	0.833557	-0.1100	Trend does not exist
	August	0.1547	0.043	2.541104	0.2354	Trend does not exist
	September	0.3536	0.15	9.113739	0.4092	Slightly positive trend exist
	October	0.1648	0.039	2.454408	0.2220	Trend does not exist
	November	-0.1648	-0.0875	-6.20998	-0.2000	Trend does not exist
	December	0.033	0.005	0.362517	0.0110	Trend does not exist
After change point	January	0.1238	0.0245	2.834001	0.1039	Trend does not exist
	February	-0.0286	-0.0044	-0.5322	-0.0740	Trend does not exist
	March	**-0.6826**	-0.2119	-27.3449	**-0.8490**	Significant trend
	April	**-0.5714**	-0.1463	-19.1345	**-0.7506**	Significant trend
	May	**-0.3923**	-0.1357	-16.9402	**-0.5380**	Significant trend
	June	0.0095	0.0037	0.409344	0.0000	Trend does not exist
	July	**-0.4476**	-0.1883	-19.3715	**-0.6000**	Significant trend for rho
	August	**-0.358**	-0.1664	-16.6917	**-0.5015**	Significant trend
	September	**-0.5012**	-0.1899	-19.1263	**-0.6281**	Significant trend
	October	**-0.4248**	-0.1472	-15.3598	**-0.5697**	Significant trend
	November	-0.2	-0.0553	-6.16823	-0.2987	Trend does not exist
	December	**-0.381**	-0.1476	-18.3378	**-0.5351**	Significant trend

Values in bold letter indicates significant (alpha=0.05)

Sen's slope estimator and relative change have been applied on the maximum water level data. Declining trend slope and higher relative change have been observed in March (-0.2119and -27.34), April (-0.1463and -19.13), May (-0.1357 and -16.94), July (-0.1883 and -19.37), August (-0.1664 and -16.69), September (-0.1899 and -19.126), October (-0.1472 and -15.359) and December (-0.1476 and -18.3378) and these are significant at 5% levels of significance.

Table-6 displays that same methods here have applied on the monthly minimum water level for pre and post change point conditions. In pre change point, only April month (-0.4641 and -0.5633) have featured negative trend and significant at 5% level of significance. Rest of the months experienced no significant trend. The magnitude of the trend and relative change also support the results derived from both the models that only April month (-0.0864 and -6.52656) have significant declining trend and change, are also significant at 5% level of significance.

Table 6
Trend analysis of Monthly Minimum water level using Mann-Kendall test and Spearman rank correlation Method

	Month	**Mann-Kendal test result**		**Relative Change (%)**	**Spearman rank correlation**	**Remarks**
		Kendall's tau	**Sen's slope:**			
Before Change point	January	0.2682	0.06	4.692388	0.3554	Slightly positive trend exist
	February	-0.1768	-0.05	-3.65782	-0.2398	Trend does not exist
	March	-0.2967	-0.0492	-3.69148	-0.4418	Slightly negative trend exist
	April	**-0.4641**	-0.0864	-6.52656	**-0.5633**	Significant trend
	May	-0.2527	-0.0533	-3.98501	-0.4110	Slightly negative trend exist
	June	0.1445	0.0175	1.248811	0.2599	Trend does not exist
	July	0.1768	0.035	2.410985	0.2244	Trend does not exist
	August	-0.0442	-0.0033	-0.21706	-0.0704	Trend does not exist
	September	-0.1667	-0.0457	-3.13902	-0.2974	Trend does not exist
	October	0.0221	0.002	0.141938	0.0132	Trend does not exist
	November	-0.0769	-0.08	-6.078	-0.0462	Trend does not exist
	December	0.0549	0.006	0.43951	0.1560	Trend does not exist
After change point	January	-0.1766	-0.0463	-5.63845	-0.1526	Trend does not exist
	February	-0.1575	-0.0383	-4.69944	-0.1838	Trend does not exist
	March	**-0.6857**	-0.2409	-32.807	**-0.8545**	Significant trend
	April	**-0.5967**	-0.1658	-22.7756	**-0.7749**	Significant trend
	May	**-0.6539**	-0.2308	-32.4074	**-0.8496**	Significant trend
	June	0.0952	0.0258	3.219693	0.0974	Trend does not exist
	July	-0.2095	-0.0436	-5.05677	-0.2922	Trend does not exist
	August	-0.0952	-0.035	-3.99496	-0.1468	Trend does not exist
	September	-0.2667	-0.0726	-8.24952	-0.4234	Trend does not exist
	October	**-0.3501**	-0.0556	-6.45	**-0.4668**	Significant trend
	November	-0.3007	-0.0764	-9.32715	-0.4307	Slightly negative trend exist
	December	**-0.381**	-0.1425	-18.0728	**-0.4909**	Significant trend

Values in bold letter indicates significant (alpha=0.05)

After change point, results are almost similar to average and maximum water level, that means all the months has experienced negative trend. The results obtained from using MK test and Spearman's rho shows that March (-0.6857 and -0.8545), April (-0.5967 and -0.7749), May (-0.6539 and -0.8496), October (-0.3501 and -0.4668) and December (-0.381 and -0.4909) month have significant downward or negative trend at 5% significant level. Figure 5 documented that there is marked gap observed between pre and post change point condition. So it can be said that natural period for stream flow regime converted into human induced flow regime.

Sen's slope estimator and relative change have been applied to estimate the trend slope and amount of change has been taking place among the months. Overall results established the fact that all the month have been documented negative trend slope and relative change are also significant such as, March (-0.2409 and -32.807), April (-0.1658 and -22.7756), May (-0.2308 and -32.4074O), October (-0.0556 and -6.45) and December (-0.1425 and -18.0728) and significant at 5% significance level.

Seasonal trend of stream flow regime: In the present study, seasonal stream flow regime is also analyzed in this study, MK and Spearman's rho tests have been applied on seasonal average, maximum and minimum water level. Table-7 summarized the result for average seasonal water level and it speaks that before change point, pre-monsoon season (-0.6952 and -0.8643) has significant negative trend, whereas positive trend has observed in monsoon season (0.3905 and 0.5786) at 5% significant level. Declining relative change (-0.19 and -14.2752) has been occurred in pre-monsoon season, while upward relative change (0.1075 and 6.83) has been observed in monsoon season.

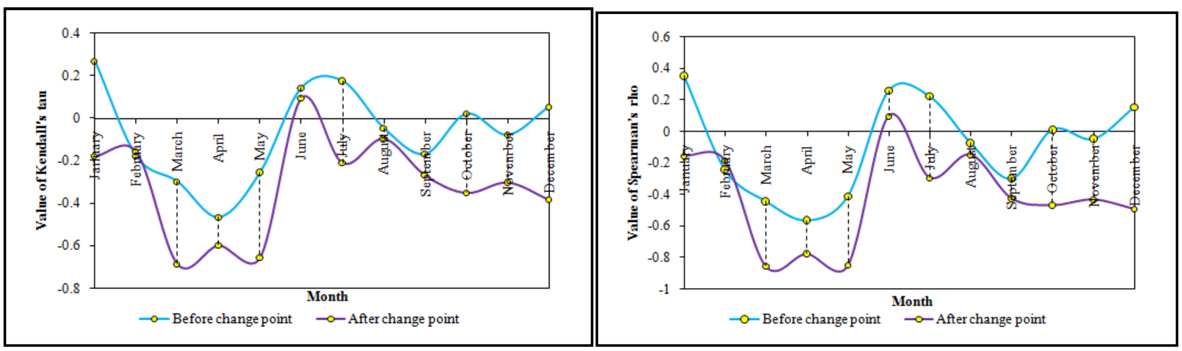

Figure-6
Comparison of Mann-Kendall's Tau with Spearman's rho for the monthly maximum water level of Pre and Post Change Point condition

Table-7
Trend of average seasonal stream flow

	Season	Mann-Kendall test result		Relative Change (%)	Spearman rank correlation	Remarks
		Kendall's tau	Sen's slope:			
Before change point (1978-1992)	winter	-0.2381	-0.0683	-5.00905	-0.1964	Trend does not exist
	pre-monsoon	**-0.6952**	-0.19	-14.2752	**-0.8643**	Significant trend
	monsoon	**0.3905**	0.1075	6.836828	**0.5786**	Significant trend
	post-monsoon	-0.0857	-0.017	-1.20476	-0.0357	Trend does not exist
After Change point (1993-2014)	winter	-0.0736	-0.0121	-1.4496	-0.2208	Trend does not exist
	pre-monsoon	**-0.7489**	-0.2327	-31.3569	**-0.9232**	Significant trend
	monsoon	-0.2381	-0.075	-8.27101	-0.3845	Slightly negative trend exist
	post-monsoon	**-0.4113**	-0.094	-11.1632	**-0.6364**	Significant trend

Values in bold letter indicates significant (alpha=0.05)

After change point, no season has positive trend and pre-monsoon (-0.7489 and -0.9232) and post monsoon (-0.4113 and -0.6364) has significant negative trend at 5% level of significance.

The decreasing trend slope observed in both pre (-0.2327 and -31.3569) and post monsoon (-0.094 and -11.16) period and relative change percentage is also quite high. Figure 6 presents the differences of seasonal change between pre and post change point. The result obtained from both the models show that there is marked negative change observed from pre change point to post change point. Figure-7 presents the 5-year-running mean and trend line based on the linear fit for the average seasonal water level for Punarbhaba River basin. Figure-7 focused that overall trend of hydrological regime is characterized negative trend for all the seasons which support the results obtained from MK test and Spearman's rho.

Table-8 summarized the results for seasonal maximum water level derived from MK test and Spearman's rho, investigating the seasonal trend of pre and post change point. The result of pre change point set up the fact that only pre monsoon period (-0.4857 and -0.6107) has observed significant negative trend and rest of the season does not have significant trend. The Sen's slope estimator and relative change also revealed same result, mean pre monsoon period (-0.1013 and -7.41) before change has experienced declining trend and declining relative change.

After change point, all the seasons, i.e. pre-monsoon (-0.7316 and -0.8984), monsoon (-0.4199 and -0.5889), post-monsoon (-0.4719 and -0.6804) have faced negative trend except winter.

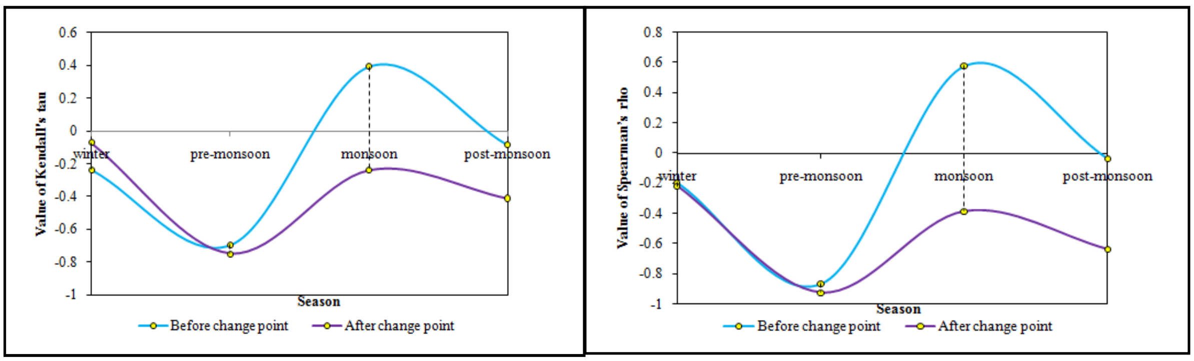

Figure-7
Comparison of Mann-Kendall's Tau with Spearman's rho for the seasonal average water level of Pre and Post Change Point conditions

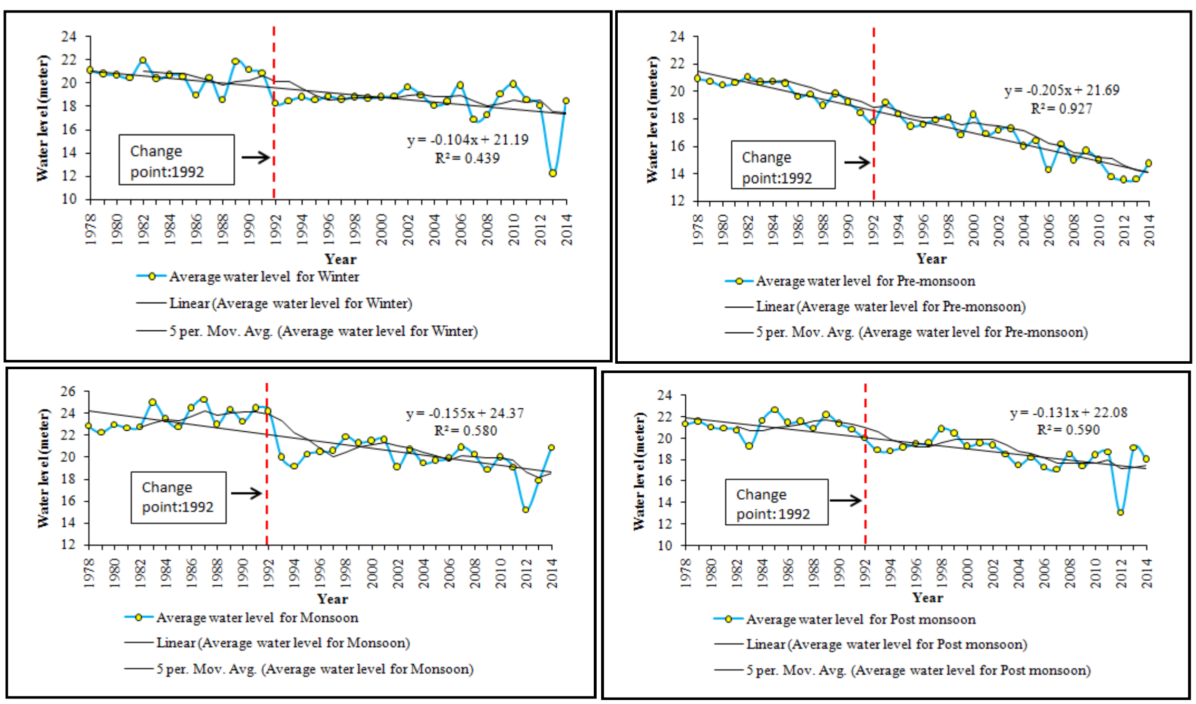

Figure-8
The 5-year-running mean and linear regression for seasonal average water level

Table-8
Trend of maximum seasonal stream flow

	Season	Mann-Kendall test result		Relative Change (%)	Spearman rank correlation	Remarks
		Kendall's tau	Sen's slope:			
Before change point (1978-1992)	winter	-0.1048	-0.02	-1.43301	-0.1250	Trend does not exist
	pre-monsoon	**-0.4857**	-0.1013	-7.40938	**-0.6107**	Significant trend
	monsoon	0.3143	0.0845	5.158485	0.4143	Slightly positive trend exist
	post-monsoon	-0.2	-0.0415	-2.84426	-0.2679	Trend does not exist
After Change point (1993-2014)	winter	-0.0303	-0.0035	-0.41394	-0.0333	Trend does not exist
	pre-monsoon	**-0.7316**	-0.181	-23.1996	**-0.8984**	Significant trend
	monsoon	**-0.4199**	-0.1202	-12.4376	**-0.5889**	Significant trend
	post-monsoon	**-0.4719**	-0.1277	-14.4035	**-0.6804**	Significant trend

Values in bold letter indicates significant (alpha=0.05)

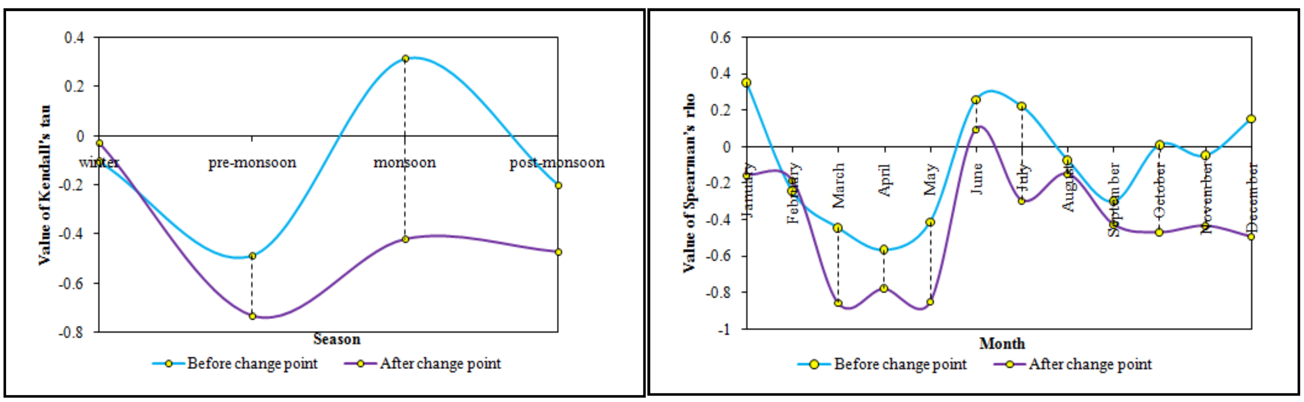

Figure-9
Comparison of Mann-Kendall's Tau with Spearman's rho for the seasonal maximum water level of Pre and Post Change Point conditions

Table-8 displays the result derived from both the models of pre-monsoon (-0.181 and -23.19), monsoon (-0.1202 and -12.437) and post monsoon (-0.127 and -14.40) periods demonstrated downward trend and negative change. So Table 8 clearly established fact is that the trend of maximum seasonal water level in post change point is much lower than pre change point. Figure 8 represents the trend of all the season and the trend is decreasing.

Table-9 describes the trend of seasonal minimum hydrological regime. Figure-9 shows both the tests results in all the seasons mentioned. All these trends highlight that in post change point condition, minimum flow regime has decreased almost 2 times. Minimum water level during pre-monsoon (-0.581 and -0.6750) has observed negative trend using MK test and Spearman's rho in pre change point. But after change point condition, the trend of seasonal minimum water flow regime has reduced. The reduction rate for Winter, pre monsoon, monsoon and post monsoon are: (0.0667 and 0.1) to (-0.1861 and -0.1530), (-0.581 and -0.6750) to (-0.8095 to -0.9413), (-0.181 and -0.1500) to (-0.0476 -0.0875) and (-0.181 and -0.15) to (-0.33 and -0.49) respectively.

Sen's slope estimator and relative change have also been calculated to estimate the trend slope and amount of changes. Table-9 represents that both the results of seasonal change during winter, pre monsoon, monsoon and post monsoon from pre change point to post change point has reduced by (0.027 and 2.08) to (-0.041 and -5.00), (-0.138 and -10.37) to (-0.22 and -30.32), (-0.09 and -1.61) to (-0.013 and -1.63) and (-0.09 and -6.65) to (-0.065 and -8.01) respectively. This form of validation is also noticed in the works of Shadmani, Marofi, and Roknian[32].

Table-9
Trend of minimum seasonal stream flow

	Season	Mann-Kendall test result		Relative Change (%)	Spearman rank correlation	Remarks
		Kendall's tau	Sen's slope:			
Before change point (1978-1992)	winter	0.0667	0.0275	2.082948	0.1000	Trend does not exist
	pre-monsoon	**-0.581**	-0.1381	-10.3727	**-0.6750**	Significant trend
	monsoon	-0.181	-0.0235	-1.61257	-0.3429	Trend does not exist
	post-monsoon	-0.181	-0.0907	-6.65209	-0.1500	Trend does not exist
After Change point (1993-2014)	winter	-0.1861	-0.041	-5.00536	-0.1530	Trend does not exist
	pre-monsoon	**-0.8095**	-0.2217	-30.3235	**-0.9413**	Significant trend
	monsoon	-0.0476	-0.0139	-1.63274	-0.0875	Trend does not exist
	post-monsoon	**-0.3333**	-0.0658	-8.01093	**-0.4918**	Significant trend

Values in bold letter indicates significant (alpha=0.05)

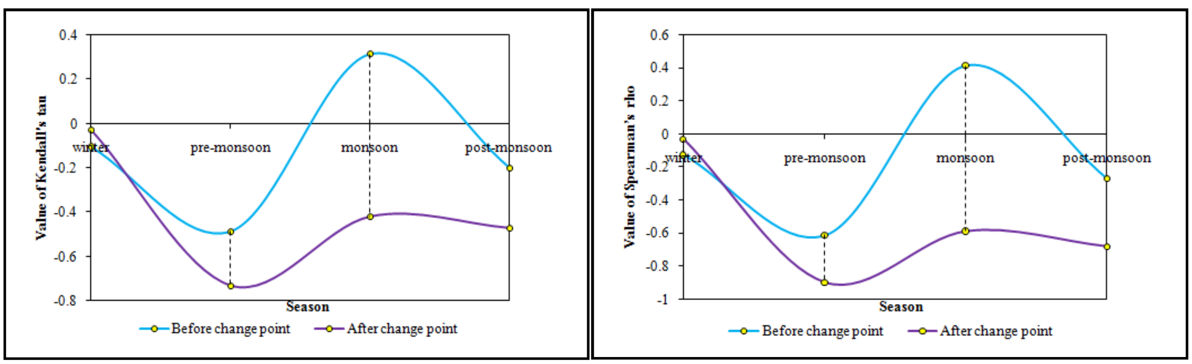

Figure 10
Comparison of Mann-Kendall's Tau with Spearman's rho for the seasonal minimum water level of Pre and Post Change Point conditions

Conclusion

The results from the study revealed that after the year 1992, the flow regime has loss its homogeneity and reduced significantly. So, this year (1992) can be treated as change point. The trend and its magnitude of annual, monthly and seasonal average, maximum and minimum flow are investigate with MK and Spearman's rho test and Sen's slope estimator. Results documented that annual, monthly and seasonal water level has experienced declining trend. But rainfall pattern does not show significant declining trend or any change point. So it can be said that climate change is not cause behind changing flow regime of Punarbhaba River. The reason may be anthropogenic that need to be investigated in further research. Whatever be the reason, curtailing of flow is highly sensitive to downstream habitat and ecosystem behavior that need to be considered with due priority.

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