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Non Parametric Trend Analysis of Climate Change in Lower Bagmati River Basin in Northern India

M.P.Akhtar[1], Amrendra Kumar[2], Deepak Khare[3]
[1]Under Secretary, Water Resources, Bihar, Patna,India,
[2]Assistant Engineer, Water Resources, Bihar, Patna,India,
[3]Dept.of WRD&M, I.I.T. Roorkee, India
Corresponding Email: parwez.wrd@gmail.com

Abstract: This study is conducted to observe the temporal variability of rainfall and temperature for 102 years (1901-2002) in the Lower Bagmati River Basin in Northern India. Annual and monsoon rainfall time series is considered to investigate the trend using non parametric methods. Trend in 102 years span indicates reduced basin water potential in recent years.

Keywords- Rainfall; Temperature; Non-Parametric Tests; Trend Analysis; Mann–Kendall and Sen's T Tests.

I. Introduction

Precipitation is the one of the most important climatic variable because it is the prime determining factor in the choice of crops and ecological change in types of food grains. The Intergovernmental Panel on Climate Change (IPCC, 2007) reported the inter-seasonal; inter annual and spatial variability in precipitation trends during the past few decades all across Asia. Decreasing trends in annual mean precipitation are observed in Russia (Peterson et al., 2002; Savelieva et al., 2000), North-East and North China (Hu et al., 2003; Zhai and Pan, 2003) and coastal belts and arid plains of Pakistan (Farooq and Khan, 2004). However, annual mean precipitation exhibits increasing trends in Western China (Shi et al., 2002), Changjiang Valley and the South-Eastern coast of China (Hu et al., 2003; Zhai and Pan, 2003), Bangladesh (Mirza, 2002; Mirza and Dixit, 1997) and along the western coasts of the Philippines (Cruz et al., 2006).

Lower Bagmati River Basin in Northern India

The Bagmati River is one of the perennial rivers of Indian State of Bihar which originates from the Shivpuri range of hills at about 16 km north-east of Kathmandu in Nepal, at latitude 27° 47' N and longitude 85° 17' E, at an elevation of 1500 m above Mean Sea Level. It enters North Bihar at about 2.5 km north of Dheng Railway Bridge and outfalls in the Kosi River at Khormaghat in North Bihar. Its total length is 597 km, out of which 206.8 km lies in Nepal and rest 390.2 km lies within Indian Territory (DWIDP 2005). Main tributaries of Bagmati River are Lalbekya, Lakhandei, Adhwara and Kamla. It drains out a total catchment area of 21616 km^2 from Nepal and the Indian State of Bihar to ultimately reach the river Ganga through the river Kosi (Flood and Drainage problems of Bihar and their remedial measures-Part-I 1994).

It is also pertinent to mention that almost 80 percent of the population in the basin area is agrarian. Floods induced miseries and loss of properties can be compensated by boosting agricultural production through irrigation. A United Nations Development Program (UNDP) funded Agriculture Sector Review for the flood ravaged plains of Bangladesh has advocated continued priority for small scale irrigation to increase crop production rapidly in the safer dry season (Brammer 1990). However, development of irrigation facilities in flood ravaged plains is a technical challenge. Floods are natural phenomena while irrigation concerns with the human activity. Hence, sustainable development of irrigation in the flood plains indeed warrants implementation of the planning through integrated approach with adequate information with respect recent rainfall and temperature trend. In practice, implementation of the irrigation in flood plains with due integration of the two is hardly found. One of the reasons may be lack of the suitable methodology for such integration. Research works pertaining to this issue are also rare.

Although a number of works related to river behaviour, flood inundation mapping, and hydrological modelling of the BRB (*Bagmati River Basin*) within Nepal territory have been reported. However, works involving rainfall and temperature trend of *Lower Bagmati River Basin* within Indian Territory are rare. There is an obvious lack of investigations looking into variability of rain fall pattern due to climate change for the *Lower Bagmati Basin*. In view of the above, the prime objectives of the present work are set as follows:

(a) To investigate the monotonic trend of rainfall of *Lower Bagmati River Basin (LBRB)* in the past 102 years using non parametric methods such as Mann–Kendall and Sen's Slope tests.

(b) To estimate the temperature trend in conjunction with rainfall trend in the whole study area comprises of four districts of Bihar in Northern Indian Territory namely *Darbhanga Khagaria*, *Muzaffarpur* and *Sitamarhi* in a time series using Sen's estimator method.

II. Material and Methodology

There are various parametric and non-parametric tests which were used for identifying trends in hydro-meteorological time series. However, from recent studies, it is observed that nonparametric tests are by and large used for non-normally distributed and censored data, including missing values, which are frequently encountered in hydrological time series. Among those, rank based non-parametric Mann–Kendall (MK) (Kendall, 1975; Mann, 1945) test is one of extensively used methods for trend analysis and preferred by various researches due to various advantages over parametric methods (Helsel, 1987). Despite of advantage, the influence of serial correlation in the time series on the results of MK test has been found in the literature (Yue *et al*., 2002).

Mann-Kendall test

The Mann-Kendall test is applicable in cases when the data values x_i of a time series can be assumed to obey the model (Eq. 1) (Alexander *et al*., 1991)

$$x = f(t) + \varepsilon_i \quad (1)$$

Where, *f(t)* is a continuous monotonic increasing or decreasing function of time and the residuals ε_i can be assumed to be from the same distribution with zero mean. It is therefore assumed that the variance of the distribution is constant in timeThe Mann-Kendall test statistic S is calculated using the formula (Eq. 2)

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^{n} \operatorname{sgn}(x_i - x_k) \quad (2)$$

Where x_j and x_k are the annual values in years j and k, $j > k$, respectively, sgn(x_i - x_k) can be given as shown in Eq. (3),

$$\operatorname{sgn}(x_j - x_k) = \begin{cases} 1 & if \quad x_j - x_k > 0 \\ 0 & if \quad x_j - x_k = 0 \\ -1 & if \quad x_j - x_k < 0 \end{cases} \quad (3)$$

If n is 9 or less, the absolute value of S is compared directly to the theoretical distribution of S derived by Mann and Kendall (Gilbert, 1987). A positive (negative) value of S indicates an upward (downward) trend. The minimum values of n with which these four significance levels can be reached, are derived from the probability table (Table 1) for S as follows.

Table 1. Significance level verses required n

Significance level α	Required n
0.1	≥ 4
0.05	≥ 5
0.01	≥ 6
0.001	≥ 7

If n is at least 10, then the normal approximation test is used. However, if there are several tied values (equal values) in the time series, it may reduce the validity of the normal approximation when the number of data values is close to 10.
Firstly, the variance of S is computed using Eq. (4) as given below, which takes into account that ties may be present,

$$VAR(S) = \frac{1}{8}\left[n(n-1)(2n+5) - \sum_{p=1}^{q} t_p (t_p - 1)(2t_p + 5) \right] \quad (4)$$

Here q is the number of tied groups and t_p is the number of data values in the p^{th} group.
The values of S and *VAR(S)* are used to compute the test statistic Z as as shown in Eq. (5)

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR}} & if \quad S > 1 \\ 0 & if \quad S = 1 \\ \frac{S+1}{\sqrt{VAR}} & if \quad S < 1 \end{cases} \quad (5)$$

The presence of statistically significant trend is evaluated using the Z value. A positive (negative) value of Z indicates an upward (downward) trend. The statistic Z has a normal distribution. To test for either an upward or downward monotone trend (a two-tailed test) at α level of significance, H_0 is rejected if the absolute value of Z is greater than $Z_{1-\alpha/2}$, where $Z_{1-\alpha/2}$ is obtained from the standard normal cumulative distribution tables. In *MAKESENS*, the tested significance levels α are 0.001, 0.01, 0.05 and 0.1.

Sen's slope Test

To estimate the true slope of an existing trend (as a change per year), the Sen's non-parametric method (Sen, 1968) is used. The Sen's method can be used in cases where the trend can assumed to be linear. This means that *f (t)* in above equation (Eq. 6) is equal to

$$f(t) = Q_t + B \quad (6)$$

Where Q is the slope and B is a constant. To get the slope estimate Q in the above equation, one can calculate the slopes of all data value pairs as shown in Eq. (7)

$$Q_j = \frac{x_j - x_k}{j - k} \quad \text{Where} \quad j > k \quad (7)$$

If there are n values xj in the time series, one gets as many as $N = n(n-1)/2$ slope estimates Q_i. The Sen's estimator of slope is the median of these N values of Q_i. The N values of Q_i are ranked from the smallest to the largest and the Sen's estimator is shown as Eq.(8),

$$Q = Q_{\frac{N+1}{2}} \quad if \quad N \text{ is odd}$$
$$Q = \frac{1}{2}\left(Q_{\frac{N}{2}}\right) \quad if \quad N \text{ is even} \quad (8)$$

Study area and data used

Bagmati river basin in India is situated in North Bihar region of state Bihar. Bagmati River originates from Nepal and meets in Ganga River in Bihar (Fig. 1)). Total catchment area of Lower Bagmati Basin situated in Indian Territory is approximately 10000 km^2. Details are stated in previous section. Monthly precipitation data of four districts covering a period of 102 years (1901–2002) were obtained from Indian Meteorological Department (*IMD; http://www.imd.gov.in/*) India. A pre-whitening procedure is done before applying these data for Mann-Kendall test.

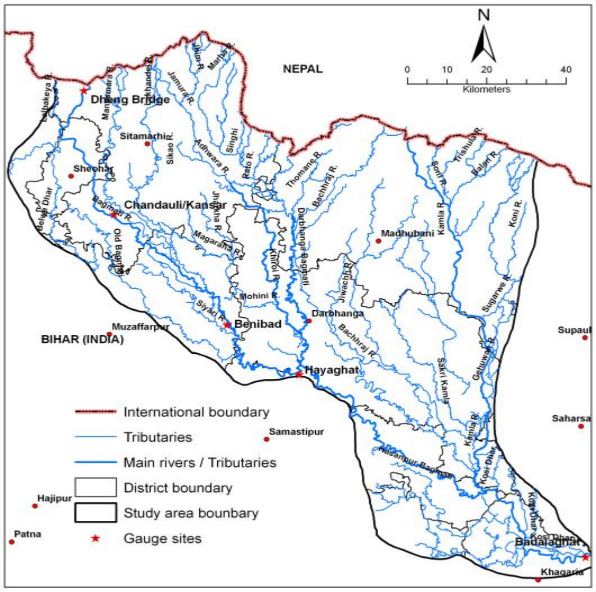

Fig.1 Map representing river system of Lower Bagmati River Basin

III. Results and Tables

Rainfall trend analysis

A spatio-temporal distribution and changing patterns in rainfall is a basic and one of the important requirements for the planning and management of water resources. Especially, the river-basin rainfall trends exhibit a considerable variability. Mann-Kendall Test results for the monthly annual and seasonal rainfall data was obtained. The whole study area under *Lower Bagmati River Basin* comprises of four districts namely *Darbhanga*, *Khagaria*, *Muzaffarpur* and *Sitamarhi* of Bihar province in Northern Indian Territory. In the present study, all four districts within the Lower Bagmati River Basin (LBRB) are exhibiting decreasing pattern in annual rainfall. For better illustration analyzed data and obtained results for two districts namely *Darbhanga* and *Muzaffarpur* are graphically represented in Fig.(2a) and Fig.(2b). Quantitatively, *Darbhanga* has shown decreasing annual rainfall of 1.56 mm/year and in monsoon a decreasing slope of 1.48 mm/year (Fig. 2a,). Similarly, *Khagaria* district has a trend of decreasing rainfall in slope of 1.86 mm/year and in monsoon a decreasing slope of 1.76 mm /year. Another district *Sitamarhi* has an indication of decreasing rainfall pattern in this time series with annual slope of -2.39 mm/year and monsoon slope of -2.4mm/year. *Muzzaffarpur* district has also shown a decreasing trend of annual slope- 2.41 mm/year and monsoon slope of- 2.26 mm/year as represented in Fig. 2b. While observing the test *Z* values, it can be readily observed that in *Darbhanga*, rainfall during six month has shown a decreasing trend while two months exhibited no trend of increasing or decreasing. Apart from that, some months indicated minute increasing trend and surprisingly these are post-monsoon and winter rainfall months. Similar to that, observing the values of *Z* test for *Khagaria*, five months are indicating a decreasing trend in both annual and monsoon rainfall with high degree of significance in months of June and July.

It can readily be observed that the monsoon months exhibiting lesser rainfall whereas pre-monsoon and post-monsoon month are showing slight increase in trend. *Sitamarhi* district has shown a steep decrease in seventh month in both annual and monsoon rainfall with very high degree of significance level in June, July and August. *Muzzaffarpur* district too has exhibited decreasing rainfall in seven months and annual and monsoon rainfall at very high significance level (Fig. 2b). It can noticeably be observed that *Muzaffarpur* district has highest *Z* values for annual and monsoon amongst all four districts with fairly high significance value.

The aforementioned test results shows that monsoon climate has changed significantly in LBRB in recent years and continuously decreasing with slight improvement in pre-monsoon and post-monsoon season. Variation of the statistical trend indicators for the entire four districts for monthly, annual, pre monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter (December-February) periods in LBRB are presented in tabular form as indicated in Table 2 and depicted in graphical form as shown in Fig. 3.

Table 2. Trend Statistics for rainfall in four districts of *Lower Bagmati River Basin* for the period 1901-2002

Time series (1901-2002)	*Darbhanga*		*Khagaria*		*Sitamarhi*		*Muzaffarpur*	
Periods	*Test Z*	*Q*	*Test Z*	*Q*	*Test Z*	*Q*	*Test Z*	*Q*
Jan.	0.95	0.02	1.53	0.05	2.53	0.08	2.82	0.08
Feb.	-0.35	-0.02	-1.19	-0.05	-0.84	-0.02	-1.01	-0.04
March	0	0	-0.76	-0.02	-0.77	-0.02	-0.78	-0.02
April	-0.23	-0.01	0.46	0.01	0.27	0.01	0.35	0.01
May	0.3	0.01	1.24	0.1	0.9	0.09	0.88	0.06
Jun.	-1.4	-0.39	-3.44	-0.84	-2.68	-0.79	-2.74	-0.65
Jul.	-1.21	-0.54	-2.39	-0.82	-2.24	-0.96	-2.33	-0.96
Aug.	0.4	0.12	-1.95	-0.46	-2.75	-0.71	-2.89	-0.79
Sept.	-0.66	-0.22	-0.58	-0.17	-0.23	-0.04	-0.16	-0.03
Oct.	0.87	0.1	0.98	0.16	-0.42	-0.09	-0.13	-0.03
Nov.	0	0	1.98	0.01	1.11	0	1.54	0
Dec.	-0.17	0	1.15	0	0.53	0	1.63	0
Annual	-2.18	-1.58	-2.79	-1.86	-2.96	-2.39	-3.26	-2.41
Pre-monsoon	-0.38	-0.03	0.45	0.06	0.57	0.07	0.62	0.05
Monsoon	-2.06	-1.46	-3.14	-1.76	-3.27	-2.4	-3.54	-2.26
Post-monsoon	0.62	0.08	1.04	0.17	-0.16	-0.04	0.06	0.01
Winter	0.34	0.04	-0.66	-0.04	0.5	0.03	0.07	0

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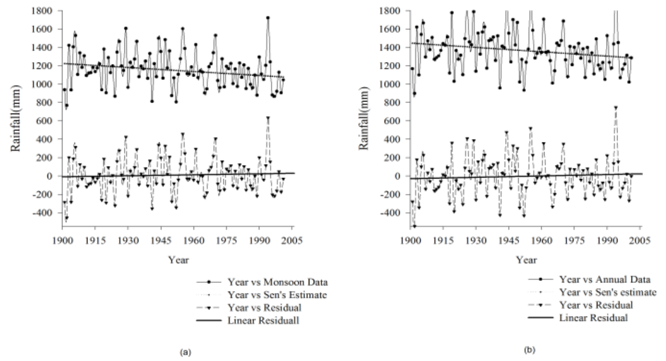

Fig. 2a Rainfall trend of *Darbhanga* district of (a) Monsoon Data (b) Annual Data for the period 1901-2002

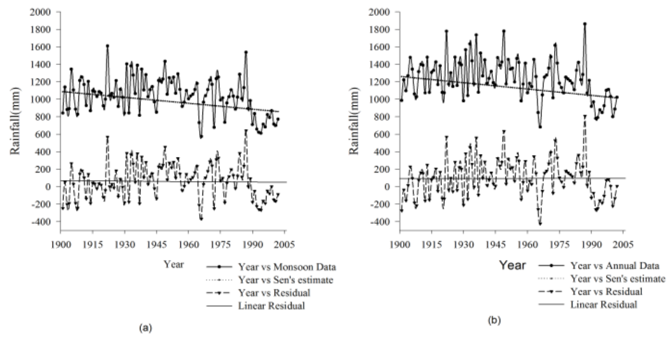

Fig. 2b Rainfall trend of *Muzaffarpur* district of (a) Monsoon Data (b) Annual Data for the period 1901-2002

Temperature trend analysis

This study has revealed that the monotonic trend (annual) for temperature time series found to be increasing (positive) with high level of significance. In the present study, all four districts within LBRB namely *Darbhanga*, *Muzaffarpur*, *Khagaria* and *Sitamarhi* are exhibiting increasing pattern in annual average temperature. For better illustration analyzed data and obtained results are graphically represented in Fig.(4a), Fig.(4b) and Fig. (5). Quantitatively, *Darbhanga* has shown increasing annual slope of 2.38 degree/year and in monsoon a decreasing slope of -0.115 degree/year (Fig. 4a). Similarly, *Khagaria* district has a trend of increasing temperature in slope of 2.68 degree/year and in monsoon a slightly increasing slope of 0.272 degree /year. Another district *Sitamarhi* has an indication of increasing temperature pattern in this time series with annual slope of 2.20 degree/year and monsoon slope of -0.075 degree/year. *Muzzaffarpur* district has shown a decreasing trend of annual slope of 2.24 degree/year and monsoon slope of -0.33 degree/year as shown in Fig. (5).

Table 3. Trend Statistics for rainfall in four districts of *Lower Bagmati River Basin* for the period 1901-2002.

Time series (1901-2002)	Darbhanga		Khagaria		Sitamarhi		Muzaffarpur	
Period	Test Z	Q	Test Z	Q	Test Z	Q	Test Z	Q
Jan.	0.12	0	0.82	0.002	0.09	0	-0.25	-0
Feb.	2.24	0.007	2.64	0.007	2.24	0.007	2.3	0.007
Mar	1.23	0.005	0.92	0.003	1.42	0.006	1.07	0.005
April.	0.38	0.002	0.16	0	0.6	0.003	0.04	0
May	0.6	0.002	0.59	0.001	0.53	0.002	0.08	0
Jun.	0.69	0.002	0.81	0.002	0.53	0.001	0.39	0.001
Jul.	0.27	0	0.16	0	-0.1	0	-0.46	-0
Aug.	-0.58	-0.001	0.09	0	-1	-0	-1.06	-0
Sept.	0.15	0	0	0	0.49	0.001	0.22	0
Oct.	2.72	0.007	2.79	0.006	2.53	0.006	2.46	0.006
Nov.	3.22	0.007	3.32	0.007	2.93	0.007	3.1	0.007
Dec.	3.74	0.011	3.61	0.01	3.8	0.011	3.9	0.012
Annual	2.38	0.003	2.68	0.003	2.23	0.002	2.2	0.003
Pre-monsoon	1.09	0.003	0.84	0.002	0.71	0.001	1.28	0.004
Mons.	0.12	0	0.27	0	-0.3	-..0003	-..08	0
Post-monsoon	3.51	0.007	3.49	0.006	3.33	0.006	3.26	0.006
Winter	2.88	0.006	3.5	0.007	2.97	0.006	2.74	0.006

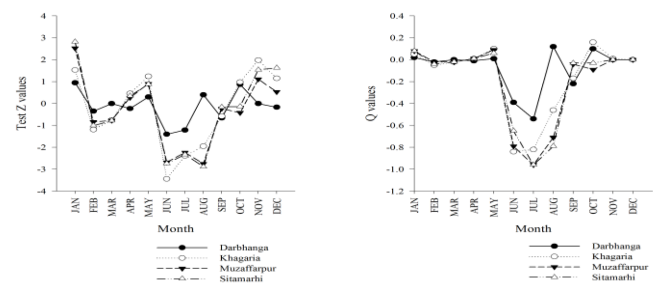

Fig. 3 Monthly trend statistics (a) *Z* values and (b) *Q* values for rainfall in four districts of *Lower Bagmati River Basin* for the period 1901-2002

Variations of the statistical trend indicators for the entire four districts for monthly, annual, pre-monsoon (March-May), monsoon (June-September), post-monsoon (October-November) and winter (December-February) periods in LBRB are presented in tabular form as indicated in Table 3 and the corresponding graphical representation is shown in Fig. (5).

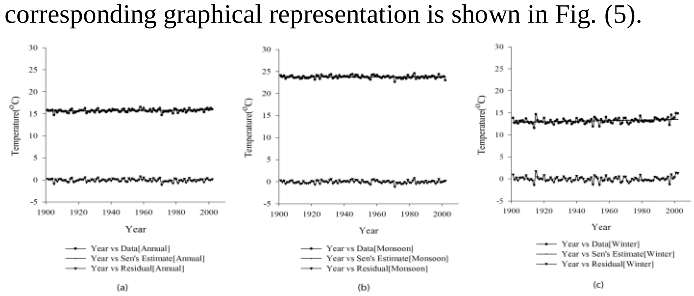

Fig. 4a Temperature trend of *Darbhanga* district of (a) monsoon data, (b) annual data and (c) winter data for the period 1901-2002

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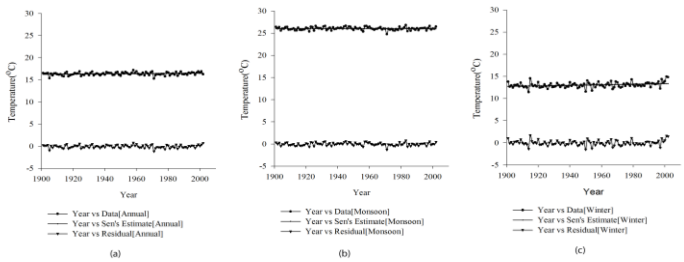

Fig. 4b Temperature trend of *Muzaffarpur* district of (a) monsoon data (b) annual data and (c) winter data for the period 1901-2002

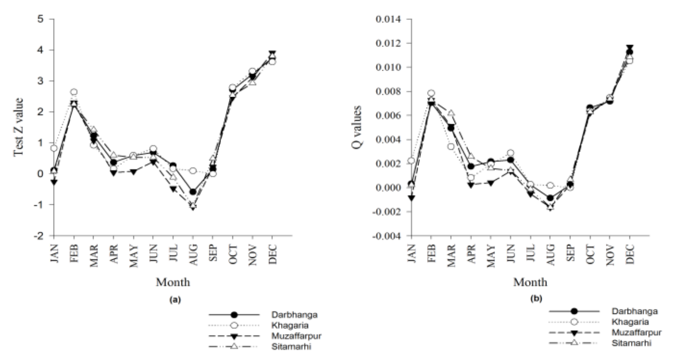

Fig. 5 Monthly trend statistics (a) *Z* values and (b) *Q* values for temperature in four districts of Lower Bagmati River Basin for the period 1901-2002

IV. Conclusion

The present analysis of the rainfall and temperature data of 102 years from 1901 to 2002 in LBRB has indicated a considerable variation in climate change with respect to temperature and rainfall in LBRB and conclusively reveals that trend of annual temperature is increasing with decrease in annual average rainfall. There is an obvious decreasing pattern in monsoon rainfall with decrease in monsoon average temperature. Due to increasing trend of temperature cloud retention has increased leading to delayed rainfall peaks, which may cause either unabated flash floods or drought like situations in the region in near future.

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