Investigations of Nonstationarity on Hydrological Data of Koshi Basin, Nepal

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***Abstract* - Hydrological designs are based on the premise that past data are representative of future and the statistical parameters of the data are stationary in nature. Many a times past data may not be representative of future and hence it becomes necessary to check assumption of stationarity of data. Further it is essential to assess the implications of this assumption on design floods and water availability estimates. Nonstationarity of 21 stations' hydrological data of the Koshi river basin are analysed. Data on many stations show nonstationarity. It is found from analysis of extreme annual discharge data of 21 stations in Koshi basin that 4 stations have short term dependence and 8 stations have long term dependence. Four stations have both short term and long term dependence. Similarly 13 stations show no trend and 4 stations show negative trend, 2 stations shows positive trend and results obtained are different in different tests on 2 stations, however overall trend obtained in both station is negative. Nonmonsoon runoff from 7 stations show the short term dependence, 9 stations show long term dependence and 5 stations show both long term and short term dependency. Similarly for monsoon runoff, 6 stations show short term dependence, 5 stations show long term dependence and 4 stations show both long term and short term dependence. For annual runoff, 7 stations show short dependence, 6 stations show long term dependence and 4 stations show both long term and short term dependence. In the trend analysis of 21 stations most of the stations show no trend in annual and seasonal runoff. One station shows negative trend in nonmonsoon runoff and 4 stations show positive trend in nonmonsoon runoff. While in the case of monsoon runoff 4 stations show negative trend and 1 station shows positive trend. Three stations of annual runoff show negative trend and only one station shows positive trend.**

Keywords: Stationarity, nonstationarity, dependence, trend, autocorrelation

I. INTRODUCTION

Hydrological time series show nonstationarity due to numbers of reasons. Land use/cover change, construction of dam upstream of the measurement site, change in climate etc. are some of the reasons of nonstationarity. A note on Stationarity and Nonstationarity, WMO (2012) discussed about stationarity and non stationarity, causes of nonstationarity, distinguishing stationary and nonstationary series, and practical application of nonstationary time series data. Stationarity and nonstationarity has great implication on the water resource management. Milly, et. al (2008) mentioned that stationary is dead due to anthropogenic causes so we need to find ways to identify nonstationary probabilistic models of relevant environmental variables and to use those models to optimize water systems. Climate change is the prominent cause for the nonstationarity in hydrological time series. Hirsh, (2010) had discussed on a perspective of nonstationarity and water management. He discussed on issue of nonstationarity due to climate change as a concerned topic to the water management community. Long term and short term dependence and trend are used for the determination of the nonstationarity. Lye, et al. (1994) studied the long term dependence in annual peak flows of Canadian rivers. They used parametric and non parametric approaches for the investigation of short term and long term dependence of the time series. The serial correlation structure of 90 Canadian rivers was analysed. Ceschia, et al. (1994) had made study trend analysis of mean monthly maximum and minimum surface temperatures of the 1951-1990 period in Friuli-Venezia Giulia. The behaviour of seasonal and yearly average of the monthly means of maximum and minimum daily surface temperature, covering the period 1951-90, in some stations of the Italian Hydrographic Service spread over the region of Friuli-Venezia Giulia has been analysed by the Spearman test with the aim of determining a possible trend.

In this paper 21 series extreme annual discharge and 21 series of average annual, monsoon and nonmonsoon runoffs from Koshi basin, Nepal are investigated for the identification of nonstationarity.

II. METHODOLOGY

A. *Investigation Of Short Term Dependence*

i. Turning Point Test (Kendall's test) (Kendall and Stuart, 1976)

Kendall's test is based on a binary series. If xi-1 < xi > xi+1 or xi-1 > xi < xi+1, then xi is assigned the value 1, otherwise, it is assumed to be zero. The number of ones, m, is approximately normally distributed for sample size n.

$$m \approx N\left\{\frac{2}{3}(n-2), \left[\frac{16n-29}{90}\right]^{1/2}\right\} \quad (1)$$

ii. Rank Von Neumann Ratio Test (Madannsky, 1988)

Let $r_1, \ldots, r_n$ denote the ranks associated with the x_i values. The rank Von Neumann ratio is given by following formula for sample size n.

$$v = \frac{\sum_{i=2}^{n}(r_i - r_{i-1})^2}{n(n^2-1)/12} \quad (2)$$

For large n, v is approximately distributed as

$$N\left[2, \left(\frac{20}{5n+7}\right)^{1/2}\right] \quad (3)$$

iii. Von Neumann Ratio Test (Madannsky, 1988)

$$\text{Let } v = \frac{\sum_{t=2}^{n}(x_t - x_{t-1})^2}{\sum_{t=1}^{n}\left(x_t - \bar{x}\right)^2} \quad (4)$$

If data are independent, v is approximately normally distributed with E(v) = 2 and

Var (v) = 4 (n - 2)/(n^2 – 1)

$$Z = (v-2)/[4(n-2)/(n^2-1)]^{1/2} \quad (5)$$

iv. Autocorrelation Test (Yevjevich, 1971)

For a sample of size n, the lag-one autocorrelation, r_1, is calculated as and r_1 is normally distributed as follows for sample size of n.

$$r_1 = \frac{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)\left(y_i - \bar{y}\right)}{\sqrt{\sum_{i=1}^{n}\left(x_i - \bar{x}\right)^2 \cdot \sum_{i=1}^{n}\left(y_i - \bar{y}\right)^2}} \quad (6)$$

$$r_1 \approx N\left\{-\frac{1}{n}, \left[\frac{n^3 - 3n^2 + 4}{n^2(n^2-1)}\right]^{1/2}\right\} \quad (7)$$

B. Investigation Of Long Term Dependence

i. Hurst K Test (Hurst, 1951)

Hurst coefficient is the measure of long term dependence. The Hurst coefficient is estimated by Hurst's K as K has a lower variance than other estimators currently in use. Calculation of Hurst's K is simple and straight forward which is given by

$$K = \frac{\log(R/S)}{\log(n/2)} \quad (8)$$

Where R is range of cumulative departures from the mean.

$$\text{i.e. } R = \text{Max.}\sum_{i=1}^{n}\left(x_i - \bar{x}\right) - \text{Min.}\sum_{i=1}^{n}\left(x_i - \bar{x}\right) \quad (9)$$

where $x_i = i^{th}$ variate

$\bar{x}$ = mean of the sample

s = standard deviation

n = sample length.

K is theoretically 0.5 for series of independent data; it increases, when there is greater degree of dependence and cannot exceed 1.0. The Hurst coefficient is only the measurement available for long term dependence.

To check the assumption of using normally distributed data for testing Hurst's K, the non-parametric bootstrap approach (Efron 1979) was used.

To test long-term dependence of a series, following procedure is adopted:

a) Annual flow series x_1, x_2,........,x_n are assumed as independent observations. Each x_i has the same probability of occurrence, 1/n.
b) Uniform random data i between one and n are generated, then x_i is chosen as one point in the bootstrap sample. This step is repeated n-time to generate a bootstrap sample of the same size n as that of original sample.
c) Hurst's K is calculated for the bootstrap samples.
d) Steps (ii) and (iii) are repeated for a large number of times (10,000 times in this study).
e) Number of times that observed K value of the sample is exceeded by the 10,000 bootstrapped K values is counted.
f) P value is calculated

$$\text{P value} = \frac{\text{No. of } K > K_{obs.}}{10{,}000} \quad (10)$$

If value of P is less than the value at specified significance level, it is concluded that the sample has long-term dependence at that level of significance. Otherwise, it has no long-term dependence.

C. Identification Of The Trend In Data Series

Trend in the time series data has been identified using Mann- Kendall test, Spearman's Rho test and Theil-Sen's slope estimator.

i. Mann-Kendall Test (Mann, 1945: Kendall, 1975)

The Mann-Kendall test is based on the test statistics S defined as follows:

$$S = \sum_{i-1}^{n-1}\sum_{j-i+1}^{n}\text{sgn}(x_j - x_i) \quad (11)$$

Where the x_j and $x_i$are the sequential data values, n is the length of the data set and

Sgn (α)= 1 if α>0
=0 if α=0
=-1 if α<0

Mann (1945) and Kendall (1975) have documented that when n≥8, the statistic S is approximately normally distributed with mean and the variance as follows:

E(S)=0

$$V(S) = [n(n-1)(2n+5) - \sum_{i=1}^{n} t_i (i-1)(2i+5)]/18 \quad (12)$$

t_i is the number of ties to the extent of i.

$$Z_{MK} = \frac{S-1}{\sqrt{Var(S)}} \text{ if } S > 0, \quad Z_{MK} = \frac{S+1}{\sqrt{Var(S)}} \text{ if } S < 0 \text{ and}$$

$$Z_{MK} = 0 \text{ if } S=0 \quad (13)$$

ii. Spearman's Rho test (Sneyers, 1990)

Let given sample data set {x_i ,i=1,2….n}

$$D=1-6\sum_{i=1}^{n}[R(x_i - i)]^2 / [n(n^2-1)] \quad (14)$$

R (x_i) is the rank of the ith observation x_i in the sample of size n. As per Sneyers, 1990)

E(D)=0

$$V(D)=\frac{1}{(n-1)} \qquad Z=\frac{D}{\sqrt{V(D)}} \quad (15)$$

iii. Theil-Sen's Slope Estimator (Theil, 1950; Sen, 1968)

It has been called "the most popular nonparametric technique for estimating a linear trend". This non-parametric statistic calculates the magnitude of any significant trends found. The Sen slope estimator (Sen, 1968) is calculated as follows:

$$Q=\frac{(x_{ij}-x_{kj})}{(i-k)} \quad (16)$$

For j=1……n $\qquad 1 \le k < i \le nj$

The slope estimate is the median of all Q values.

III. RESULTS

To detect the nonstationarity different statistical tests for short term and long term dependence have been carried out including trend detection tests in the data series. These tests have been applied for the 95% confidence level.

A. Analysis of the Instantaneous Peak Annual Discharge

There are 21 stations at different rivers on Koshi basin in Nepal whose annual instantaneous peak discharges are available. Those data are investigated for the short term and long term dependence. The results are shown in Table 1.

Out of 21 stations data, 4 stations have short term dependence and 8 stations have long term dependence. Four stations have both short term and long term dependence.

Trend in the given extreme annual discharge is also calculated. The summary of the trend analysis is shown in Table 2.

In the trend analysis 13 stations out of 21 stations show no trend and 4 station show negative trend. Two stations shows positive trend. In 2 stations different results are obtained from the different tests for the significance level of 5%. However the overall trend in these two stations is also negative.

B. Analysis of the Average Annual and Seasonal Runoff

Average monthly runoff (Million Cubic Meter-MCM) is calculated for each station from available average monthly discharge. Month of June to October are considered as monsoon period and remaining November to May are considered as nonmonsoon period.

Analysis of the long term and short term dependence of annual and seasonal runoffs has been made and presented in Table 3.

From the dependence analysis it has been found that nonmonsoon runoff of 7 stations show the short term dependence, 9 stations show long term dependence and 5 stations show both long term and short term dependence.

Similarly for monsoon runoff 6 numbers of data stations show short term dependence, 5 stations show long term dependence and 4 stations show both long term and short term dependence. In case of annual runoff 7 stations show short dependence, 6 stations show long term dependence and 4 stations show both long term and short term dependence.

Trend analysis has also been made for all the average annual, monsoon and nonmonsoon runoff. The summary of the result obtained from trend analysis has been presented in Table 4.

Out of 21 stations most of stations show no trend in annual and seasonal runoff. One station shows negative trend in nonmonsoon runoff and 4 stations show positive trend in nonmonsoon runoff. While in the case of monsoon runoff 4 stations show negative trend and 1 station shows positive trend. Three stations of annual runoff show negative trend and only one station shows positive trend. Three stations show different result in different tests but nature of the trend is same in both tests.

Table 1. Summary of test statistics and dependence of Annual peak discharge

Station No.	Data Length (Year)	Turning Point Test	Rank Von Neuman Ratio Test	Von Neuman Ratio Test	Auto-Correlation Test	Short term Dependence	Hurst Coefficient (K)	Generated Sample (K)	Long term persistence
600.1	22	0.35	1.58	0.56	-0.73	No	0.65	0.65	No
602	30	0.60	-0.56	-0.18	0.32	No	0.71	0.64	No
602.5	25	0.33	-1.10	-0.78	0.75	No	0.73	0.65	No
604.5	32	1.30	-0.27	0.49	-0.46	No	0.63	0.64	No
606	21	-2.53	-1.47	-1.66	1.62	No	0.84	0.66	Yes
610	35	-1.24	1.22	0.92	-0.80	No	0.65	0.63	No
620	42	0.12	-0.27	-0.39	0.39	No	0.79	0.63	Yes
627.5	17	0.00	-1.36	0.02	0.21	No	0.63	0.65	No
630	42	-1.60	-2.34	-2.07	2.07	Yes	0.74	0.63	Yes
640	24	1.17	-1.20	0.02	0.17	No	0.72	0.65	No
647	33	0.14	-2.01	-1.88	2.03	Yes	0.82	0.64	Yes
650	41	-1.14	-3.30	-0.41	0.53	No	0.73	0.63	Yes
652	22	-1.89	-1.14	-0.57	0.71	No	0.76	0.64	Yes
660	22	-0.68	-0.33	-0.41	0.37	No	0.69	0.63	No
668.5	20	0.56	-2.03	-2.36	2.60	Yes	0.91	0.65	Yes
670	22	-1.23	-1.88	0.20	-0.04	No	0.71	0.63	No
680	20	-0.50	0.72	1.19	-1.11	No	0.65	0.67	No
681	16	0.42	-0.53	-0.12	0.07	No	0.76	0.66	No
684	11	0.00	-0.93	-0.36	0.37	No	0.69	0.67	No
690	22	-3.24	-2.55	-2.40	2.47	Yes	0.78	0.63	Yes
695	22	-1.36	-1.25	-0.02	0.16	No	0.61	0.64	No

Table 2. Summary of test statistics and trend status of Annual Peak discharge

Station No.	Data Length (Year)	Mann Kendall test	Spearman's Rho test	Theil-Sen's Slope Estimate (Q)	Remarks on Trend
600.1	22	0.0283	-0.0052	0.000	No Trend
602	30	-2.9644	-2.8286	-5.273	Negative Trend
602.5	25	-2.0797	-2.3138	-0.929	Negative Trend
604.5	32	-0.0649	-0.0602	-1.450	No Trend
606	21	-2.2668	-2.2709	-108.000	Negative Trend
610	35	-0.4408	-0.3046	-1.500	No Trend
620	42	-1.6479	-1.5187	-7.407	No Trend
627.5	17	-0.6596	-0.5931	-0.523	No Trend
630	42	-2.4182	-2.2426	-18.000	Negative Trend
640	24	-1.9111	-2.2269	-0.925	Different result
647	33	2.9911	3.1404	14.514	Positive Trend
650	41	-0.0225	-0.5118	0.000	No Trend
652	22	0.4361	0.5947	-94.615	No Trend
660	22	-0.5181	-0.4165	1.938	No Trend
668.5	20	2.9864	2.789	3.178	Positive Trend
670	22	1.0996	1.6065	3.333	No Trend

680	20	-0.7543	-0.4175	1.389	No Trend
681	16	0.4052	0.4556	22.000	No Trend
684	11	-1.796	-2.113	-146.667	Different result
690	22	1.7237	1.8004	-6.471	No Trend
695	22	-0.9759	-0.8902	-86.667	No Trend

Table 3. Summary of test statistics and dependence of Annual and Seasonal runoff

Station No./Data Length (Yr)	Description	Turning Point Test	Rank Von Neuman Ratio Test	Von Neuman Ratio Test	Auto Correlatio n Test	Short term Dependence	Hurst Coefficient (K)	Generate d Sample (K)	Long term persiste nce
600.1/19	Nonmonsoon Runoff	-0.76	-2.96	-3.35	3.40	Yes	0.90	0.66	Yes
	Monsoon Runoff	-0.76	-3.05	-3.30	3.34	Yes	0.89	0.66	Yes
	Annual Runoff	-0.76	-2.96	-3.35	3.40	Yes	0.90	0.66	Yes
602/24	Nonmonsoon Runoff	-1.34	-0.92	-0.65	0.77	No	0.69	0.65	No
	Monsoon Runoff	-1.34	-0.95	-0.91	1.05	No	0.70	0.65	No
	Annual Runoff	-1.34	-0.92	-0.65	0.77	No	0.69	0.65	No
602.5/22	Nonmonsoon Runoff	-0.18	-1.37	-1.51	1.45	No	0.82	0.65	Yes
	Monsoon Runoff	-0.18	-2.11	-2.66	1.74	No	0.71	0.65	No
	Annual Runoff	-0.18	-1.91	-1.77	1.00	No	0.69	0.65	No
604.5/30	Nonmonsoon Runoff	-0.74	-3.25	-3.17	3.21	No	0.82	0.64	Yes
	Monsoon Runoff	1.49	-0.81	-0.69	0.79	No	0.78	0.64	Yes
	Annual Runoff	1.49	-0.94	-0.99	1.14	No	0.82	0.64	Yes
606/20	Nonmonsoon Runoff	-1.67	-0.98	-1.45	1.03	No	0.74	0.65	No
	Monsoon Runoff	-1.67	-2.35	-2.25	2.07	No	0.89	0.66	Yes
	Annual Runoff	-2.22	-1.92	-1.91	1.72	No	0.85	0.66	Yes
610/33	Nonmonsoon Runoff	-1.56	-2.09	-0.72	0.89	No	0.78	0.63	Yes
	Monsoon Runoff	-0.28	-0.19	0.15	-0.07	No	0.70	0.64	No
	Annual Runoff	0.14	-0.40	-0.34	0.43	No	0.75	0.64	No
620/42	Nonmonsoon Runoff	-1.75	-3.40	-2.92	2.85	Yes	0.77	0.63	Yes
	Monsoon Runoff	-1.00	-3.57	-2.88	2.98	Yes	0.72	0.63	No
	Annual Runoff	-1.00	-3.95	-3.23	3.30	Yes	0.74	0.63	No
627.5/15	Nonmonsoon Runoff	-0.44	-0.22	-0.21	0.46	No	0.78	0.67	No
	Monsoon Runoff	-0.44	-1.34	-0.11	0.30	No	0.64	0.66	No
	Annual Runoff	-0.44	-1.34	0.01	0.17	No	0.63	0.66	No
630/37	Nonmonsoon Runoff	-0.53	-1.96	-1.42	1.44	No	0.75	0.64	No
	Monsoon Runoff	-0.13	-2.83	-2.90	2.84	Yes	0.89	0.63	Yes
	Annual Runoff	0.27	-2.65	-2.61	2.65	Yes	0.90	0.63	Yes
640/22	Nonmonsoon Runoff	-0.18	-2.45	-2.25	2.43	Yes	0.64	0.65	No
	Monsoon Runoff	1.41	0.50	0.58	-0.45	Yes	0.62	0.66	No
	Annual Runoff	1.41	0.16	0.07	0.12	Yes	0.64	0.66	No
647/29	Nonmonsoon Runoff	-1.82	-1.97	-1.51	1.62	No	0.77	0.64	No
	Monsoon Runoff	0.45	1.02	0.74	-0.64	No	0.63	0.64	No
	Annual Runoff	0.45	1.41	0.90	-0.79	No	0.60	0.64	No

650/39	Nonmonsoon Runoff	-2.20	-4.51	-3.71	3.81	Yes	0.82	0.63	Yes
	Monsoon Runoff	0.13	-4.13	-3.51	3.62	Yes	0.89	0.63	Yes
	Annual Runoff	0.52	-4.05	-3.56	3.67	Yes	0.89	0.63	Yes
652/34	Nonmonsoon Runoff	-0.98	-1.30	-1.69	1.56	No	0.75	0.64	No
	Monsoon Runoff	-0.14	-1.24	-1.75	1.93	No	0.76	0.64	No
	Annual Runoff	-0.14	-1.57	-1.57	1.72	No	0.75	0.64	No
660/27	Nonmonsoon Runoff	-1.26	-1.99	-1.67	1.47	No	0.72	0.65	No
	Monsoon Runoff	-0.79	-0.93	-1.19	1.34	No	0.64	0.65	No
	Annual Runoff	-0.79	-0.96	-1.31	1.52	No	0.64	0.65	No
668.5/19	Nonmonsoon Runoff	0.38	-2.56	-2.67	2.49	Yes	0.89	0.66	Yes
	Monsoon Runoff	-0.19	-1.20	-0.93	1.12	No	0.80	0.65	No
	Annual Runoff	-0.19	-1.66	-1.14	1.35	No	0.81	0.65	No
670/39	Nonmonsoon Runoff	-1.04	-2.25	-2.66	2.79	Yes	0.74	0.64	No
	Monsoon Runoff	-0.26	-0.44	-0.72	0.82	No	0.68	0.63	No
	Annual Runoff	-0.26	-0.74	-0.88	0.97	No	0.68	0.63	No
680/20	Nonmonsoon Runoff	1.11	0.82	-0.76	1.27	No	0.65	0.65	No
	Monsoon Runoff	0.56	-0.77	-1.01	1.08	No	0.71	0.65	No
	Annual Runoff	0.56	-0.74	-0.92	0.94	No	0.69	0.65	No
681/15	Nonmonsoon Runoff	-0.44	-1.99	-2.34	-0.07	No	0.66	0.66	No
	Monsoon Runoff	0.87	0.41	-0.22	-0.18	No	0.72	0.66	No
	Annual Runoff	0.87	0.12	-0.31	-0.06	No	0.68	0.66	No
684/10	Nonmonsoon Runoff	0.55	-0.72	-0.96	0.14	No	0.74	0.67	No
	Monsoon Runoff	0.55	-1.61	-1.70	1.63	No	0.85	0.68	No
	Annual Runoff	0.55	-1.61	-1.71	1.55	No	0.86	0.68	No
690/39	Nonmonsoon Runoff	-1.82	-2.71	-3.01	3.21	Yes	0.77	0.64	Yes
	Monsoon Runoff	-0.26	-3.80	-4.63	4.82	Yes	0.82	0.63	Yes
	Annual Runoff	-2.20	-4.11	-4.64	4.85	Yes	0.82	0.63	Yes
695/26	Nonmonsoon Runoff	-1.45	-1.94	-1.88	1.99	No	0.82	0.65	Yes
	Monsoon Runoff	0.00	-1.53	-1.37	1.43	No	0.77	0.65	No
	Annual Runoff	-0.96	-1.25	-1.17	1.19	No	0.73	0.65	No

Table 4. Summary of test statistics and trend status

Station No./Data Length (Yr)	Description	Mann Kendall test	Spearman's Rho test	Theil-Sen's Slope	Remarks for trend
600.1/19	Nonmonsoon Runoff	-3.01	-2.79	-192.83	Negative Trend
	Monsoon Runoff	-2.94	-2.75	-162.09	Negative Trend
	Annual Runoff	-3.01	-2.79	-192.83	Negative Trend
602/24	Nonmonsoon Runoff	1.02	0.79	5.23	No Trend
	Monsoon Runoff	0.77	0.62	2.78	No Trend
	Annual Runoff	1.02	0.79	5.23	No Trend
602.5/22	Nonmonsoon Runoff	2.26	2.28	0.90	Positive Trend
	Monsoon Runoff	-1.75	-1.88	-2.48	No Trend
	Annual Runoff	-0.56	-0.73	-0.86	No Trend

604.5/30	Nonmonsoon Runoff	-1.53	-1.45	-15.85	No Trend
	Monsoon Runoff	1.75	1.90	59.88	No Trend
	Annual Runoff	1.36	1.60	46.48	No Trend
606/20	Nonmonsoon Runoff	1.59	1.39	44.11	No Trend
	Monsoon Runoff	-2.95	-3.06	-277.47	Negative Trend
	Annual Runoff	-2.76	-2.78	-239.66	Negative Trend
610/33	Nonmonsoon Runoff	3.33	3.21	4.62	Positive Trend
	Monsoon Runoff	0.70	0.44	4.03	No Trend
	Annual Runoff	1.44	1.08	8.89	No Trend
620/42	Nonmonsoon Runoff	4.10	3.84	2.15	Positive Trend
	Monsoon Runoff	2.30	2.41	6.44	Positive Trend
	Annual Runoff	2.71	2.74	8.95	Positive Trend
627.5/15	Nonmonsoon Runoff	0.99	1.43	1.25	No Trend
	Monsoon Runoff	0.20	0.36	2.61	No Trend
	Annual Runoff	0.40	0.49	4.39	No Trend
630/37	Nonmonsoon Runoff	-0.98	-1.07	-2.99	No Trend
	Monsoon Runoff	-3.96	-3.87	-58.59	Negative Trend
	Annual Runoff	-3.73	-3.75	-60.29	Negative Trend
640/22	Nonmonsoon Runoff	1.52	1.65	0.28	No Trend
	Monsoon Runoff	-0.28	-0.57	-0.26	No Trend
	Annual Runoff	-0.06	-0.13	-0.08	No Trend
647/29	Nonmonsoon Runoff	-2.01	-1.90	-3.65	Different Result
	Monsoon Runoff	-0.66	-0.54	-5.19	No Trend
	Annual Runoff	-0.62	-0.62	-6.44	No Trend
650/39	Nonmonsoon Runoff	-0.75	-0.82	-0.34	No Trend
	Monsoon Runoff	-0.48	-0.94	-0.70	No Trend
	Annual Runoff	-0.19	-0.85	-0.65	No Trend
652/34	Nonmonsoon Runoff	-0.50	-0.43	-3.02	No Trend
	Monsoon Runoff	1.22	1.30	43.68	No Trend
	Annual Runoff	0.86	1.15	46.30	No Trend
660/27	Nonmonsoon Runoff	0.38	0.25	0.66	No Trend
	Monsoon Runoff	-0.17	-0.24	-1.22	No Trend
	Annual Runoff	-0.04	-0.04	-1.24	No Trend
668.5/19	Nonmonsoon Runoff	3.05	2.98	2.07	Positive Trend
	Monsoon Runoff	1.02	1.24	6.54	No Trend
	Annual Runoff	1.23	1.44	8.07	No Trend
670/39	Nonmonsoon Runoff	-0.70	-0.54	-1.75	No Trend
	Monsoon Runoff	0.22	0.39	2.87	No Trend
	Annual Runoff	0.05	0.38	1.47	No Trend
680/20	Nonmonsoon Runoff	1.24	0.62	20.20	No Trend
	Monsoon Runoff	1.78	1.82	269.77	No Trend
	Annual Runoff	1.72	1.80	275.84	No Trend
681/15	Nonmonsoon Runoff	2.08	1.95	46.47	Positive Trend
	Monsoon Runoff	0.79	0.64	222.39	No Trend
	Annual Runoff	1.09	1.12	326.41	No Trend

684/10	Nonmonsoon Runoff	-1.61	-1.69	-24.51	No Trend
	Monsoon Runoff	-2.15	-2.09	-303.42	Negative Trend
	Annual Runoff	-2.15	-2.09	-342.94	Negative Trend
690/39	Nonmonsoon Runoff	0.48	0.68	3.58	No Trend
	Monsoon Runoff	1.89	2.32	61.84	Different Result
	Annual Runoff	1.72	2.28	59.86	Different Result
695/26	Nonmonsoon Runoff	-1.37	-1.65	-41.89	No Trend
	Monsoon Runoff	0.79	0.60	137.09	No Trend
	Annual Runoff	0.40	0.37	65.85	No Trend

IV. CONCLUSION

Nonstationarity on the annual peak discharge and average annual and seasonal runoffs on 21 stations of Koshi basin has been analysed. Many stations show the dependence and trend. So the nonstationarity behaviour in hydrological data series cannot be disregarded. Thus the nonstationarity shall be considered in the prevailing practice of flood frequency analysis to minimize the risk associated due to nonstationary characteristics of the hydrological time series.

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