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SPATIAL AND TEMPORAL RAINFALL TRENDS AND ITS VARIABILITY ANALYSIS OVER CHAMPUA SUB-WATERSHED OF BAITARANI RIVER BASIN OF ODISHA

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ABSTRACT

Champua catchment has blessed with the Baitarani river lies in Odisha district and situated in Eastern part of India. In the present study, uncertainty and erratic distribution of rainfall are analyzed at small catchment area as it plays a vital role in agriculture growth and sustains the natural resources on a watershed. The annual and seasonal variations in different sub-watershed of the study area are investigated to study the climate change pattern in different sub-catchment of the Study area. Statistical non-parametric tests like Mann-Kendall (MK) test, Modified Mann-Kendall (MMK) test and Sen's slope were used to find the monotonic trend and its magnitude. Mann Whitney Pettitt (MWP) test and standard normal homogeneity test (SNHT) have been adopted for probably break or change point detection in the time series. In this study, entire data is divided into three classes, i.e. before 1946, after 1947 and entire series 1901-2013.From the analysis of annual and monsoon rainfall, It was found that overall there is a decreasing rainfall trend in entire series from 1901-2013. Also, before 1946, the significantly increasing rainfall trend and decreasing rainfall trend after 1947 in most of the sub-watershed. These results are useful for the developing country like India whose economy and food security depend upon the water availability.

Keywords: *Mann-kendall; modified mann-kendall test; rainfall variability; IMD gridded data*

INTRODUCTION

The rainfall distribution is the highly erratic term and it varies over the smaller areas due to climate variation over the decades. Climate changes affect the rainfall distribution all over the world. The change in rainfall distribution would change the surface runoff, soil moisture, recharge and storage. Also, the rainfall increases the discharge and water availability to the river. The agriculture is the main source of income for tribal people and it depends on the water availability. The availability of water decrease due to change in climate and population growth both together would adversely affect the India up to the year of the 2050s (IPCC, 2007). The most of the rivers are dried up in the non-monsoon period due to climate change. The dependability of water resources is increasing for fulfilling the water requirement for irrigation land and industrial growth for growing population. The researchers (Bradley *et al.,* 1987; Rodriguez-Puebla *et al*., 1998) have indicated that the global warming is one of the factors which highly influences the changes in rainfall pattern at regional scale as well as in all over the world. The rainfall variability analysis was quite useful in deciding the cropping pattern according to the water availability.

The rainfall variability analysis is quite useful in deciding the cropping pattern according to the water availability. Goswami *et al., (*2006) found both the frequency and magnitude of extreme rain events in rising trends and moderate events showed the decreasing trend in the frequency of rainfall in most of central India in monsoon seasons. In recent past, various studies have been done regarding the rainfall variability and climate change. In most of the Indian regions, high frequency of rainfall in monsoon season shows increasing trend in most of central and north-west India and Andaman and Nicobar island while decreasing trend is found in winter, pre-monsoon and post-monsoon season (Dash et al.,2007). It was noticed that annual rainfall trend in Punjab and Haryana shows an increasing trend (Kumar et al., 2010). The significant negative trend in annual/monsoon time series in most of the states (East Madhya Pradesh, Chhattisgarh, Nagaland, Manipur, Mizoram and Tripura) (Krishan et al., 2015). Patra et al., (2012) have found the insignificant decline trends of annual and monsoon rainfall in Odisha state. Most of the districts in Madhya Pradesh have shown declining trend during 1901 to 2011 (Kundu et al., 2015).The decline trends are found in annual, monsoon and winter precipitation of Jharkhand state during 1901-2011(Chandniha et al., 2015). As per review process, it was seen that the climate changes mostly pronounced with the natural and anthropogenic change in space as well as time. Hence, the present study is to find out the trend analysis at the watershed level. In India, most of the water resources and agricultural planning are associated with the administrative boundary. In the present study, highlights the watershed level rainfall variability and trend analysis for future prospects. The adopted analysis plays an essential role in an identification of climatic behavior in the past which is also responsible for future strategic planning and mitigation over the study area.

STUDY AREA

The Champua catchment area extended from $85^0$9'42.66" to $85^0$44'10.42" E. longitude and $21^0$6'52.92" to $22^0$11'51.65" N. latitude. The most of the study area (1815 km^2) covered in Keonjhar district of Odisha and rich with the Baitarani River. The trend analysis has been performed at watershed and period of analysis is about 113 years (1901-2013). The long-term annual average rainfall of the catchment is about 1425 mm and Kendujhar district is about 1,505 mm. Agriculture is the main source of livelihood for a most tribal community are living in the study area. The overall weather of the Odisha state is humid tropical, medium to high rainfall, short and mild winter. Figure 1 shows the study area, i.e. area location of 6 sub-catchment in Odisha State.

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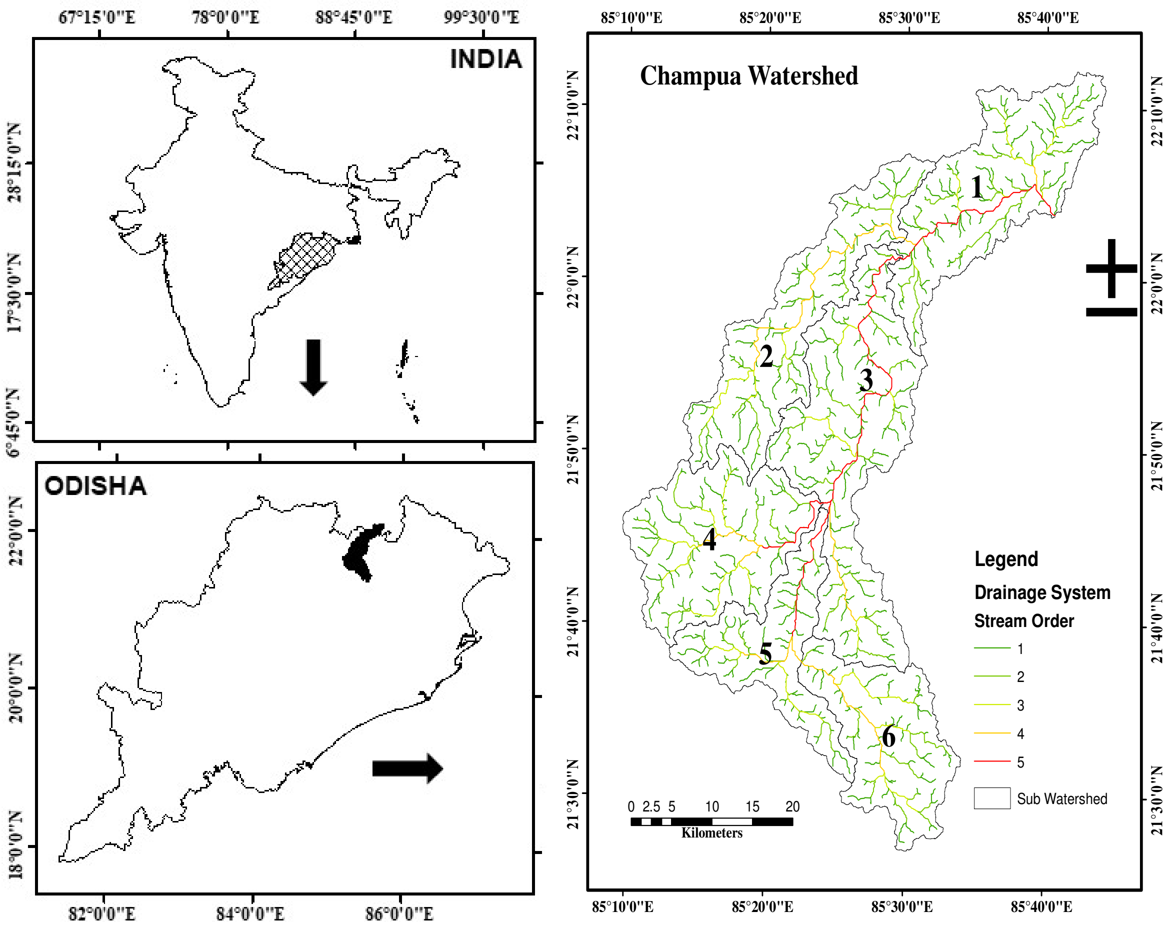

Fig. 1: Location map of the study area (Champua sub-watershed)

DATA AND ANALYSIS METHODS

The yearly rainfall data are divided into four distinct seasons (December–February), pre-monsoon (March-May), monsoon (June–September), and post-monsoon (October–November), for examining changes in rainfall. The analysis has been performed for six sub-watershed wise and about 4 (IMD) rainfall stations contribute in each watershed by Thiessen polygons were aggregated into monthly rainfall and annual values for each sub-watershed (C-WS1, C-WS2, C-WS3, C-WS4, C-WS5, C-WS6) as per boundary generated by delineation of the watershed by Arc GIS 2012. Then, monthly, seasonal and annual rainfall series are formed for the trend analysis. The rainfall trends are generally affected by weather and climate conditions, therefore rainfall series is examined for homogeneity using SNHT. Long-term trend analysis has been performed for each district by monthly, seasonal and annual basis by (Alexandersson 1986; Alexandersson, et al. 1997) and SNHT are used for homogeneity test for long data series at 5 % level of significance.

MK and MMK tests, non-parametric test are better than other parametric tests for detection of a monotonic trend in persistent data (Kendall 1975a; Mann 1945). So in the current study, these tests have been adopted for the long-term rainfall trend analysis. The magnitude of trend has been calculated by Theil-Sen's estimator (Duhan, et al. 2013; Jhajharia et al. 2012) and positive and negative values represent the increasing and decreasing trend respectively. MWP test was used to detect the possible break point in time series (Pettitt A., 1979) for each watershed of Champua basin. Thereafter, change percentages have been carried out by magnitude for both the data sets before and after breakpoint individually. The rainfall trends results are separately expressed in the form of time series and found there were positive, negative, significantly positive and negative trends at 5% level of significance over the watersheds. Attempts have also been made by Jaiswal et al. (2014, 2015a, 2015b) to analyse the rainfall trend and change point detection.

The spatial rainfall trends change over the time shown by a random variable can be detected by the non-parametric test are ***MK Test** and **MMK test.*** The historic researchers were showed that a non-parametric test is very efficient for identifying the rainfall trends.

MK Test:

The MK statistic, S, is defined as:

$$S = \sum_{j=1}^{m-1} \sum_{k=j+1}^{m} \mathrm{sgn}\left(x_k - x_j\right) \text{, for all k>j} \qquad (1)$$

With all the x_j (j>k, j=2, 3 … n, recall that n=113 years) showing the annual rainfall values and their significance ($x_k - x_j = \theta$) represented by

$$Sgn(\theta)=\begin{cases} 1 & if\ x_k - x_j > 0 \\ 0 & if\ x_k - x_j = 0 \\ -1 & if\ x_k - x_j < 0 \end{cases} \quad (2)$$

Assuming independent data with related variances *S* statistic may be calculated by Eq. (3) (Kendall, 1975)

$$E[S]=0,\ Var(S)=\frac{n(n-1)(2n+5)-\sum_{i=1}^{m} t_i(t_i-1)(2t_i+5)}{18} \quad (3)$$

However, if t_i tied exists in the observation data, *Zmk statistics were derived from.*

$$Zmk=\begin{cases} \frac{S-1}{\sqrt{Var(S)}} & If\ S>0 \\ 0 & If\ S=0 \\ \frac{S+1}{\sqrt{Var(S)}} & If\ S<0 \end{cases} \quad (4)$$

If Zmk is positive, then the increasing are found and if *Zmk* is negative, then the decreasing are found. Also, If *Zmk* is positive and more than 1.96 then it represents a significant increasing trend whereas, reverses negative *Zmk*, and shows significant decreasing trends at a significance level of 0.05.

MMK Test:

Mann-Kendall test is modified by using the modified variance of *S*, designated as *Var(S)**, expressed as follows:

$$Var(S)^* = V(S)\frac{n}{n^*} \quad (5)$$

where, n*= effective sample size. Based on the work done by (Hamed., et al. 1998), the n/n* ratio may be defined as

$$\frac{n}{n^*}=1+\frac{2}{n(n-1)(n-2)}\sum_{i=1}^{n-1}(n-1)(n-i-1)(n-i-2)ri \quad (6)$$

where, *n*= actual number of sample data: and *ri*=lag-i significant autocorrelation coefficient of rank *i* of time series. Once, the computed values of Var(*S*)*(Eq.5) is substituted for Var(*S*) in Eq. (3). The results are compared with threshold levels at 5% and the values above ±1.96 are at significant level.

Sen's Slope Estimator

As suggested by Sen (1968), for a linear trend time series the true slope (change per unit time) can be estimated by the nonparametric methods (Jain, S.K., et al. 2012) ,the magnitude of a trend in hydro-meteorological time series in the form of slope. In this method, the N pairs of data are first calculated to estimate the slopes was derived from:

$$Q_i=\frac{x_j-x_k}{j-k} \quad \text{for } i=1,2,3,\ldots\ldots,n \quad (7)$$

where, x_j and x_k are time series values at a time j k ($j>k$) and Q_i (i=1,2,3….,n). The median of these N values of Q_i is sen's estimator of the slope was derived from:

$$\beta=\begin{cases} Q_{[(N+1[N/2])/2]} & N\ is\ odd \\ \frac{1}{2}\left(Q+Q_{(N+2)/2}\right) & N\ is\ even \end{cases} \quad (8)$$

The results are compared with threshold levels at 5% and the β values above ±1.96 are significant (increasing/decreasing) trends.

RESULTS AND DISCUSSION

The annual and seasonal rainfall statistical characteristics:

The rainfall statistical characteristics for the duration period of 113 years (1901-2013) for Champua watershed. This statistic result indicates that the regions having greater rainfall has lesser variability than the regions with relatively lower rainfall. The mean, standard deviation (SD) and coefficient of variation (CV) are shown in the form of Table 1.

Homogeneity test in the times series (1901-2013)

Homogeneity test has been applied to the time series using SNHT with the significance level of 5% (Alaxanderdsson et al. 1986; Alexandersson et al. 1997).The change shift point has been detected using MWP and SNHT test are shown in table 2. The change point (P values) has been computed using 10000 Monte Carlo simulations. The test interpretation, H_0

Table 1: The annual and seasonal rainfall statistical summary for Champua watershed

Watersheds	Area	Annual			Pre-Monsoon			Monsoon			Post-Monsoon			Winter		
		Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV	Mean	SD	CV
C-WS1	332.0	1414	271	19	146	61	42	1118	235	21	99	72	73	52	49	94
C-WS2	306.6	1443	271	19	148	64	43	1136	237	21	107	78	73	53	49	94
C-WS3	425.6	1423	269	19	156	65	42	1104	227	21	110	77	70	53	50	94
C-WS4	312.5	1415	278	20	159	94	59	1084	231	21	118	88	75	54	51	96
C-WS5	204.3	1418	262	18	160	85	53	1085	217	20	120	86	72	54	50	94
C-WS6	234.0	1427	268	19	163	72	44	1082	221	20	127	91	72	54	50	93
Whole watershed	1815.4	1423	248	17	155	66	43	1104	210	19	112	78	70	53	49	92

stands for the homogeneous series and *Ha* for the heterogeneous series at 5% level of significance. The trend *Ho* and *Ha* are shown after comparing the p-values and significance level at 5%. The two test indicates the year 1946 is the most probable change point in rainfall series for Champua watershed. The Pettit's test is more precise than SNHT; the results showed that most of the sub-watersheds change point near to the year 1946.

trend in the month of September and in the month of July has three watersheds (C-WS1, C-WS2, C-WS3) showed a negative and remaining showed a positive trend. The two watershed showed(C-WS1, C-WS3) showed decreasing trend in the month of August and October. The detail description of results is shown with the help of table 3a.

Annual and Seasonal Trends:
The annual and seasonal scale data have analysed, and it was found that various watersheds have significant positive or negative trends in different seasons for the period of 1901-2013, but the trends of four watersheds (C-WS1, C-WS2, C-WS3, and C-WS6) were negative trend in which watershed no.C-WS3 are significantly negative trend on annual basis. In case of the monsoon season, only C-WS4 showed positive trend and remaining showed negative trend in which C-WS1, C-WS2 and C-WSS3 are showing the significantly negative trend. The pre-monsoon and post-monsoon data showed almost all positive trend except in case of watershed no C-WS1 which showed negative trend in post-monsoon and winter data showed negative trend for all watersheds. The detailed description of the trend analysis results are shown in Table 3(b).

Table 2: The MWP test and SNHT test for Watershed (1901–2013).

Watersheds	Pettit's Test			SNHT Test		
	P value	Year	Trend	P value	Year	Trend
SWS-1	0.017	1956	*Ha*	0.044	1961	*Ha*
SWS-2	0.052	1946	*Ho*	0.141	1946	*Ho*
SWS-3	0.003	1956	*Ha*	0.004	1956	*Ha*
SWS-4	0.247	1983	*Ho*	0.285	1983	*Ho*
SWS-5	0.307	1946	*Ho*	0.692	1946	*Ho*
SWS-6	0.191	1946	*Ho*	0.291	2004	*Ho*
Whole watershed	0.044	1946	*Ha*	0.121	1946	*Ho*

H_0, H_a, represents homogeneous and heterogeneous series at significance level of 5% respectively

Rainfall trend analysis:
For the purpose, MK, MMK and Theil Sen slope estimator test(s) have been adopted for analysis of sub-watershed (Champua) of Baitarani river of Odisha state using monthly, seasonal and annual rainfall basis.

MK/MMK test of rainfall series:
The MK and MMK test statistics at 5% of significant level are presented in Table 3 with notation of 's' (superscript). Positive and negative z-statistics values indicate increasing and decreasing trends respectively. The overall results are segregated with three-time series scales, i.e., whole series (1901-2013), before (1901-1946) and after shift change point (1947-2013). The entire methodologies have been adopted for these three segments.

Monthly trends
The whole analysis divided into three-time steps, i.e., 1901-2013, 1901-1946 and 1947-2013.It has been found that almost all sub watershed showed negative trend in the month of July in both tests during 1901-2013. The four sub-watersheds (C-WS1, C-WS2, C-WS3, and C-WS6) showed the significant trend at the level of 5% by MMK test while in case of MK test all significant negative trend. In August, three watersheds showed positive trend and remaining showed negative trend by MMK. It has found that the MMK test results are more distinct than the MK test. Therefore, the results are discussed with the help of MMK test. The detailed description of the results are shown in Table 3(a). Before change point (1901-1946), it has been found that all positive trends were in the month of July to November while in the month of March showed all negative trends. In December month, three watersheds (C-WS4, C-WS5, and C-WS6) showed negative trend and remaining watershed showed a positive trend. After change point (1947-2013), it has been found that all negative

For the period 1901-1946, it was noticed that in annual and monsoon season all sub-watershed showed the positive trend at 5% level of significance. The pre-monsoon season showed all negative trend and post-monsoon season showed all positive trend in which C-WS1, C-WS2, and C-WS3 watersheds have shown significantly positive trend. The winter season showed almost all negative trend except in case of watershed no. C-WS1. For the period 1947-2013, it was noticed that C-WS4 and C-WS5 showed the significantly positive trend in annual series whereas no significant positive trend in monsoon season in which C-WS1 and C-WS3 showed the negative trend. The pre-monsoon season showed the positive trend in all watershed whereas in post monsoon there is fall in the positive trend in which C-WS1 and C-WS3 showed the negative trend. The winter season showed almost all negative trend except in case of watershed no. C-WS6. The detailed description of the results are shown in Table 3(b).

Table 3a: Trend analysis on monthly basis by MK and MMK test

1901-2013	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
C-WS1(MK)	-1.45	-2.52s	-1.17	1.3	0.67	0.31	-3.46s	-0.35	0.47	0.16	0.2	0.14
C-WS2(MK)	-1.32	-2.35s	-0.52	1.49	1.05	0.45	-3.14s	0.04	0.96	0.72	0.4	0.29
C-WS3(MK)	-1.25	-2.3s	-0.67	1.36	0.38	0.23	-3.66s	-1.01	0.63	0.41	0.35	0.21
C-WS4(MK)	-0.76	-1.67	0.36	1.68	0.63	1.71	-1.98s	0.93	1.23	1.11	1.11	0.28
C-WS5(MK)	-0.88	-1.73	0.13	1.47	0.58	1.57	-2.35s	0.32	1.21	1.06	0.88	0.2
C-WS6(MK)	-1.03	-1.94	-0.22	1.48	0.95	1.26	-2.47s	-0.01	0.77	1.05	0.6	0.07
1901-2013												
C-WS1(MMK)	-0.61	-1.12	-1.12	1.48	0.5	0.35	-3.08s	-0.35	0.47	0.16	0.07	0.14
C-WS2(MMK)	-0.7	-1.22	-0.59	1.49	1.44	0.45	-3.2s	0.04	0.96	0.7	0.17	0.29
C-WS3(MMK)	-0.54	-1.23	-0.67	1.36	0.53	0.19	-3.41s	-1.12	0.63	0.46	0.14	0.21
C-WS4(MMK)	-0.35	-1.02	0.27	1.29	0.53	1.71	-1.24	1.16	1.36	1.11	0.63	0.28
C-WS5(MMK)	-0.44	-1.03	0.11	1.1	0.58	1.47	-1.77	0.37	1.03	0.89	0.41	0.2
C-WS6(MMK)	-0.47	-1.37	-0.22	1.26	1.07	1.68	-2.19s	-0.01	0.93	0.98	0.34	0.07
1901-1946												
C-WS1(MK)	0.04	0.08	-0.98	1.03	-0.59	0.27	2.03s	2.76s	0.28	1.93	0.79	0.01
C-WS2(MK)	0.01	-0.06	-1.23	0.82	-0.15	0.06	1.84	1.84	1.02	1.93	1.02	0.01
C-WS3(MK)	-0.1	-0.09	-1.16	1.11	0.32	0.21	2.12s	2.16s	0.87	1.78	1.31	0
C-WS4(MK)	-0.28	0	-1.65	0.77	0.19	0.17	1.78	1.1	0.68	1.51	1.44	-0
C-WS5(MK)	-0.28	-0.07	-1.5	0.8	0.04	0.11	1.76	1.27	0.87	1.53	1.13	-0.2
C-WS6(MK)	-0.14	-0.09	-1.25	0.96	-0.08	0.15	2.14s	1.51	0.8	1.53	1.15	-0.2
1901-1946												
C-WS1(MMK)	0.04	0.08	-0.82	1.03	-0.59	0.73	2.03s	3.26s	0.28	1.93	0.75	0.01
C-WS2(MMK)	0.01	-0.06	-1.23	0.82	-0.15	0.07	1.74	2.25s	1.02	2.15s	0.62	0.01
C-WS3(MMK)	-0.09	-0.09	-1.16	3.41s	0.32	0.21	2.51s	2.16s	0.87	2.39s	0.85	0
C-WS4(MMK)	-0.22	0	-1.12	0.77	0.24	0.17	1.82	1.1	0.68	1.51	0.7	-0
C-WS5(MMK)	-0.27	-0.07	-1.13	0.8	0.04	0.11	1.76	2.16s	0.87	1.53	0.66	-0.2
C-WS6(MMK)	-0.14	-0.08	-0.96	0.96	-0.08	0.15	2.14s	1.51	0.8	1.23	0.91	-0.2
1947-2013												
C-WS1(MK)	-0.82	-1.64	-2.06s	1.99s	1.22	1.26	-1.63	-0.65	-0.61	-0.14	0	0.1
C-WS2(MK)	-0.49	-1.44	-1.01	2.53s	1.58	1.35	-0.94	0.01	-0.06	0.45	-0.1	2.1s
C-WS3(MK)	-0.4	-1.45	-1.36	1.59	0.94	1.27	-1.2	-1.02	-1.09	-0.17	-0.3	0.1
C-WS4(MK)	-0.1	-1.12	0	2.16s	1.72	2.19s	1.14	0.43	-0.16	0.39	0.5	0.1
C-WS5(MK)	-0.18	-1.1	-0.34	1.92	1.73	2.22s	0.63	0	-0.37	0.31	0.5	1.2
C-WS6(MK)	-0.11	-1.34	-0.79	1.66	2s	2.15s	0.29	0.05	-0.8	0.15	0.3	0
1947-2013												
C-WS1(MMK)	-0.42	-1.39	-1.38	1.62	1.22	1.09	-1.63	-0.65	-0.61	-0.14	-0	0.1
C-WS2(MMK)	-0.28	-1.04	-1.01	2.53s	1.58	1.35	-0.94	0.01	-0.07	0.49	-0.1	0.18
C-WS3(MMK)	-0.32	-1.1	-1.57	1.59	0.94	1.02	-1.43	-1.02	-1.09	-0.21	-0.3	0.1
C-WS4(MMK)	-0.06	-0.75	0	1.78	1.72	2.01s	1.14	0.43	-0.16	0.37	0.62	0.14
C-WS5(MMK)	-0.11	-0.92	-0.34	2.96s	2.63s	2.39s	0.68	0	-0.37	0.31	0.5	0.1
C-WS6(MMK)	-0.06	-0.9	-0.92	1.66	2s	2.15s	0.29	0.06	-1.11	0.21	0.37	-0

'*s*' represent the 5% level of significance level

Table 3b: Trend analysis on annual and seasonal basis by MK and MMK test

1901-2013	Annual	Pre-Monsoon	Monsoon	Post-Monsoon	Winter
C-WS1(MK)	-1.51	0.68	-1.59	-0.07	-2.52s
C-WS2(MK)	-1.01	1.47	-1.33	0.41	-2.26s
C-WS3(MK)	-2.23s	0.72	-2.37s	0.06	-2.56s
C-WS4(MK)	0.44	0.86	0.03	0.97	-1.65
C-WS5(MK)	0.04	0.93	-0.41	0.83	-1.83
C-WS6(MK)	-0.6	1.31	-1	0.81	-1.8
1901-2013					
C-WS1(MMK)	-1.31	0.73	-1.98s	-0.09	-2.03s
C-WS2(MMK)	-0.89	2.09s	-2.4s	0.41	-2.26s
C-WS3(MMK)	-2.23s	0.77	-2.37s	0.06	-1.87
C-WS4(MMK)	0.44	1.06	0.03	1.18	-1.36
C-WS5(MMK)	0.04	0.93	-0.46	0.8	-1.83
C-WS6(MMK)	-0.49	1.56	-1	0.89	-2.03s
1901-1946					
C-WS1(MK)	3.2s	-0.68	3.47s	2.06s	0.02
C-WS2(MK)	2.81s	-0.45	2.84s	2.06s	-0.09
C-WS3(MK)	3.01s	-0.13	3.05s	2.03s	-0.27
C-WS4(MK)	2.07s	-0.83	2.12s	1.81	-0.59
C-WS5(MK)	2.23s	-0.63	2.4s	1.89	-0.64
C-WS6(MK)	2.4s	-0.56	2.52s	1.77	-0.61
1901-1946					
C-WS1(MMK)	3.2s	-0.64	3.47s	2.06s	0.02
C-WS2(MMK)	2.81s	-0.45	5.64s	2.06s	-0.09
C-WS3(MMK)	3.51s	-0.13	3.05s	2.03s	-0.27
C-WS4(MMK)	3.11s	-0.83	2.66s	1.81	-0.59
C-WS5(MMK)	3.49s	-0.63	5.94s	1.89	-0.64
C-WS6(MMK)	2.4s	-0.56	2.52s	1.77	-0.61
1947-2013					
C-WS1(MK)	0.16	0.56	-0.39	-0.13	-0.24
C-WS2(MK)	1.11	1.76	0.34	0.23	-0.11
C-WS3(MK)	-0.19	0.65	-0.77	-0.37	-0.43
C-WS4(MK)	2.54s	1.95	1.7	0.3	-0.18
C-WS5(MK)	2.23s	1.78	1.26	0.16	-0.14
C-WS6(MK)	1.19	1.68	0.63	0.06	0.11
1947-2013					
C-WS1(MMK)	0.16	0.56	-0.39	-0.13	-0.53
C-WS2(MMK)	1.11	1.89	0.34	0.23	-0.15
C-WS3(MMK)	-0.24	0.6	-1.04	-0.41	-0.83
C-WS4(MMK)	2.54s	1.95	1.7	0.3	-0.2
C-WS5(MMK)	2.23s	1.78	1.26	0.16	-0.2
C-WS6(MMK)	1.14	1.68	0.63	0.06	0.14

'*s*' represent the 5% level of significance level

Theil-Sen's slope analysis for rainfall series

Monthly trends are shown in Figure 2 (a, b and c) using the box plot of Theil-Sen's slope method for the Champua watershed of Baitarani River. The central box line represents median, upper and lower lines represent the 75th and 25th percentile, respectively. Also, the upper and lower lines represent the maximum and minimum values of rainfall slopes. According to analysis, before the change point 1901-1946 in the month of July and August the slope are positive, but after the change point 1947-2013, it showed the negative slopes, and for whole series 1901-2013, it showed the negative trend. Seasonal trends are shown in Figure 2(d, e and f) and found that before the change point, the magnitude values of annual and monsoon slopes are quite positive, and after change point, the slopes are less positive and for whole series it showed negative slopes while pre-monsoon and post-monsoon and winter monsoon season showed less variation in all three cases.

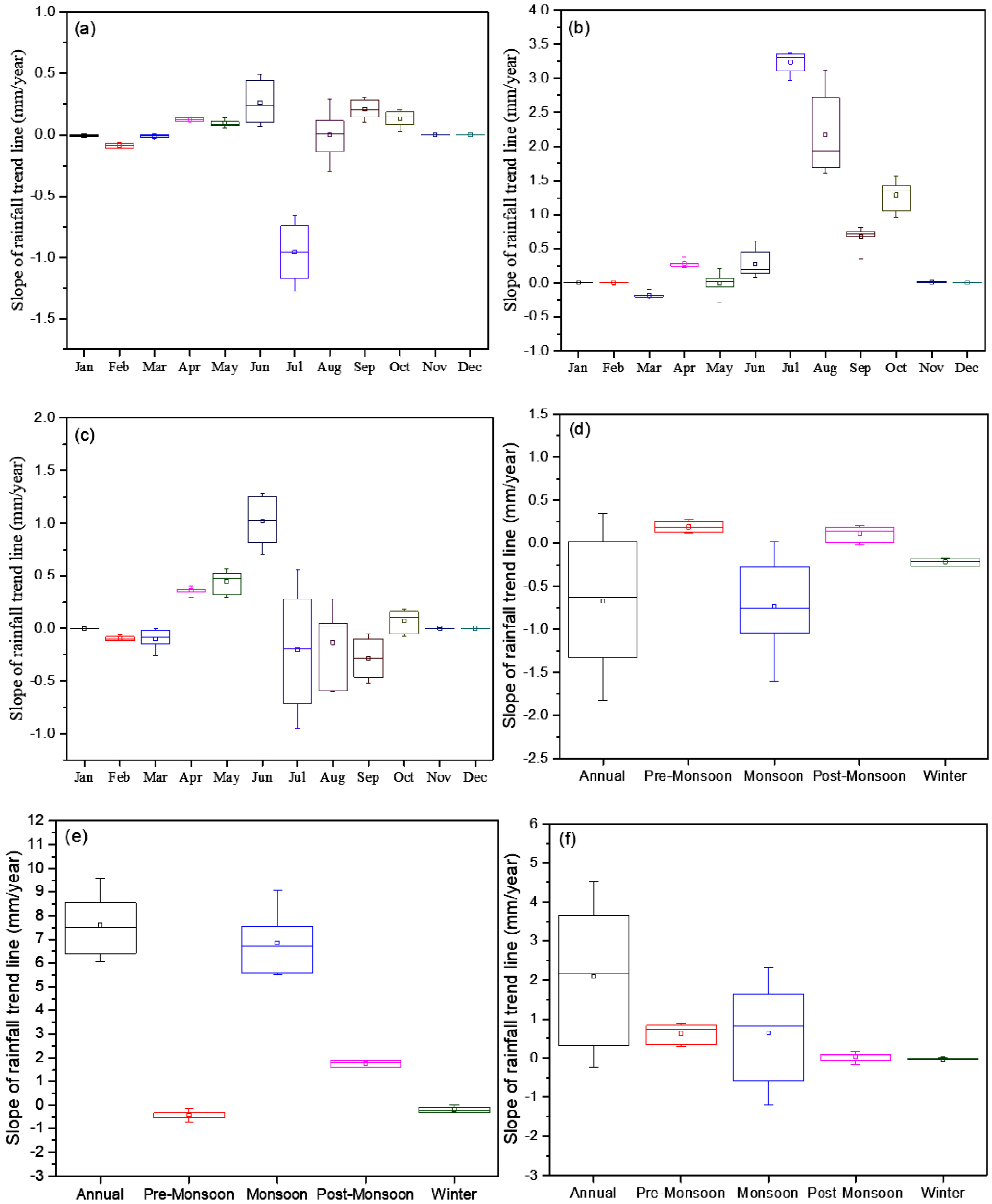

Fig. 2: Box plot on the basis of monthly rainfall time series (a) 1901-2013; (b) 1901-1946; (c) 1947-2013; and seasonal rainfall time series (d) 1901-2013; (e) 1901-1946; (f) 1947-2013 of Champua watershed.

CONCLUSIONS

The non-parametric (MK and MMK) test are used to find out trend analysis on the watershed level over the period of (1901-2013).The accuracy of MMK test in term of significance level was more precise than MK test at the watershed level. Also, it was noticed that more variation of rainfall trends is observed at sub-watershed. The result shows the variety of rainfall trends at the sub-watersheds level and found that one watershed C-WS3(MMK) showed significantly decreasing trend (-2.23s), and remaining sub-watersheds are showing less decreasing trends in annual and monsoon season for the entire time series(1901-2013). Also, all watersheds showed a significantly positive trend in rainfall before 1946 and negative trend after 1947.The pre-monsoon rainfall trend shows positive trend and the negative trend in post-monsoon for all-time series. This may be because of climates change and global warming effects; it also shows that the increase in the intensity of rainfall and the erratic distribution of rainfall over the sub-watershed. These results may provide useful input for agricultural (*Rabi* and *Kharif crop planning*), natural resources and water resources planning and management.

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