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ANALYSIS OF RAINFALL TREND IN ETHIOPIA

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Abstract: Agricultural production in Ethiopia is predominantly rainfed. Variation of rainfall in space and time affects the agricultural production system in the country. This needs a close study on rainfall variation. Rainfall variation, called trend, has been assessed for total annual, Kiremt (June-September) and Belg (February-May) rainfall, using 10 selected stations over the period of 1973-2002 in Ethiopia. Trend-free Pre-whitening Mann-Kendall statistical test at the stations show that Belg rainfall totals do not show significant trend while Kiremt rainfall totals on Gore (-7.75mm/year) and Jijiga (-5.87mm/year), Sep-Nov total rainfall on N.Borena (-3.25mm/year) and annual rainfall totals on Gore (-12.2mm/year) and N.Borena (-11.11mm/year) show significant decreasing trend during the period. It is recommended to extend the study on more number of stations to conclude at regional level.

Key words: Trend, Mann Kendall, Kiremt, Belg, Annual

INTRODUCTION

Agricultural production in Ethiopia highly depends on rainfall and it is predominantly rain-fed. Variation of rainfall in space and time affects even the agricultural production system in the country. These have made the country vulnerable to famine. The famine is usually caused by drought. Historically, Ethiopia was affected by drought/famine, for example, in 1913/14 (Northern Ethiopia); in 1920/22, 1932/34, 1953, 1957/58, and 1964/66, 1973/74 and recently, during 1983-1984, 1987-1988 and 1990-92, 1993/94 (Wolde-Georgis, 1997). Drought, by definition, is a protracted period of deficient precipitation resulting in extensive damage to crops. The impact of 1983/84 droughts in Ethiopia, for example, had resulted in a total loss of the annual food production over some areas, while in other areas the loss was as high as 50% of the annual total (NMSA, 1996).

These facts direct us towards the importance of looking closely to the Ethiopian climate especially its rainfall. The climate of Ethiopia is characterized by high rainfall variation.

Such climatic conditions have caused major constraints to agricultural development as discussed in the previous paragraph.

Rainfall shows systematic and irregular variation over time. These variations play a significant role in adopting farming systems, agricultural planning, crop selection and thus productivity. Characterization of these systematic variations is very helpful in rain-fed agriculture. It is important, too, to know whether there is any significant change in rainfall quantity so that this information may be useful for practitioner to improve water resources and agricultural planning.

Trends are certain types of systematic changes in rainfall series. Inconsistency (systematic error) and non-homogeneity (changes made in nature by humans or by natural disruptive, evolutive or similar sudden process) are mainly responsible for the over year trends. Long and uninterrupted rainfall data series are required to interpret such changes. These data series could be subjected to statistical techniques to identify significant trends and their slope.

Therefore, Rainfall being an important climatic element, the study of its variation, particularly, trends (gradual change) of total annual and seasonal rainfall in Ethiopia are studied in this paper. Such a study gives information on the availability of water and crop production in a region.

Detection of gradual change (Trends)

There are parametric and non-parametric tests for trends detection (Maidement, 1993). Parametric tests are distribution dependent tests. The power of the tests would be higher if the distributional assumption of data sets is correct. Non-Parametric tests are distribution free tests in which they can be much more powerful than parametric tests if the data distributions depart substantially from the assumed distribution.

One type of parametric test used for assessing the significance of a linear trend is the statistical t-test. The t-test requires a tested series to be normally distributed. If the tested series are not normal, transformation of the data to normal should be implemented before the t-test was applied.

Two common types of non-parametric tests used for detecting monotonic trend in a time series are Mann-Kendall (MK) and Spearman's rho(SR) test. Both MK and SR methods are rank based non-parametric tests. However, the MK test has been popularly to applied assess the significance of trends in hydrometer-logical time series (Yue et al., 2002(2)). The simulation experiments they made have demonstrated that SR test provided results almost identical to those obtained by the MK test. However, the SR test is seldom used in hydro-meteorological trend analysis.

Advantage of the non-parametric statistical test over the parametric test is that the former is more suitable to non-normally distributed, outlier, censored and missing data, which are frequently encountered in hydrological time series (Yue et al., 2002(2)). Moreover, t-test requires transformation of the data to normal if the data is non-normally distributed, which increases the computational procedure. Hence, in this paper, non-parametric MK test is used to assess the trend.

Mann-Kendall (MK) Test

The method of Mann-Kendall test is well described by Yue et al, 2002 (1) and Yue et al, 2002 (2). According to both articles, it is briefly described below:-

MK test is non-parametric test, which tests for a trend in a time series without specifying whether the trend is linear or non-linear. The null hypothesis H_o is that a sample data Y_i, i = 1, 2…n doesn't change as a function of time.

Each value of Y_i, i = 1, 2…n-1 is compared with all subsequent values Y_j, j = i+1, i+2…n and the statistics S of Kendall's tau is defined as follows:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \operatorname{sgn}(Y_j - Y_i) \qquad (1)$$

Where the Y_j are the sequential data values, n is the length of the data set, and

$$\operatorname{sgn}(\theta) = \begin{cases} 1 & if\theta > 0 \\ 0 & if\theta = 0 \\ -1 & if\theta < 0 \end{cases} \tag{2}$$

Where; $\operatorname{sgn}(\theta) = \operatorname{sgn}(Y_j - Y_i)$

This statistics represents the number of positive differences minus the number of negative differences after considering all the differences.

Mann and Kendall (Yue et al, 2002(1)) have documented that when n $\geq$ 8, the statistics S is approximately normally distributed with the mean and the variance as follows:

$$E(S) = 0 \tag{3}$$

$$V(S) = \left[\frac{n(n-1)(2n+5) - \sum_{i=1}^{n} e_i i(i-1)(2i+5)}{18} \right] \tag{4}$$

Where: e_i is the number of ties of extent i.

The standardized test statistics Z is computed by:

$$Z = \begin{cases} \frac{S-1}{\sqrt{\operatorname{var}(S)}} & S > 0 \\ 0 & S = 0 \\ \frac{S+1}{\sqrt{\operatorname{var}(S)}} & S < 0 \end{cases} \tag{5}$$

The standardized MK test statistics, Z follows the standard normal distribution with mean of zero and variance of one.

The P-value (probability value, p) of the MK statistics S of sample data can be estimated using the normal CDF as

$$P = \frac{1}{\sqrt{2\pi}} \int_{-\infty}^{Z} e^{\frac{-t^2}{2}} dt \qquad (6)$$

For independent sample data without trend the P value should be equal to 0.5. For sample data with a large positive trend the P value should be closer to 1.0, whereas a large negative trend should yield P value closer to 0.0.

The slope of a trend is estimated using the Theil-Sen approach (Yue et al, 2002(1)), and it is estimated as follows:

$$b = median\left(\frac{Y_j - Y_l}{j - l}\right) \quad \forall l < j \qquad (7)$$

Where b is the estimate of the slope of the trend and X_l is the l^{th} observation. The slope determined by the Theil-Sen approach (TSA) is a robust estimate of the magnitude of a trend. The TSA approach has been popularly employed for identifying the slope of trends in hydrological time series (Yue et al, 2002 (1)).

Power of MK test

The power of a test is the probability of correctly rejecting the null hypothesis when it is false. When sampling from a population that represents the case where the null hypothesis is false, the power can be estimated by;

$$power = \frac{N_{rej}}{N} \qquad (8)$$

Where: N is the total number of simulation experiments

N_{reg} is the number of experiments that fall in the critical region

Yue et al (2002(2)) conducted Monte Carlo simulation to observe the power of the MK test. The result obtained from the simulation is summarized as follows:

I. For a fixed significance level α, the power of a test is increasing function of the absolute slope.

II. For a fixed slope of the trend, increasing the significance level also increases the power.

III. The power of the test is an increasing function of both the absolute slope and the sample size.

IV. For a fixed slope, the power of a test is a decreasing function of the coefficient of variation of a time series.

V. In case of no trend, the power of the test is independent of distribution type of time series. However, in the case some trend exists, the power of the test is dependent on the distribution type.

In addition Yue et al (2002(1)) showed that, the MK test requires a time series to be serially independent. The existence of serial correlation in time series will affect the ability of the test to correctly assess the significance of trends. They showed that the existence of positive serial correlation increases the type I error i.e. increase tendency to reject the null hypothesis of no trend while it is true. In contrast, negative serial correlation underestimates the probability of detecting trends.

In order to detect a significant trend in a time series with significant serial correlation, a modified pre-whitening procedure, termed Trend –Free Pre-Whitening (TFPW) was proposed by Yue et al (2002(1)):

a. The slope b of a trend in a sample data is estimated by TSA. If the slope is almost equal to zero, then it is not necessary to continue to conduct trend analysis. If it is different from zero, then it is assumed to be linear, and the sample data are detrended by

$$Y_i' = Y_i - T_i = Y_i - bi \qquad (9)$$

b. The lag-1 serial correlation coefficient r_1 of the detrended series Y_i' is computed and then the Auto Regressive One (AR (1)) is removed from the Y_i' by

$$X_i' = Y_i' - r_1 Y_{i-1}' \quad (10)$$

This pre-whitening procedure after de-trending the series is referred to as the trend-free pre-whitening (TFPW) procedure. The residual series after applying the TFPW procedure should be an independent series.

c. The identified series T_i and the residual X_i' are blended by

$$X_i = X_i' + T_i \quad (11)$$

It is evident that the blended series X_i could preserve the true trend and is no longer influenced by the effects of autocorrelation.

d. The MK test is applied to the blended series to assess the significance of the trend

Yue et al (2002(1)) noted that the above procedure assumes that a hydrological time series can be represented by a linear trend ($T_i = bi$) and an AR(1) component with noise. They have two reasons for only taking these simplest processes into account. First, much of the existing literature investigating the possibility of change has assumed it to be gradual and monotonic. Second, most of the hydrological time series have relatively weak serial correlation and their stochastic behavior can therefore be approximated by an AR (1) process.

DATA

For the study of rainfall trend detection in annual and seasonal basis in recent years in Ethiopia, 10 stations are selected and used in the analysis which are shown on Fig.1, which have less number of missing data and which have continuous record compared to other station in Ethiopia. The record period 1973-2002 are taken as the common period where statistical test is applied to detect and measure trend. This 30 year period is selected to see change of rainfall variation recently in the country.

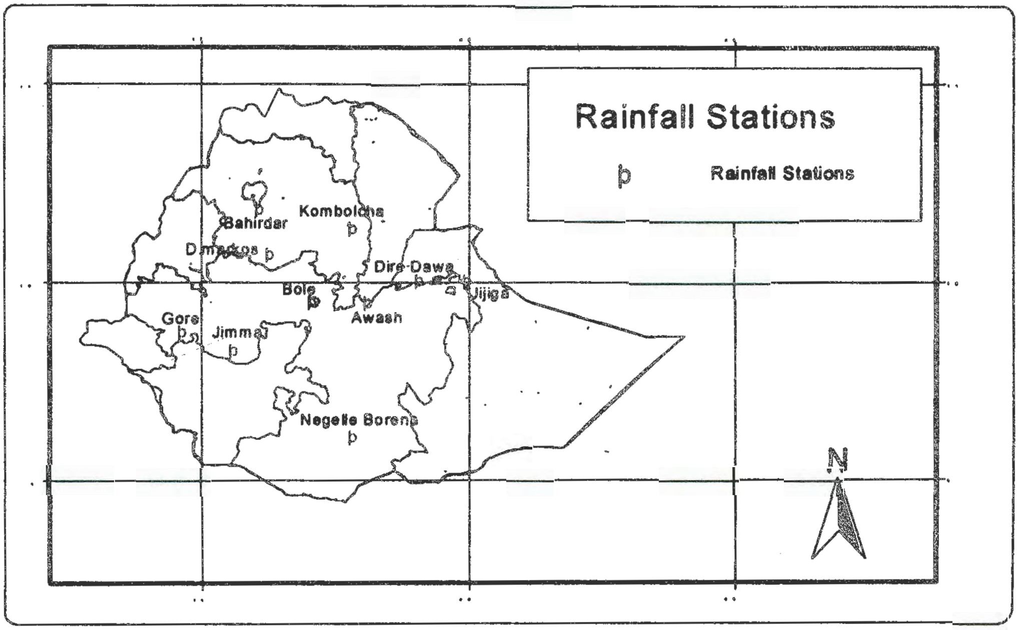

Fig 1 Gauged Stations Used in Trend Detection

METHODOLOGY

In this study, the trend of rainfall at station level is investigated in a time period of 1973-2002. Mann-Kendall statistical test described above is performed to assess the significance of trend in this period for annual and seasonal ('Kiremt'[2] and 'Belg'[3]) rainfall totals in Ethiopia.

The rainfall stations (Fig 1) that have long and rather complete records are selected from available stations in the country. Here ten stations, having 30 years record length, with the best complete records are selected.

Among the stations, Gore station has monthly missing data continuously or two complete years (1991 and 1992), and Negelle Borena and Jijiga have monthly missing data, randomly distributed in the study period. In these stations, missed months are estimated from nearby stations using simple average method. Estimation is required since the sample data is

[2] 'Kiremt' is defined by months June to September
[3] 'Belg' is defined by months February to May

modeled by AR(1) to remove serial coefficient as shown in Equation 10. The other seven stations have rather complete record in the study period.

To judge if observed sample data and TFPW data are serially correlated, the significance of the lag-1 serial correlation coefficient at the significance level $\alpha = 0.10$ of the two tailed test is assessed using the following approximation (Yue et al, 2002(1)):

$$\frac{-1-1.645\sqrt{n-2}}{n-1} \leq r_1 \leq \frac{-1+1.645\sqrt{n-2}}{n-2}$$

RESULT

Studies of recent changes by Seleshi et al (2004) over Ethiopian rainfall have shown that the annual and the June-September total rainfalls for the eastern (Jijiga, 137mm/decade), southern (Negele, 119mm/decade) and southwestern (Gore, 257mm/decade) stations show a significant decline since 1982. The non-parametric Mann-Kendall test has been used in the study. However, the effect of autocorrelation on the method was not considered in the study. For example, a study made on detection of trends in annual extreme rainfall in Canada by Adamowski et al (2003) showed that stations containing significant autocorrelation were pre-whitened. Yue et al, 2002(1) proved that significant autocorrelation in the sample data misleads the result of the test. Hence, in this work, the effect of autocorrelation is taken into consideration.

For a normally distributed random series, its skew-ness and kurtosis should be equal to 0. It is evident from Table 1, column 5 and 6, the data are positively skewed and the relative peaked-ness is large for some stations. Most of the data could not be represented by normal distribution. As a result, the choice for Mann-Kendall statistical test from t-test could be appropriate.

Column 4 of Table 1 calculates the coefficient of variation (CV) of the data at different stations. This provides a measure of year-to-year variation in the data series. NMSA (1996) documented that CV less than 0.20 is less variable, CV between 0.20 and 0.30 is moderately variable and CV greater than 0.30 is highly variable. The Belg rain in all stations shows that there is high variability since CV is greater than 0.30. Jima, Gore, D.Markos, Addis Ababa and Kombolcha stations have less variability in the annual and Kiremt rainfall. Other stations in annual and Kiremt rainfall show moderate variation.

The lag-1 serial correlation coefficient (ρ_1) and it's upper and lower limits for confidence interval at the significance level of 0.10 of the two-tailed test for the original and TFPW data are presented in columns 7 up to 10 of Table 1. The table shows that N.Borena (Annual & Kiremt), Jijiga (Annual & Kiremt), Bahir Dar (Annual & Kiremt), Gore (Kiremt), and Dire Dewa (Annual) are significant serially correlated at the significance level of 0.10. Therefore, Trend free pre-whitening procedure should be followed to the series to remove the effect of serial correlation on MK test. As it is shown in column 8, the TFPW procedure made the series independent and serially uncorrelated. However, the remaining stations and Belg rainfall series over all stations are not significantly correlated. Hence, MK test is applied directly to the rainfall total series.

The magnitude of the Mann-Kendall statistics S, the standardized normal variate Z and P-value are given in columns 10, 11 and 12, respectively of Table 1. When S and Z values are positive, these indicate an upward trend, negative values indicate downward trend in the rainfall series. At a significance level of α = 0.05, Z value is used to measure the significance of the trend. P-value in column 12 indicates that significant downward trend is seen at N.Borena[4] (Annual,-11.11mm/year and Sep-Nov,-3.25mm/year) (Fig 2(C)), Gore (Kiremt-7.7mm/year and Annual-12.2mm/year) (Fig 2(B)) and Jijiga (Kiremt-5.8mm/year) (Fig 2(A)) stations. Belg total rainfall doesn't show significant trend in any of the stations. These results are similar to the result of study made by Seleshi et al. (2004). The slope of trend on stations, which show significant trend, is determined by the Theil-Sen approach (TSA). And it is shown in column 13 of Table 1..

Fig 2(D,E,F and G) showed that, for instance, there is no significant trend for annual rainfall at Bahir Dar, Kombolcha, Jima, and Dire Dawa stations, respectively. Seleshi et al (2004) reported that a persistent increase in December-February sea-level pressure over the tropical eastern pacific ocean and persistent warming of the South Atlantic Ocean over the

[4] Main rainfall season for the station is March to May while second rainfall season is September to November.

period approximately from 1986 to 2002 correspond to a persistent decline in the annual rainfall at Jijiga, Negele-Borena and Gore.

Gore and Jima are found in the same rainfall regime called Monomodal. Cross-correlation of annual rainfall between the two stations in the period of 1973-2002 is around 0.36, which is low. Though they are in the same rainfall regime, the correlation shows that they may not be subjected to the same climatic change influence. However, number of other stations near to Gore and Jima (for example, Gambela, Bonga) should be checked for trend, and their correlation to SSTs and SOI data should be investigated so that conclusion on rainfall trend at regional (field) level will be easy.

Similarly, Jijiga and Dire Dawa stations are found in the same rainfall regimes. And their annual rainfall cross-correlation is around 0.02, which is almost zero. Therefore, the work requires number of other stations, which are found around Jijiga and Dire Dawa to generalize trend at regional level. As well, stations near to Negele-Borena (Yabelo, Moyale, etc) should be investigated for trend to make similar conclusion.

Moreover, 3-year moving averages of annual rainfall over Dire-Dawa, D/Markos and Jijiga stations (Fig 2, (H), and (I)) tend to show cyclicity component of rainfall about average value, which should be checked, in further studies. In contrast, Jima and Addis Ababa stations (Fig 2, (J)) show weak cycle about the average value. This cyclic component may lead to wrong conclusion of trend detection if the period of analysis includes incomplete part of the cycle.

Study made by Mersha (2002) on rainfall cyclicity over selected stations in Ethiopia also shows that there appears to be cyclic tendency in the annual rainfall data. Gode, Dire Dawa, Negelle, and Debre Zeit stations show a clear cyclic pattern and are under 52, 52, 36 and 46 years rainfall cycle. Over Kombolcha, Gonder and Jima stations the cyclic trend are not strong and are under 48, 46 and 46 years of rainfall cyclic, respectively.

Therefore, it is necessary to check the effect of this cyclic component on trend detection. Moreover, more number of stations should be checked for cyclicity and trend to generalize at the regional level.

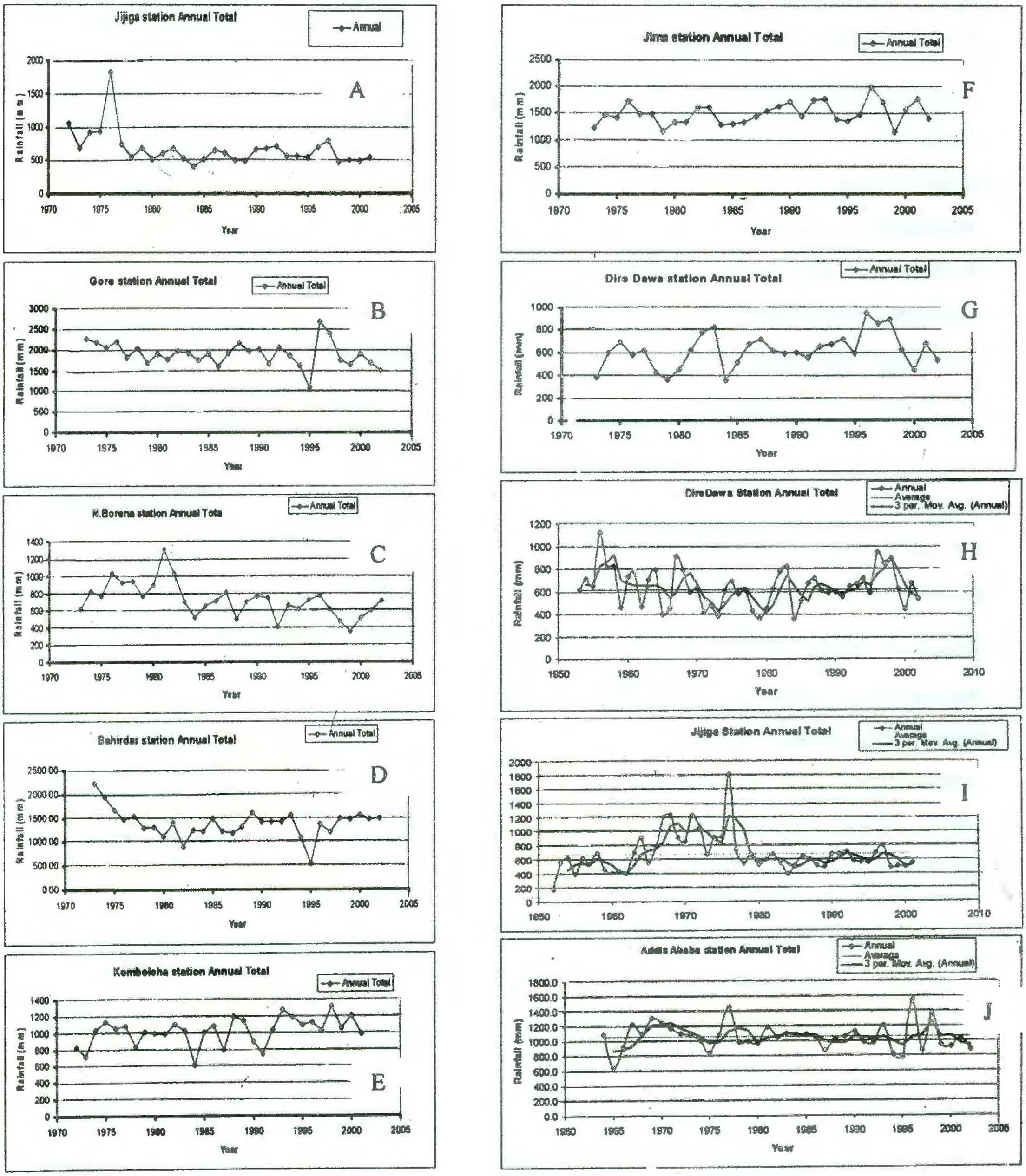

Figure 2 Time Series Plot of monthly annual of station (A) Jijiga, (B) Gore, (C) N. Borena, (D) Bahir Dar, (E) Kombolcha, (F) Jima, (G) Dire Dawa, and 3 year moving average pot of station (H) Dire Dawa, (I) Jijiga, (J) Addis Ababa (Bole)

Table 1 Statistical Properties and Result of Mann-Kendall Test for 10 Selected Stations

1	2	3	4	5	6	7	8	For $\alpha = 0.10$		11	12	13	14
Station	Seasons	No Years	CV[5]	Skew-ness	Kurtosis	ρ_1 raw data	ρ_1 after TFPW	Upper	Lower	S	Z	P	Slope (mm/year)
Dire Dawa	Annual	30	0.24	0.21	-0.09	0.352	0.178	0.27	-0.33	75	1.32	0.91	
	Kiremt	30	0.35	0.46	-0.39	0.006		0.27	-0.33	61	1.07	0.86	
	Belg	30	0.46	0.63	0.60	0.23		0.27	-0.33	5	0.07	0.53	
Bole	Annual	30	0.17	1.22	1.96	-0.32		0.27	-0.33	-59	-1.03	0.15	
	Kiremt	30	0.20	0.12	3.36	-0.28		0.27	-0.33	-55	-0.96	0.17	
	Belg	30	0.39	0.08	-0.88	-0.11		0.27	-0.33	11	0.18	0.57	
D. Markos	Annual	30	0.11	0.41	0.50	-0.09		0.27	-0.33	61	1.07	0.86	
	Kiremt	30	0.11	0.10	-1.05	-0.09		0.27	-0.33	33	0.57	0.72	
	Belg	30	0.37	0.60	0.03	-0.015		0.27	-0.33	-19	-0.32	0.37	
Jima	Annual	30	0.13	0.36	-0.26	0.16		0.27	-0.33	101	1.78	0.96	
	Kiremt	30	0.15	0.25	0.69	0.046		0.27	-0.33	17	0.29	0.61	
	Belg	30	0.20	0.09	0.30	-0.283		0.27	-0.33	7	0.11	0.54	
Bahirdar	Annual	30	0.22	0.00	3.11	0.46	-0.03	0.27	-0.33	-33	-0.57	0.28	
	Kiremt	30	0.23	-0.27	1.41	0.37	0.06	0.27	-0.33	-45	-0.79	0.22	
	Belg	30	0.69	1.27	1.91	-0.027		0.27	-0.33	-13	-0.23	0.41	
Awash	Annual	30	0.24	-0.32	-0.19	-0.059		0.27	-0.33	33	0.57	0.716	
	Kiremt	30	0.25	0.15	1.21	-0.179		0.27	-0.33	71	1.25	0.89	
	Belg	30	0.48	1.15	1.88	0.199		0.27	-0.33	-33	-0.57	0.28	

[5] Coefficient of variation

1	2	3	4	5	6	7	8	For α = 0.10		11	12	13	14
Station	**Seasons**	No Years	CV[6]	Skew-ness	Kurtosis	ρ_1 raw data	ρ_1 after TFPW	Upper	Lower	S	Z	P	Slope (mm/year)
N. Borena	Annual	30	0.28	0.70	1.27	0.56	0.092	0.27	-0.33	-215	-3.818	7E-05	-11.11
	Sep-Nov	30	0.43	0.72	0.63	0.38	0.003	0.27	-0.33	-117	-2.07	0.019	-3.255
	Mar-May	30	0.42	0.72	1.50	0.24		0.27	-0.33	-107	-1.89	0.029	
Kombolcha	Annual	30	0.16	-0.65	0.30	0.15		0.27	-0.33	109	1.93	0.97	
	Kiremt	30	0.24	-0.18	-0.06	0.09		0.27	-0.33	79	1.39	0.92	
	Belg	30	0.39	0.23	0.33	-0.043		0.27	-0.33	3	0.04	0.51	
Gore	Annual	30	0.13	0.93	1.56	0.04		0.27	-0.33	-125	-2.21	0.013	-12.19
	Kiremt	30	0.12	0.26	-0.30	0.41	0.14	0.27	-0.33	-125	-2.21	0.013	-7.75
	Belg	30	0.63	0.21	-0.54	0.11		0.27	-0.33	-53	-0.93	0.18	
Jijiga	Annual	30	0.39	3.14	12.21	0.34	-0.02	0.27	-0.33	-107	-1.89	0.029	
	Kiremt	30	0.45	2.02	4.06	0.6	-0.002	0.27	-0.33	-159	-2.82	0.0024	-5.87
	Belg	30	0.52	1.80	4.51	-0.019		0.27	-0.33	-67	-1.18	0.12	

[6] Coefficient of variation

CONCLUSIONS

In the work of identifying any change on total annual and seasonal rainfall within recent years in the country using 10 stations, the result leads to the following conclusion.

I. Belg rainfall totals in study area in the country do not show any significant change (trend).

II. Kiremt rainfall totals show significant change at Gore and Jijiga station. Sep-Nov rainfall total shows significant change at N.Borena.

III. Annual rainfall totals also show significant change at Gore and N. Borena station.

RECOMMENDATIONS

Here, annual and seasonal rainfall totals are studied using only 10 gauge stations. To generalize trend of rainfall at regional level and to increase the spatial coverage, it is recommended to extend this study by including more number of stations.

In addition, the moving average plot and research made by Mersha(2002) show that there appears to be cyclic tendency in annual rainfall. The cyclicity of rainfall should be checked on more number of stations and its effect on detection of rainfall trend should be studied.

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