Advances in Physics Theories and Applications
ISSN 2224-719X (Paper) ISSN 2225-0638 (Online)
Vol.55, 2016

Temporal Variation of Trend in Seasonal and Annual Rainfall in Southwest Ethiopia in Case of Drought Prone Wolaita Zone

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Abstract

Monthly total rainfall data of ten stations were obtained from the south region meteorology office for cash. Stations data vary in time of record and the number of missing values. Stations which have more than ten percent missing data over their recording period are excluded from the study. This reduces the number of stations to eight. Missing values were estimated using linear regression of neighbor stations with none missing value. After infilling, seasonal Spring ('Belg', February-May) and summer ('Kiremt', June-September) and annual total data were prepared by summing monthly values in respective time scale. Following the test for the presence of autocorrelation, Mann–Kendall (Modified Mann–Kendall) test was applied to non-auto correlated (auto correlated) series to detect the trends in rainfall data. Theil and Sen's slope estimator test was used for quantifying the magnitude of change over a time period. In addition, the percentage change of the mean over a period of time was determined too. In annual rainfall data three stations show decreasing trend while the rest five stations show an increasing trend, however, all trends observed in annual data were non-significant. Based on seasonal trend analysis, non-significant trends were observed in seven stations(four increasing and three decreasing) and one station show a significant decreasing trend in spring. During summer seven (six increasing and one decreasing) non-significant and one significant decreasing trends were observed.

Keywords: Trend, Mann–Kendall test, Sen's slope estimator, Rainfall, Wolaita zone

1 Introduction

Rainfall is a vital climatic element of paramount importance for developing nations like Ethiopia, whose economy largely depend on agriculture, which is highly vulnerable to the amounts and distribution of rainfall. The sector, Agriculture, contributes roughly around 43 percent to overall GDP,(Ministry of Finance and Economic Development (MoFED), 2014), 90 percent of export earnings, and supplies 70 percent of the country‘s raw materials for the secondary activities . Apart from being the driver of the national economy, the sector is vital source of livelihood for an overwhelming majority of the Ethiopian population, with irrigated agriculture accounting for less than 1% of the country's total cultivated land.

Much reliance of the overall economic development strategy of the country (i.e. Agriculture Development Led Industrialization) and livelihood strategy of population (i.e. agricultural activities: crop production and livestock rearing) upon on the rainfall emphasizes a paramount importance of the amount and temporal distribution of rainfall that occurs in the country. Thus, it is really crucial to study and characterize rainfall at different level, national, regional and sub-regional scale. The aim of this study is to analyze in detail and detect the existence of a trend in rainfall data over the Southern Nations Nationalities and People Regional State in case of drought prone Wolaita Zone.

2 Material and Methods

2.1 Study Area

The study is conducted in southwest part of the country located between 6:40- 7:10 N latitude and 37:40-38:20 E, longitude, covering a total area of 4511 km^2. The altitude in the area varies between 900 - 2600 meters above sea level. As in most parts of the country, the major economic activities in the area are agriculture (production of legumes, root crops and some cereals), and livestock rearing. The farming community is totally dependent on rainfall that is highly irregular, inadequate, showing poor seasonal distribution, or a combination thereof. Rainfall in the area occurs in two distinct rainy seasons: the main rains (locally called 'kiremt' rains) occur in summer (June-September) and a shorter rainy season (locally called the 'Belg' rains) occurs in spring (March-May) (Gecho, Ayele, Lemma, & Alemu, 2014). `Kiremt' is the main production season, but the occurrence of rain during the 'Belg'season is equally important, as it has significant implications on the food security of households. Rainfall variability and associated drought have been major causes of food shortage and famine in the area.

2.2 Rainfall Data

Historical monthly total rainfall data of ten rainfall stations over the study area were obtained from the National meteorological services Agency of Ethiopian(NMSA) see

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Table 1: Rain gauge stations in the study area.

S.No	Name	Longitude (Degree)	Latitude (Degree)	Altitude (Meter)	Recording year	Length	Missing
1	Areka	*37.45*	*7.04*	*1752*	1994-2013	20	9
2	Beddesa	*37.59*	*6.55*	*1609*	1987-2013	27	3
3	Billate	*38.08*	*6.82*	*1361*	1980-2013	34	12
4	Billate tena	*38.12*	*6.93*	*1496*	1975-2013	39	34
5	Bodity	*37.51*	*6.57*	*2043*	1986-2013	28	3
6	Dana_1	*37.45*	*6.4*	*1279*	1976-2013	38	147
7	Humbo tebela	*37.75*	*6.7*	*1618*	1987-2013	27	20
8	Gesuba	*37.38*	*6.35*	*1552*	1976-2013	38	135
9	Mayokote	*37.58*	*6.58*	*2121*	1990-2013	24	6
10	Wsodo	*37.73*	*6.81*	*1854*	1975-2013	39	9

2.3 Serial Dependance/Autocorrelation

The existence of serial dependance/or an autocorrelation in hydrological time series data makes the task of trend detection tough enough.i.e, if time series possess (positive /negative) significant lag-1 autocorrelation,the trend detected will be erroneous. For instance,the possibility of detecting non-existed trend in positively autocorrelated data is high. For this reason, time series of both annual and seasonal rainfall data are checked for serial dependance using the same equation as (Sayemuzzaman & Jha, 2014),

$$r_1 = \frac{\frac{1}{n-1}\sum_{i=1}^{n-1}(x_i - E(x_i))(x_{i+1} - E(x_{i+1}))}{\frac{1}{n}\sum_{i=1}^{n}(x_i - E(x_i))^2}, \qquad 1$$

$$E(x_i) = \frac{1}{n}\sum_{i=1}^{n} x_i . \qquad 2$$

where $E(x_i)$ is the mean of sample data and n is the number of observations in the data. More over the significance of r_1 is tested using t-test,

$$t = r_1\sqrt{\frac{n-2}{1-r_1^2}} \qquad 3$$

where the t-test statistic has a Student's t-distribution with $(n-2)$ degrees of freedom. Then the computed r_1 is considered significant if $|t| \geq t_{\alpha/2}$,then the null hypothesis about serial independence is rejected at the significance level α .

2.4 Mann-Kendall (MK) trend test

The non-parametric Mann-Kendall test is widely used procedure to detect monotonic trends in time series of meteorological data. The null hypothesis, H_0 , is that the data come from a population with independent realizations and are identically distributed. The alternative hypothesis, H_A , is that the data follow a monotonic trend. The Mann- Kendall statistic S (Al-mashagbah & Al-farajat, 2013; Hirsch, Slack, & Smith, 1982; Karmeshu, 2012; Mondal, Kundu, & Mukhopadhyay, 2012; Rahman & Begum, 2013) is computed as:

$$S = \sum_{i=1}^{n-1}\sum_{j=i+1}^{n} sgn(x_j - x_i), \qquad 4$$

where n is total number of data points, x_i and x_j are the consecutive data values in time i and $j(j > i)$, respectively, and,

$$sgn(x_j - x_i) = \begin{cases} +1, & \text{if}(x_j - x_i) > 0 \\ 0, & \text{if}(x_j - x_i) = 0 \\ -1, & \text{if}(x_j - x_i) < 0. \end{cases} \qquad 5$$

This statistics represents the number of positive differences minus the number of negative differences for all the differences considered. For large samples $n \geq 10$, the statistic S is approximately normally distributed(Gilbert, 1987; Hirsch et al., 1982) with the mean $E(S) = 0$ and variance as,

$$\sigma^2(S) = \frac{n(n-1)(2n+5) - \sum_{l=1}^{m} t_l(t_l-1)(2t_l+5)}{18}, \tag{6}$$

where, m is the number of tied(zero difference between compared values) groups and t_i is the number of data points in the ith tied group. The standardised test statistic Z_S is computed by,

$$Z_S = \begin{cases} \dfrac{S-1}{\sigma(S)}, & \text{if } S > 0 \\ 0, & \text{if } S = 0 \\ \dfrac{S+1}{\sigma(S)}, & \text{if } S < 0. \end{cases} \tag{7}$$

The standardized MK test statistic (Z_S) follows the standard normal distribution with a mean of zero and variance of one. To test for either upward or downward trend (a two-tailed test) at the α level of significance, H_0 is rejected in favor of the alternative H_A if $|Z_S| \geq Z_{1-\frac{\alpha}{2}}$.In one side test if H_A is for increasing trend H_0 rejected if $Z_s > 0$ and $Z_S \geq Z_{1-\alpha}$ and if H_A is for decreasing trend H_0 rejected if $Z_s < 0$and$|Z_S| \geq Z_{1-\alpha}$(Al-mashagbah & Al-farajat, 2013; Gilbert, 1987; Hirsch et al., 1982; Mondal et al., 2012; Rahman & Begum, 2013; Sahu & Khare, 2015).

2.5 Modified Mann-Kendall (MK) trend test

In case of existence of significant autocorrelation in hydrological time series data customarily, pre-whitening is utilized to remove its effect(Burn & Hag Elnur, 2002; Murumkar & Arya, 2014; Rahman & Begum, 2013). But (Yue, Pilon, & Phinney, 2003) showed that pre-whitening will remove a portion of the trend. Taking in to account the effect of autocorrelation,(Hamed & Ramachandra Rao, 1998) suggest a modified Mann-Kendall test, which calculates the autocorrelation between the ranks of the observations data after removing the trend estimate. The adjusted variance as in (Taxak, Murumkar, & Arya, 2014; WMO, 1988) given by,

$$\frac{n}{n_s^*} = 1 + \frac{2}{n(n-1)(n-2)} \times \sum_{k}^{n-1} (n-k)(n-k-1)(n-k-2) r_k \tag{8}$$

where, n is actual number of observations, n_s^* is considered as an 'effective' number of observations to account for autocorrelation in data and r_k is the autocorrelation function of ranks of the observations. The corrected variance is then computed as

$$var^*(S) = \sigma^2(S) \times \frac{n}{n_s^*} \tag{9}$$

where, $\sigma^2(S)$ is given by Equation 6.

2.6 Sen's slope estimator test

In addition to detecting existence of trend,in this study, the magnitude of a trend was also estimated by a Theil-Sen's slope estimator β (Theil, 1950; Sen, 1968). The slope of n pairs of data points was calculated as

$$Q_i = \frac{x_j - x_k}{j-k} \quad \text{for } i = 1,2,3,\ldots N, \tag{10}$$

where, x_j and x_k are data values in time j and $k (j > k)$, respectively. The median of these N values of Q_i is Sen's estimator of slope which is computed as,

$$\beta = \begin{cases} Q_{\frac{N+1}{2}}, & \text{if N is odd,} \\ \frac{1}{2}\left(Q_{\frac{N}{2}} + Q_{\frac{N+2}{2}}\right), & \text{if N is even.} \end{cases} \qquad 11$$

A positive value of β indicates an upward (increasing) trend and a negative value indicates a downward (decreasing) trend in the time series.

2.7 *Percentage Change in mean .*

The percentage change of mean over a period of time can be estimated by approximating it with a linear trend (Yue and Hashino ,2003). That is change percentage equals Sen's slope(β) multiplied by the period length (n) divided by the corresponding mean, expressed as($\%\Delta$),

$$\%\Delta = \frac{\beta \times n}{\text{mean}} \times 100. \qquad 12$$

3 Result and Discussion

3.1 *Autocorrelation result*

The autocorrelation analysis is performed before trend detection for each stations during their time of record on both annual and seasonal time scale. Statistically significant lag 1 autocorrelation is revealed at 5% significance level only on two summer season series of stations Bessesa and Bodity , as shown in Table 2

Table 2. Lag one autocorrelation result.

S.No	Station	Season								
		Spring			Summer			ANNUAL		
		r1	t_calc	t_table	r1	t_calc	t_table	r1	t_calc	t_table
1	Areka	0.09	0.383	2.101	0.12	0.496	2.101	-0.22	-0.950	2.101
2	Beddesa	-0.03	-0.131	2.060	**-0.48**	**-2.730**	**2.060**	-0.10	-0.522	2.060
3	Billate	0.20	1.171	2.037	-0.24	-1.388	2.037	0.15	0.864	2.037
4	Billate tena	-0.11	-0.649	2.026	-0.01	-0.032	2.026	0.21	1.292	2.026
5	Bodity	-0.04	-0.181	2.056	**-0.39**	**-2.146**	**2.056**	0.02	0.101	2.056
6	Humbo tebela	0.05	0.232	2.060	-0.21	-1.051	2.060	-0.01	-0.073	2.060
7	Mykote	-0.15	-0.696	2.074	-0.22	-1.041	2.074	-0.24	-1.145	2.074
8	Wolaita sodo	-0.06	-0.358	2.026	0.02	0.145	2.026	0.19	1.174	2.026

r1 is lag 1 autocorrelation coefficient, t_calc is calculated t value and t_table is t value of t distribution

3.2 *Annual and seasonal trend analysis*

Mann-Kendall (MK) and Modified Mann-Kendall (MMK) tests were employed for detection of the monotonic trend in non-autocorrelated and autocorelated series respectively. Quantification of magnitude of trend is made using the Sen's slope estimator. In addition, the percentage change of the moon over a period of time was calculated. The results of the MK/MMK test statistics, Zs, Sen's slope (β) and percentage change (%Δ) are presented in Table 3 for seasonal and annual series.

Table 3. Result of MK (MMK) test (at 5% level) Sen's slope and percentage change in mean.

S.No	Station	Season								
		Spring			Summer			Annual		
		Zs	β	%Δ	Z	β	%Δ	Z	B	%Δ
1	Areka	-2.04	-8.78	-41.3	0.60	3.86	13.1	-0.16	-1.73	-2.35
2	Beddesa	1.25	2.48	16.6	2.60	4.45	33.0	1.00	4.61	11.2
3	Billate	0.44	0.83	10.3	1.40	2.47	34.8	1.16	3.30	14.2
4	Billate tena	-0.80	-1.37	-16.2	-0.41	-0.71	-9.60	-0.44	-2.87	-12.0
5	Bodity	-0.69	-1.25	-8.2	0.30	0.49	3.1	-1.20	-4.51	-10.2
6	Humbo tebela	0.79	0.79	5.9	0.71	4.35	26.7	0.83	2.85	6.8
7	Mykote	0.10	0.86	3.9	0.89	6.64	26.1	1.03	3.18	4.8
8	Wolaita sodo	-0.60	-1.45	-12.9	0.36	0.99	7.5	0.00	-0.32	-0.94

Zs is standardized Mk (MMK) test statistic, β is Sen's slope, %Δ is the percentage change in the mean.

In seasonal scale analysis, during spring, rainfall in four stations Areka, Billate tena, Bodity and Wolaita sodo show decreasing trends, but only rainfall in station Areka show a significant decreasing trend in rainfall during the season. In stations Beddesa, Billate , Humbo tebela and Mykote rainfall show increasing trend, but none were statistically significant. During summer non-significant decreasing trend is observed only in one station Billate tena, in the rest of stations increasing trend is exhibited but the only significant trend is observed in station Beddesa.

In annual rainfall data three stations Areka, Billate tena, and Bodity shows decreasing trend while the rest five stations Beddesa, Billate , Humbo tebela , Mykote and Wolaita sodo show increasing trend, but none were significant.

4 Conclusions

In the present study, trends for annual and seasonal (Spring and Summer) total rainfall data was analyzed using the Mann-Kendall (modified Mann-Kendall) and Sen's slope estimator non-parametric test for trend detection and quantification of its magnitude respectively. The MK / MMK test represents both increasing and decreasing trends in the area, although non-significant in all but two stations. Sen's Slope is also indicating increasing and decreasing the magnitude of the slope in correspondence with the MK/MMK test values. The significant decreasing/increasing trend has been found only in spring/summer season, respectively.

Acknowledgements

My sincere gratitude goes first to the Almighty God for enabling me to accomplish the task. Second to my lovely wife and daughter for their support and endless love. Last but not least, to Wolaita sodo university for funding the study and to all friends who stood by me.

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