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ANALYSIS OF RAINFALL TRENDS (1979-2013) USING NON PARAMETRIC TEST IN NORTH WEST, ETHIOPIA

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ABSTRACT

It is well known that climate change has been contributing to change in amount of rainfall worldwide. This research was conducted in Northeast parts of Ethiopia with a particular reference to Northwest Ethiopia. This area had been distressing from recurrent droughts and faced water scarcity several times. The threat is still hampering the life and agricultural activities of the people. The objective of this study was to determine the existence of trend and rainfall frequency analyses using Mann- Kendall test and Sen's slope estimator techniques. Standardized rainfall anomaly index, rainfall concentration index and coefficient of variation were also used to describe rainfall variability. Thirty five years of observational data for total annual rainfall recorded at meteorological station of the area was obtained from the National Meteorology Service Agency of Ethiopia. The result of the study elucidated that there are rising rates of rainfall in some months and decreasing trend in some other months obtained by these statistical tests. However, the overall rainfall trends were not statistically significant ($p < 0.05$), but it was highly variably. The trend of the series for individual 12 months from January to December in the Mann-Kendall test are -0.103, -0.402, -0.321, -0.103, -0.025, -0.022, 0.284, 0.190, 0.170, -0.027, 0.106, -0.039, respectively. The rainfall concentration index revealed that 30% of years with values of PCI >16 in Northwest Ethiopia showed poor and irregular monthly distribution of rainfall. The coefficient variation of the study area was 39% which confirmed high inter-annual variability. The results of this study are in good agreement with the findings of early studies. To conclude, policy makers and practitioners should propose strategies and plans by taking a rainfall variability impacts on livelihoods of rural farming community into consideration and similar work in adjacent districts will be required to better understand the processes responsible for those trends and to properly place them in their larger context.

***KEYWORDS*:** Manna Kendall Test, Sen's slope Estimator, Trend Analysis, Standard Anomaly Index, Precipitation Concentration Index

INTRODUCTION

Rainfall trend analyses, on different spatial and temporal scales, have been of great concern during the past century because of the attention given to global climate change from the scientific community: they indicate a small positive global trend, even though large areas are instead characterized by negative trends (IPCC, 1996). Ethiopia is frequently portrayed as a drought suffering country, both in the media and the scientific literature (McCann 1990). Farmers in northern Ethiopia claim to have shifted to more drought resistant crops due to declining rainfall during the last couple of generations (Meze-Hausken 2004). In Ethiopia, rainfall is by far the most important factor climate, as is true for most of Africa. Low-productivity agriculture, which accounts for a majority of the national economy, relies heavily on rainfall. Climate extremes such as drought or flood often lead to famine and disaster for the vulnerable agricultural, social and economic environment in Ethiopia, which lacks structural and non-structural water regulating and storage mechanisms. In particular, flood, as a result of extreme precipitation, poses serious threat on food security and public safety. Estimating the probability of extreme precipitation and characterizing the uncertainty of the estimates are crucial to, for instance, structural design, public safety alerts, evacuation management, and loss mitigation. The fact that the mean annual precipitation in parts of the Ethiopian highlands exceeds 2000 mm may make the impression of Ethiopia as a dry country seems paradoxical (Griffiths 1972).

Studies have been done for different parts of Ethiopia. For examples, studies had been conducted in southern and eastern parts of Ethiopia with the attempt of analyzing the long term trends of rainfall confirmed that declines have been documented, most strongly for the spring season (Seleshi and Camberlin 2006; Williams and Funk 2011). However, there is little evidence for rainfall trends in northern region, particularly in and around the Semien Mountains, neither in seasonal rainfall amounts, nor in the trends and intensity of events.

According to various studies on trend analysis, non-parametric methods are mainly used, Mann-Kendall test (Mann, 1945 and Kendall, 1975) is one of the best methods amongst them, which is preferred by various researchers (Douglas et al, 2003; Jain and Kumar, 2012). Mann-Kendall test is used for trend analysis as it eliminates the effect of serial dependence on auto-correlated data which modifies the variance in datasets (Hamed and Rao, 1998). To analyze the magnitude of trend in the series, Sen's slope estimation, non-parametric, (Sen, 1968) method is used. The purpose of this study to assess the variability of precipitation in Northwest Ethiopia zone which is vulnerable as variable rain is affecting the agriculture (the district economy is primarily dependent on agriculture).

METHODS AND MATERIALS

Description of the study area:

Northwest Ethiopia is located in the Northern parts of Ethiopia which is embraced in the drought prone areas of the country. Based on the 2007 national census conducted by the Central Statistical Agency of Ethiopia (CSA), a total of 3,498,476 households were counted, resulting in an average of 4.92 persons to a household. It is dominantly lies under moist Dega agro-ecological zone.

It is geographically located between 11^0-13^0N longitude and 38^0E To 40^0 E latitude. Northwest Ethiopia's altitude varies from 600 to 4284 meter above sea level (Masl). It has four agro-ecological zones, namely, lowland (Kolla) 500-1500 Masl 38 per cent; Mid-altitude (Woina-Dega) 1500-2300 Masl is about 34 per cent, Highland (Dega) 2300-3200 Masl is 21% and Wurch >3200 is about 7 per cent of the Zone.

According to the daily air temperature data collected by Sirinka Agriculture Research Center (located about 12km south of Woldiya), the mean monthly temperature at Sirinka ranges between 12^0c to 25^0c. A bi-modal nature characterizes rainfall in most parts of Northwest Ethiopia. The short rainy season (Belg), occurs between February and April and long rainy season (Meher), on the other hand occurs between June and September. In most cases, the highland areas (Dega) are mainly dependent on Belg rain whereas, the Woina-Dega and Kolla areas are Meher rain dependent for crop production.

The principal feature of rainfall in most parts of Northwest Ethiopia Zone is its seasonal character, poor distribution and variability from year to year. For the past three decades, an erratic distribution of rainfall has been the major climatic factor affecting crop yields in the area. The highest amount of rainfall was recorded during the months of July and August according to the data recorded at Sirinka station. On the other hand, the Belg rain (February-April) was inadequate for crop cultivation. Such an erratic nature of rainfall has been a contributing factor to the declining production, which affects most farmers in the zone.

Agriculture is the main economic activities and is dominated by small-scale and mixed crop and livestock farmers. Crop production is mainly rain-fed. Tourism also plays a major role in income generation in the areas.

Dataset Description:

Time series of daily precipitation covering Northwest Ethiopia of Ethiopia was obtained from the National Meteorological Agency for the periods from 1979 to 2013. The t-test has been applied in homogeneity testing.

The statistical trend test selected was the Mann-Kendall non-parametric test for trend (Mann, 1945; Kendall, 1975). This trend test has been commonly used in similar applications (Hirsch et al., 1982) and has been found to be an effective tool for identifying trends in hydrological and other related variables. Mann-Kendall's test checks the hypothesis of no trend versus the alternative hypothesis of the existence of increasing or decreasing trend. The test statistic for the Mann-Kendall test is given in the form:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(X_j - X_i)$$

Where X_j are the sequential data values, n is the total number of data points in the set and *sgn* is the *signum* function. The variance associated with S is calculated from (Mann, 1945; Kendall, 1975).

$$Z(S) = \frac{n(n-1)(2n+5) - \sum_{k=1}^{m} t_k(t_k - 1)(2t_k + 5)}{18}$$

Where *m* is the number of tied groups and t_k is the number of data points in group *k*.

The presence of a statistically significant trend is evaluated using the Z value. Positive values of *Z(S)* indicate increasing trends, while negative *Z(S)* values reflect decreasing trends. Trends are considered significant if |*Z(S)*| are greater than the standard normal deviate $Z_{1-\alpha/2}$ for the desired value of 0.05. Positive value of indicates an upward or increasing trend and a negative value of gives a downward or decreasing trend in the time series.

Standardized rainfall anomaly index, rainfall concentration index and coefficient of variation were used as descriptors of rainfall variability. The rainfall variability for representative meteorological stations was determined by calculating the coefficient of variation (CV) as the ratio of the standard deviation to the mean rainfall in a given period as used by (Belay, 2014). Standardized Anomaly Index was calculated as the difference between the annual total of a particular year and the long term average rainfall records divided by the standard deviation of the long term data. It is computed as:

$$Z = \frac{(X - ?)}{\delta}$$

Where, Z is standardized rainfall anomaly; x is the annual rainfall total of a particular year; µ is mean annual rainfall over a period of observation and is the standard deviation of annual rainfall over the period of observation. Standardized anomaly index value was categorized according to McKee (1993) classification (Table 1).

Table 1. Standardized anomaly index value categories

No.	Standardized Anomaly Index value	Classification
1	2.0+	Extremely wet
2	1.5 to 1.99	Very wet
3	1.0 to 1.49	Moderately wet
4	-0.99 to 0.99	Near normal
5	-1.0 to -1.49	Moderately dry
6	-1.5 to -1.99	Severely dry
7	-2 and below	Extremely dry

Source: McKee (1993).

This study also used precipitation concentration index (PCI) to investigate heterogeneity of monthly rainfall (Oliver, 1980).

$$\text{PCI} = \frac{(\sum_{i=1}^{12} pi^2)}{(\sum_{pi=1}^{12})^2}*100$$

Where pi is the monthly rainfall in month i. The seasonal scale of Rainfall Concentration Index was calculated using the equation:

$$\text{PCI}_{\text{seasonal}} = \frac{(\sum_{i=1}^{3} pi^2)}{(\sum_{pi=1}^{3})^2}*25$$

According to Oliver's classification11: i. PCI < 10 indicates uniform precipitation distribution (low precipitation concentration), ii. PCI >11 and <15 indicates moderate precipitation concentration; iii. PCI >16 and < 20 indicates irregular distribution, iv. PCI > 20 indicates a strong irregularity (i.e., high precipitation concentration) (Oliver, 1980).

RESULTS AND DISCUSSION

This section presents findings of the study area on the trend, rainfall anomaly, and intensity of the rainfall data.

Rainfall anomalies and Concentration:

As indicated below in (table 2), there was variation across months in the amount of precipitation received by the study area for over 35 years. The analysis of monthly rainfall and the coefficient of variation between 1979 and 2013 showed a dry season with average blew 12mm extend from December to April and a relatively rainy season from June to September with maximum in August. The coefficient of variation shows lowest values for

July, August and September which can be interpreted as they are the most reliable month for rainfall occurrences. The average of annual precipitation during 1979–2013 was around 285.7mm and the annual rain- fall varied considerably during this 35 years duration.

In line with finding, it has been frequently cited by researchers that the seasonality of rainfall varies in different areas of Ethiopia. In the northwest parts of Amhara region, rains come twice a year during the March to June Belg season, and in summer (June to September) Kiremt rains. Many farmers plant slowly maturing but high yielding 'long cycle' crops that grow during both the Belg and Kiremt seasons.

Table 2. Basic monthly statistics of rainfall data in Northwest Ethiopia from 1979 to 2013

Variable	**Minimum**	**Maximum**	**Mean**	**Std. deviation**
Jan.	0.000	101.120	8.462	18.459
Feb.	0.000	73.280	12.390	19.880
Mar.	0.120	215.380	57.264	57.397
Apr.	15.460	258.950	85.320	62.719
May.	19.040	445.850	101.181	98.653
Jun.	154.910	1001.920	456.785	22.551
Jul.	642.340	2143.450	1222.961	13.560
Aug.	797.110	1583.260	1081.488	10.459
Sep.	109.130	796.910	303.937	12.512
Oct.	1.070	479.270	73.919	98.341
Nov.	0.000	159.420	17.991	42.945
Dec.	785.770	76.270	6.526	34.458

Table 3. Annual and seasonal PCI values of Northwest Ethiopia Station.

Station Name	Annual and Seasonal PCI values of Northwest Ethiopia Zone					
	<10	<16	>16	% of years above a value of 16 PCI	Summer PCI	Autumn PCI
Northwest Ethiopia	0.0	28	4.0	15	22-31	42-58

The result indicted that the calculated value of PCI at annual level showed values >16 in the station which is moderate rainfall irregularity. Rainfall concentration index (PCI) values of less than 10 indicated uniform monthly distribution of rainfall, values between 11 and 20 indicate high concentration, and values above 21 indicate very high concentration (Oliver, 1980). The result indicated that study area ranges from moderate to high monthly rainfall concentration.

Table 4. Standardized rainfall indices of Northwest Ethiopia

		Percentage and frequency of occurrence (Years)	
SAI values	**Drought classification**	**Frequency**	**Percentage (%)**
2.0+	Extremely wet	4	11.4
1.5 to 1.99	Very wet	8	22.9
0.01 to 1.49	Moderately wet	10	28.6
-0.99 to 0	Near normal	2	5.7
-1.0 to -1.49	Moderately dry	6	17.1
-1.5 to -1.99	Severely dry	4	11.4
-2 and below	Extremely dry	1	2.9

This study used SAI to demonstrate the intensity and frequency of drought and inter-annual variation at various time scales and area. The negative anomalies of Northwest Ethiopia station was 37.1% during the period of 1979 to 2013.

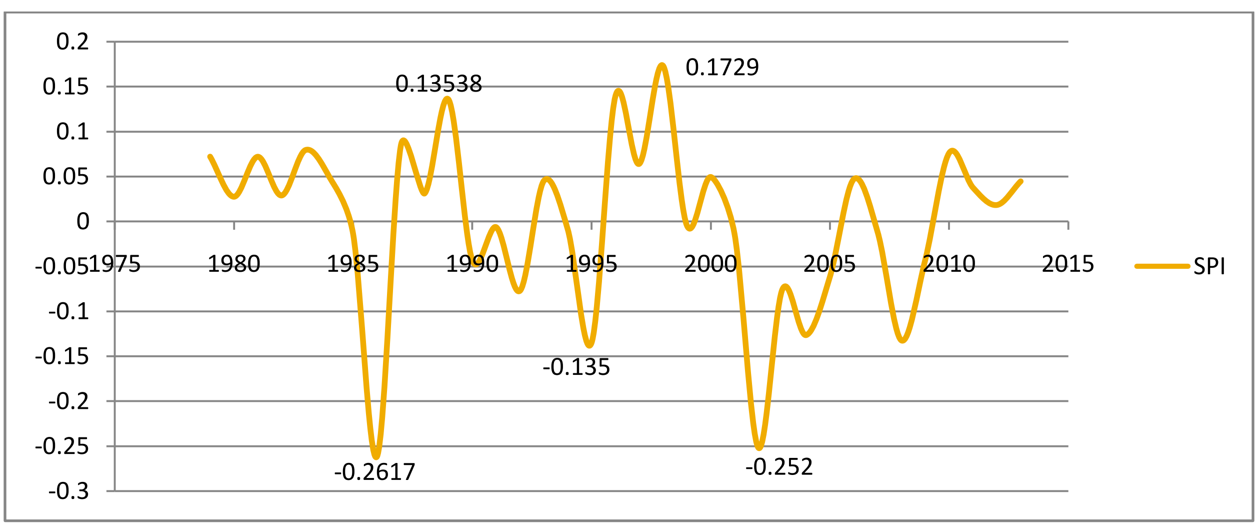

Figure 2. Northwest Ethiopia's Standard anomaly index over the period of (1979-2013).

The most obvious droughts occurred during the 1990's in several years as indicted by Figure 1 (anomalies graphs and moving average). On the other hand, during 1980's and 2000's periods, rainfall anomalies were above the average. The anomalies of the July to August rainfall (Figure 1) reveal the general trend of annual rainfall. Therefore these two months could modulate the annual rainfall time series.

Monthly and Annual Trend of Rainfall

Table 5. Estimated Monthly non parametric results and significance test.

Month	Mann-Kendall trend test	P value	Sen's slop	Trend significant over 35 years
January	-0.103	0.4	-0.027	No
February	-0.402	0.001*	-0.20 3	Yes
March	-0.321	0.006*	-1.828	Yes
April	-0.103	0.397	-0.821	No
May	-0.025	0.844	-0.496	No
June	-0.022	0.866	-0.743	No
July	0.284	0.016*	7.625	Yes
August	0.190	0.112	7.104	No
September	0.170	0.157	3.587	No
October	-0.027	0.831	-0.134	No
November	0.106	0.382	0.181	No
December	-0.039	0.754	-0.049	No

** are 0.05 level of significance.*

The results of Mann-Kendall test for trend analysis of data are presented in table 5 above. The trend analysis has been done for all months of the year for the station under study in the district. The estimated Sen's slope has been calculated for January to December. As it can be elucidated in (table 5) above, there was a significant decreasing trend on February and March while there was a significant increasing rainfall trend over the district. On the other hand on January, April, May, June, October and December, there was a negative trend but the trend was not statistically significant. August, September and November shows statistically a non-significant increasing trend of rainfall. This result is quite significant as the months where Mann-Kendall trend analysis has shown negative trend, similar negative slope has been observed for the Sen's Slope and vice versa.

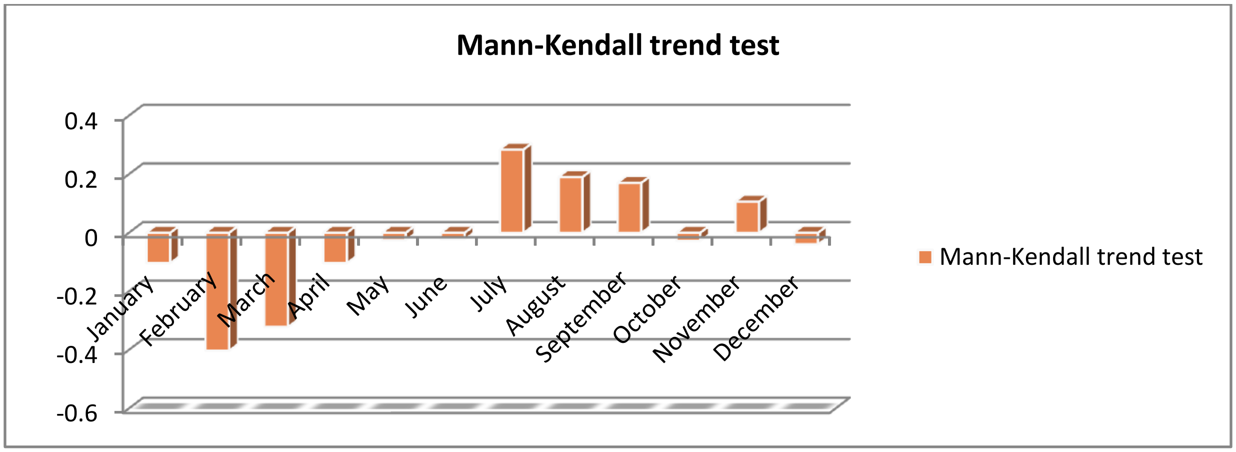

Figure 3: Mann-Kendal trend analysis of average monthly precipitation of Northwest Ethiopia District rain gauge station (1979-2013)

In the non parametric Mann-Kendall test, trend of rainfall for 35 years from January to December has been calculated for each month individually together with the Sen's magnitude of slope. In the Mann-Kendall test describes the trend of the series for individual 12 months from January to December which are -0.103, -0.402, -0.321, -0.103, -0.025, -0.022, 0.284, 0.190, 0.170, -0.027, 0.106, -0.039, respectively. For July, August, September, and November there is an evidence of rising trend while test value is showing negative trend in January, February, March, April, May, June, October, and December. Thus test values for four months show a positive trend and for other eight months.

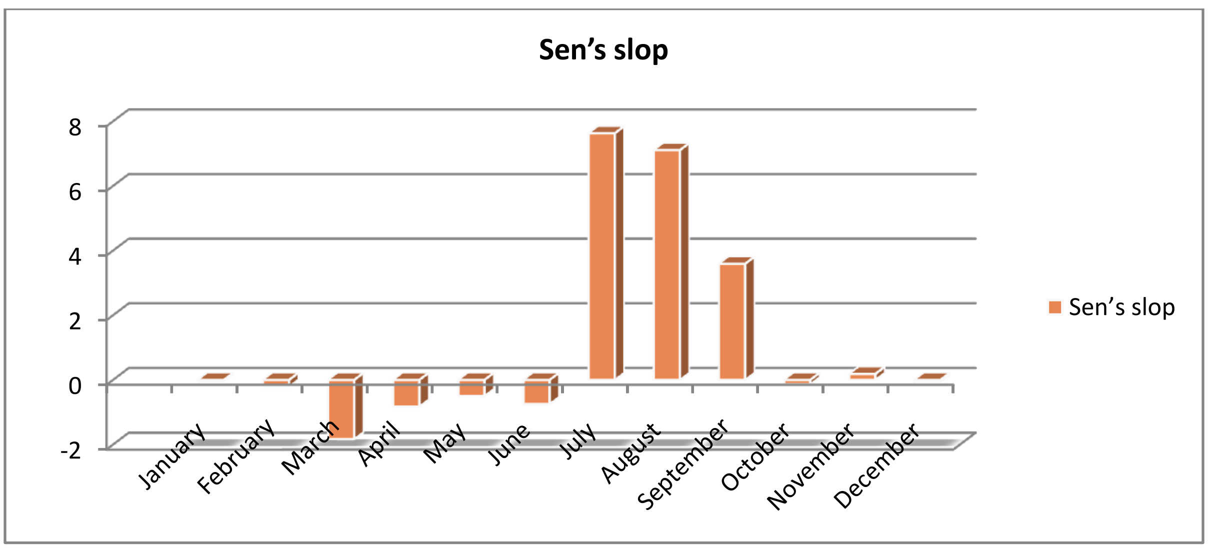

Figure 4: Sen's slop estimator analysis of average monthly precipitation of Northwest Ethiopia District rain gauge station (1979-2013).

Annual rainfall trend test

In order to determine the trend on annual scale, analysis has been done for the station.

Table 6: Annual rainfall trend test of Northwest Ethiopia district

Kendall's tau	-0.029
Sen's slop	-1.701
p-value	0.822
Alpha	0.05

As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0. The risk to reject the null hypothesis H0 while it is true is 82.17%. Insignificant decrease and increase of trend is found for the data set in the district.

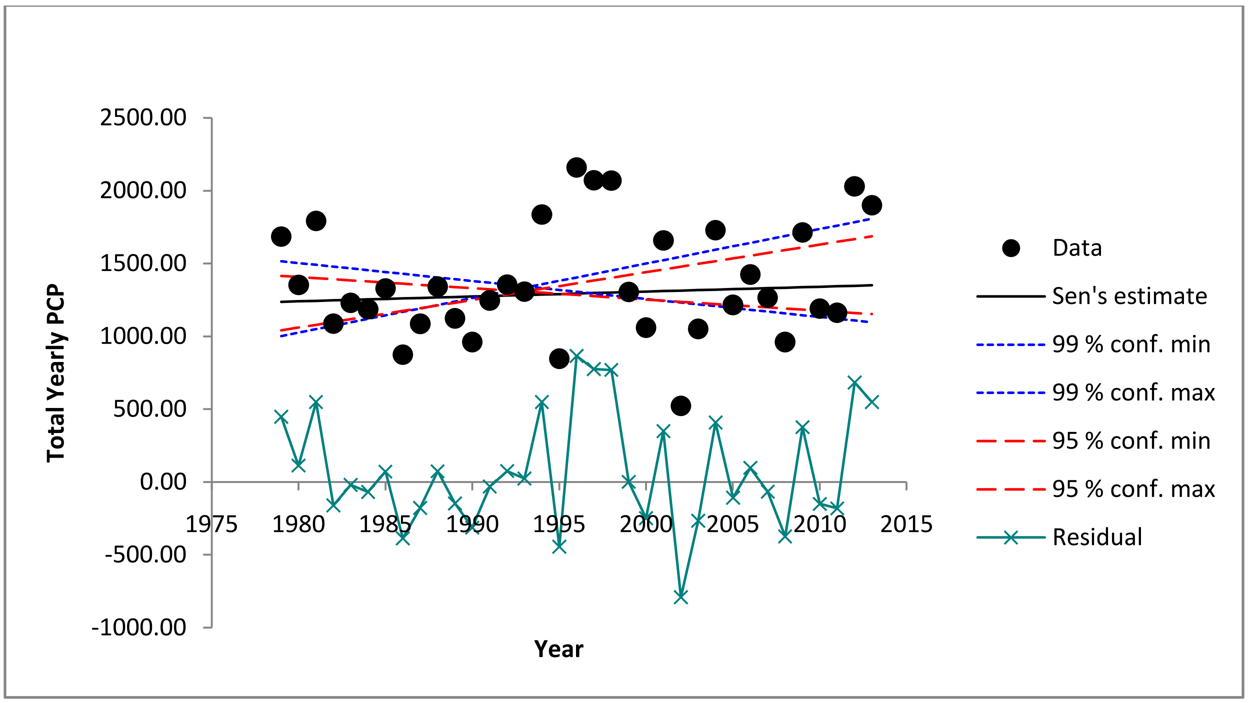

Figure 4: Sen's estimator values of Northwest Ethiopia District

In general, at the district level there is an insignificant trend for the entire data set.

CONCLUSION

The trend and variability of rainfall over the past 35 years in annual and seasonal scale indicated that there was considerable variability. This study has been done for the period 1979-2013. The study area is unique as it has ups and downs relief features at the higher altitudes. The amount of rainfall varies between different months in different years, with the variation extending across decades. From the trend analysis of precipitation data it can be concluded that even though insignificant change in precipitation pattern exists over the last few decades in most parts of the region, there is evidence of some change in precipitation trends in some months. The Mann-Kendall test represents both positive and negative trend in the area although not much significant. Sen's Slope is also indicating increasing and decreasing magnitude of slope in correspondence with the Mann-Kendall Test values. There are three months with increasing trend value along with the increasing slope magnitude, and five months with decreasing or negative value and Sen's Slope and four month shows no trend. The rainfall trend was characterized by a high inter-annual variability with wet periods in 1990's and 2011. On the other hand, the prolonged drought appeared in late1990's. Therefore, the change in rainfall patterns could be attributed to the climatic changes, which affected Northwest Ethiopia district of Northwest Ethiopia.

Further studies are needed to address the issue of trend attributes and rainfall linkage with other climate parameters of the district.

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