Trend analysis of seasonal rainfall and temperature pattern in Damota Gale districts of Wolaita Zone, Ethiopia

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Research

Keywords: Trend analysis, seasonal rainfall, Damota Gale, Mann-Kendall test

Posted Date: August 10th, 2021

DOI: <https://doi.org/10.21203/rs.3.rs-757668/v1>

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Abstract

Background: This paper investigated the recent trends of precipitation and temperature on Damota Gale districts of Wolaita Zone. This study used the observed historical meteorological data from 1987 to 2019 to analyze the trends. The magnitude of the variability or fluctuations of the factors varies according to locations. Hence, examining the spatiotemporal dynamics of meteorological variables in the context of changing climate, particularly in countries where rain fed agriculture is predominant, is vital to assess climate-induced changes and suggest feasible adaptation strategies.

Results: Both rainfall and temperature data for period of 1987 to 2019 were analyzed in this study. Statistical trend analysis techniques namely Mann–Kendall test and Sen's slope estimator were used to examine and analyze the problems. The long-term trend of rainfall and temperature was evaluated by linear regression and Mann–Kendall test. The temperature was shown a positive trend for the both annual and seasonal periods and had a statistical significance at 95%.

Conclusion: This study concluded that there were a declining rainfall in the three seasons; spring, summer and winter but in autumn it shows increasing trends and rapid warming, especially in the last 32 years. The detailed analysis of the data for 32 years indicate that the annual maximum temperature and annual minimum temperature have shown an increasing trend, whereas the Damota Gale seasonal maximum and minimum temperatures have shown an increasing trend. The findings of this study will serve as a reference for climate researchers, policy and decision makers.

Introduction

Climate is one of the key components in the earth system. There are many variables such as temperature, rainfall, atmospheric pressure, humidity that constitute weather and climate. Climate is usually defined as the average weather. In broad sense, it is the statistical description in terms of the mean and variability of relevant quantities over a period of time ranging from months to thousands or millions of years (IPCC, 2007).

The analysis of long-term changes in climatic variables is a fundamental task in studies on climate change detection. Global climate changes may influence long-term rainfall patterns impacting the availability of water, along with the danger of increasing occurrences of droughts and floods (Pal and Mishra, 2017). The rainfall and temperatures (Singh et al., 2013) are the most important fundamental physical parameters among the climate as these parameters determine the environmental condition of the particular region which affects the agricultural productivity (Modarres and da Silva, 2007; Kumar and Gautam, 2014).

Hence, the purpose of this study is to investigate the variability of the rainfall and temperature of Wolaita Zone in Damot Gale districts one of the most backward regions in the state of SNNPR and Ethiopia. Seasonal trend of both the parameters has been investigated on an inter-annual basis and the fluctuations have been calculated on monthly basis with major focus on season (June–September).

Trend is defined as the general movement of a series over an extended period of time or it is the long-term change in the dependent variable over a long period of time (Webber and Hawkins, 1980). Trend is determined by the relationship between the two variables of temperature, rainfall and their temporal resolution. This includes an understanding of the area's rainfall and temperature trends and variability. Understanding the uncertainties associated with rainfall and temperature patterns will provide a knowledge base for better management of agriculture, irrigation and other water related activities in the selected area. For the assessment of climate variability and trends, different parametric (e.g., T-test, F-test, and linear regression) and nonparametric (e.g., Mann–Kendall test, Kruskal–Wallis test, and Sen's slope estimator) methods have been reported in the literature and are reviewed in detail in these studies, such as Esterby(1996), Zang et al(1996), and Sonali(2012.10) and Nagesh (2013)

The objective of this study is to analyze seasonal rainfall and temperature pattern in Damota Gale districts of Wolaita Zone, Ethiopia using long time series data and to assess the significance of rainfall trends over selected study area by using combination of linear regression, The Mann-Kendall (MK) Test to gather with Sen's Slope Estimator.

Study Area

Wolayita is an administrative zone in the [Southern Nations, Nationalities, and Peoples' Region](#) (SNNPR) of [Ethiopia](#). **Wolayita** is one of the 16 Zonal Administrations of the Southern Region in Ethiopia, located 300 kilometers south of Addis Ababa.

Wolayta is limited north west by Tambaro, eastward by Bilate river which divides it from Arsi-Oromo, Southward by [Lake Abaya](#) and Kucha, westward by [Omo River](#). [Gilgel Gibe III Dam](#) is a hydroelectric power plant built on Omo River; and with the capacity of 1870 Megawatt, it is the third largest hydroelectric plant in Africa. [1] **Damot Gale** is one of the [woredas](#) (districts) in the [Southern Nations, Nationalities, and Peoples' Region](#) of [Ethiopia](#). Part of the [Wolayita Zone](#), Damot Gale is bordered on the southwest by [Sodo Zuria](#), on the northwest by [Boloso Sore](#) and [Damot Pulasa](#), on the north by the [Hadiya Zone](#), on the east by [Diguna Fango](#), and on the southeast by [Damot Weyde](#). The administrative center of Damot Gale is [Boditi](#). Damot Pulasa Woreda was separated from Damot Gale. Damot Gale has 29 kilometers of asphalt roads, 1 kilometer of all-weather road and 57 kilometers of dry-weather roads, for an average road density of 209 kilometers per 1000 square kilometers. [1]

Material And Methods

The study was conducted using rain fall and temperature data. Rain fall data from 1987- 2019and temperature data from 1987- 2019were employed. The data were employed from Boditi high school station which is found in Damot Gale district. Monthly precipitation data from meteorological stations were obtained from the Damot Gale district the period of 1987- 2019.

The climate variability such as the temperature and rainfall pattern is examined in this study. Data were obtained from the Ethiopian Meteorological Department from 1987 to 2019. The rainfall and temperature data are expressed by in millimeter and degree Celsius, respectively. Also, there are no missing values in this study. Data were subjected to regression for trend analysis of climate variability (temperature or rainfall) during 1987- 2019, and the regression formula is given below.

The summary of the descriptive statistics, the coefficient of variation (CV) and the correlation also performed for the annual and seasonal rainfall and temperature. The CV is used to evaluate the degree of variability of rainfall (Hare, 2003), below 20% is less variability, 20–30% is moderate and above 30% is high. To estimate the true slope of an existing trend such as amount of change per year, Sen's non-parametric method is used and the test has been performed using XLSTAT 2021 software. A positive value of Sen's slope indicates an upward or increasing trend and a negative value gives a downward or decreasing trend in the time series.

The regression line is used to an explained trend of long-term (annual and seasonal) pattern of temperature and rainfall. Data were subjected to regression for trend analysis of climate variability (temperature or rainfall) during 1987- 2019, and the regression formula is given below.

$$Y = a + b X \quad \dots\dots\dots (1)$$

Where Y is the independent variable, a- is the intercept and b is the slope and X is the dependent variable. The nonparametric method is appropriate for the non-normally distributed censored data which includes missing value.

Trend Analysis

Statistically trend is a significant change over time which is detectable by parametric and non-parametric procedures while trend analysis of a time series consists of the magnitude of trend and its statistical significance. In this study statistical significance trend analysis was done by using Man- Kendall test while for the magnitude of trend was determined by non-parametric Sen's estimator method

The Mann–Kendall test is widely used to estimate the monotonic trend of the hydro-meteorological time series and is used here as a significant test. This has carried out with the hypothesis (H_0) that it of is no trend in the rainfall/temperature, but it has an alternative hypothesis (H_A) that there is a monotonic trend in rainfall/temperature. Thus, MK statistic is the sum of the number of positive difference minus number of negative difference, which is calculated by using given formula

$$S = \sum_{k=1}^{n-1} \sum_{j=k+1}^n \text{sgn} (x_j - x_k) \quad \dots\dots\dots (2)$$

$$\text{sgn} (x_j - x_k) = 1 \quad \text{if } x_j - x_k > 0$$

$$=0 \quad \text{if } x_j - X_k = 0$$

$$= -1 \quad \text{if } x_j - X_k < 0$$

A normalized test statistic is utilized to evaluate the statistical significance of the trend tendency of mean temperature and rainfall at 5% significance level.

Sen's Slope Estimator Test: The magnitude of trend is predicted by the Sen's estimator. Here, the slope (T_i) of all data pairs is computed as (Sen, 1968)

$$T = \frac{x_j - x_k}{j - k} \quad \dots\dots\dots (3)$$

For $i = 1, 2, \dots, N$.

Where, x_j and x_k are considered as data values at time j and k ($j > k$) correspondingly. The median of these N values of T_i is represented as Sen's estimator of slope which is given as:

$$\begin{aligned} & \frac{TN + 1}{2} && \text{if } N \text{ is odd} && \dots\dots\dots(4) \\ & \frac{1}{2} \left(T \frac{N}{2} + \frac{TN + 2}{2} \right) && \text{if } N \text{ is even} \end{aligned}$$

Sen's estimator is computed as $Q_{\text{med}} = T (N+1)/2$ if N appears odd, and it is considered as

$$Q_{\text{med}} = [TN/2 + T (N+2)/2]/2 \text{ if } N \text{ appears even.}$$

At the end, Q_{med} is computed by a two sided test at 100 (1- α) % confidence interval and then a true slope can be obtained by the non-parametric test. Positive value of Q_i indicates an upward or increasing trend and a negative value of Q_i gives a downward or decreasing trend in the time series.

Regression Analysis: Regression analysis is a statistical process for estimating the relationships among variables. It includes many techniques for modeling and analyzing several variables, when the focus is on

the relationship between a dependent variable and one or more independent variables. This is parametric analysis which assumes normal distribution of time series data. The regression analysis is generally applied for testing a linear trend by developing inner relationship between time and the variable of interest. The precise use of this method needs the variables to be distributed normally and spatial and temporal independent. The regression analysis was performed on the observed rainfall time series data. In a specific station, Trend in rainfall can be studied by regression analysis with respect to time as the independent variable and annual and sessional rainfall as the dependent variable.

A linear equation, $y = mx + c$, defined by c (the intercept) and trend m (the slope), which represents the rate of increase or decrease of the variable, can be fitted by regression and t is time in years.

Results And Discussion

In the present study trend analysis of rainfall of selected districts of Wolaita Zone, **Damot Gale, Boditi high school** gauge was done using Mann-Kendall to gather with Sen's slope estimator for 32 years of time series data (1987- 2019) on monthly, seasonally and yearly basis.

Trend analysis of seasonal rainfall data as well as seasonal Max and Min Temperature data (June - September) has been analyzed by Mann-Kendall and Sen's Slope Estimator in this study for evaluating trend and magnitude for **Damot Gale** District. The Regression analysis has also been used for developing linear relationship between observed rainfall data with respect to time. The results obtained using seasonal rainfall trend analyses are given in Table 2. The mean rainfall of the study area over 32 years was found to be 1195.361 mm and the mean rainfall for four seasons; spring, summer, autumn, and winter are 411.076, 422.812, 257.012, and 104.461 respectively.

Table 1 Characteristics of stations for recorded precipitation and temperature data.

Station Name	Elevation	Geogr1	Geogr2	Period
Boditi School	2043	37.955	6.954	1987-2019

Seasonal Rainfall Trend Analysis

The preliminary data analysis was carried out to find the statistical parameters (mean, standard deviation, Mann-Kendall trend, significance level α), Sen's Slope and coefficient of variation) of annual precipitation series for the period 1987-2019. Rainfall trend was analyzed on four seasons as discussed below.

It is evident from Fig-2 that the maximum rainfall occurs in study area in season of summer (June, July, and August). It has been also observed that the seasonal rainfall received during season of winter (average 104.461mm) was lowest than the other season which were considered for the study followed by Autumn (average 257.012 mm), then spring season (average 411.076 mm) and maximum rainfall was

received on summer (average 422.812 mm),. This analysis revealed negative (decreasing) trend for spring, summer and winter whereas Kendall's tau values indicated a positive trend for autumn season. The Sen's estimator which is to measure the magnitude of seasonal rainfall was found as -3.419, -2.054, 1.179 and -2.812 for season spring, summer, autumn and Winter respectively. The Regression analysis was performed for the Annual rainfall time series data as well as the seasonal rainfall time series data for the season of spring, summer; autumn and winter are showed in the Fig-2, respectively.

The developed functional relationships for the variables are also showed in the figures. Table.2 represents the regression analysis values of for all the four season (i.e. spring, summer, autumn, and winter). The slope coefficient specifies the rate of change in the rainfall characteristic. The sign of the slope describes the direction of the trend of the rainfall, if sign is positive then it has increasing trend and if sign is negative then it has decreasing trend.

Table.2: Seasonal rainfall Trend results for Mann-Kendall test, Sen's Slope estimator and Regression Analysis.

Statistical Parameters	Spring	Summer	Autumn	Winter	Annual
Kendall's tau	-0.136	-0.136	0.133	-0.265	-0.220
S	-72.000	-72.000	70.000	-140.000	-116.000
Var(S)	1798.033	4165.333	4165.333	4165.333	4165.333
p-value (Two tailed)	0.094	0.271	0.285	0.031	0.075
alpha	0.050	0.050	0.050	0.050	0.050
Sen's Slope	-3.419	-2.054	1.179	-2.812	-7.038
Regression Analysis(R^2)	-0.122	-0.196	0.1818	-0.034	-0.175
Slope (m)	-3.420	-2.054	1.179	-2.812	15280.785
Intercept (c)	7255.843	4498.601	-2135.920	5728.880	15280.785
Minimum	196.400	261.500	133.400	15.700	1.000
Maximum	653.800	658.600	534.000	277.200	17.000
Mean	411.076	422.812	257.012	104.461	8.488
Std. deviation	128.110	106.523	91.056	72.819	3.138

Seasonal variation of rainfall trend depends upon temperature variation

Four seasons were used depending upon temperature i.e. winter, summer, spring and autumn. The value of Z and Q –Statistics for three seasons, winter, summer and spring is negative which showed significant decreasing trend while the autumn season indicate increasing trend as shown in Fig.2

Seasonal Temperature Trend Analysis for both Max and Min Temperature

Seasonal variation of Max Temperature trend Analysis

Table 3: Seasonal Max Temperature Trend results for Mann-Kendall test, Sen's Slope estimator and Regression Analysis (R^2)

Statistical Parameters	Spring	Summer	Autumn	Winter	Annual
Kendall's tau	0.442	0.143	0.040	0.462	0.443
S	226.000	73.000	20.000	231.000	224.000
Var(S)	3200.509	4107.667	4060.667	7942.820	4088.000
p-value (Two tailed)	<0.0001	0.261	0.766	0.010	0.000
alpha	0.050	0.050	0.050	0.050	0.050
Sen's Slope	0.103	0.029	0.000	0.095	0.094
Regression Analysis(R^2)	0.270	0.698	#N/A	-0.288	0.297
Slope (m)	0.103	0.029	0.000	0.095	0.094
Intercept (c)	-175.398	-31.461	28.000	-160.843	-157.438
Minimum	27.000	23.600	25.800	27.000	27.400
Maximum	34.000	30.000	34.000	35.100	35.100
Mean	29.979	26.382	28.030	29.906	30.667
Std. deviation	1.637	1.640	1.412	1.602	1.726

Four seasons were used depending upon temperature i.e. winter, summer, spring and autumn. The value of Z and Q –Statistics for four seasons, winter, summer, and spring is positive which showed significant increasing trend while the autumn season indicate non-trend as shown in Fig.4

Seasonal variation of Min Temperature trend Analysis

Table 4: Seasonal Min Temperature Trend results for Mann-Kendall test, Sen's Slope estimator and Regression Analysis.

Statistical Parameters	Spring	Summer	Autumn	Winter	Annual
Kendall's tau	0.179	0.362	0.272	0.285	0.215
S	90.000	184.000	137.000	141.000	108.000
Var(S)	4063.333	6657.245	1858.908	3987.000	4032.667
p-value (Two tailed)	0.163	0.025	0.002	0.027	0.092
alpha	0.050	0.050	0.050	0.050	0.050
Sen's Slope	0.038	0.077	0.063	0.04	0.038
Regression Analysis(R^2)	0.277	0.137	0.155	0.228	0.237
Slope (m)	0.038	0.077	0.063	0.04	0.038
Intercept (c)	-65.500	-143.704	-115.063	-70.400	-65.600
Minimum	2.000	1.000	3.500	3.000	1.000
Maximum	25.000	22.500	24.000	17.000	17.000
Mean	11.136	10.391	9.870	9.248	8.488
Std. deviation	3.562	3.530	3.423	2.585	3.138

Four seasons were used depending upon temperature i.e. winter, summer, spring and autumn. The value of Z and Q –Statistics for four seasons, winter, summer, and spring is positive which showed significant increasing trend while the autumn season indicate non-trend as shown in Fig.7

This result shows that approaching to global warming study has important impact on the regional climate in the study area for the last three decades. Also, it is observed that the average seasonal maximum and minimum temperature for the studied period, the Sen's Slope estimator (Q –Statistics) varies from seasons to seasons, that means more or less the seasonal maximum or minimum temperature show stability over time and less variability is examined. Hear it is Sen's slop of seasonal maximum temperature is: 0.103, 0.025, 0.00, and 0.095 for spring, summer, autumn and winter respectively. Likewise, seasonal minimum temperature is: 0.038, 0.077, 0.063 and 0.04 seasonal maximum temperature. The coefficient of Kendall's tau in case of seasonal maximum temperature is the highest in the seasons of winter which is 0.462 and the data are positively skewed. The trends of seasonal mean minimum and maximum temperature over different years are also obtained using linear regression best fit lines. The linear regression trends with their linear regression equations and coefficient of determination are represented in Fig 6 and 7. The coefficient of variation for mean (Lewis and King, 2016) monthly minimum temperature shows a variation ranging from 8.74 to 19.73%. Although the variation is less, but from the study, it is proved that seasonal maximum temperature shows more variation than the seasonal minimum temperature. As far as coefficient of Kendall's tau in seasonal maximum temperature is concerned, it is the highest in winter and it is lowest autumn that is 0.462, and

0.040 respectively. And like maximum temperature the data are positively trend in the time series. And the coefficient of Kendall's tau in seasonal minimum temperature is concerned, is the highest in summer and is the lowest in spring that is 0.179 and 0.362 respectively.

Conclusion

In this study, Sen's slope estimator, non-parametric Mann-Kendall test, and linear regression test were investigating trends of Seasonal rain fall and seasonal Temperature (maximum and minimum) and annual rainfall for Damot gale district. The records of Damot District rain station for the period of 32 years from 1987–1988 to 2018–2019 were analyzed. The results showed that there are decreasing in the trend of the seasons, spring, summer, and winter, additionally in annual rainfall data with significant trends observed at the 95% confidence levels. Hence, the seasons of autumn shows the increasing rate was 1.179. The trend of the seasons, spring, summer, and winter rainfall decreasing rate was equal to -3.419mm/year, -2.054 mm/year, -2.812mm/year and - 7.038 mm/year annual rain fall. The results of analysis the seasonal monthly rainfall trend revealed an increasing trend for the season's autumn and decreasing for the other seasons. The analysis of Sen's slope estimator and Mann-Kendall test showed the same trend results for the seasonal maximum and minimum temperature, except for the all seasons which show the positive linear regression. The results obtained in this work are promising and might help policy makers, which will be helpful in controlling flood causing when designing the water resources structures and decision makers of agricultural sector in the district.

Abbreviations

CV: Coefficient of variation

MK: The Mann-Kendall

SNNPR: Southern Nations, Nationalities, and Peoples' Region

IPCC: Intergovernmental Panel on Climate Change

Declarations

This work is original and has not been published elsewhere, nor is it currently under consideration for publication elsewhere.

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethical considerations

Ethics approval is not applicable.

Although these studies present a minimal risk to participants, has been conducted in accordance with the declaration of Helsinki that provides guidance for the researcher to protect research subjects. Oral informed consent was obtained before the interviews. The objectives of the research were explained to all respondent in brief.

Consent to participation

Not applicable

Consent to publication

All authors agreed to the public this original research work

Competing interests

The authors declare that they have no competing interests

Funding statement

The authors declare that no specific funding from any fundraising organizations.

Authors' contribution statement

All authors contributed to the study conception and design. Material preparation, data collection, and analysis were performed by Elias Bojago and Dalga Yaya. All authors read and approved the final manuscript.

Acknowledgments

We would like to acknowledge Wolaita Sodo University for giving permission to do this research. We also thank the respondents for their willingness to take part in study.

Availability of data and materials

The data generated and analyzed during the current study is included in the body of this paper.

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Figures

Image not available with this version

Figure 1

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Figure 2

Seasonal variation of rainfall trend with Sen's slope estimator

Figure 3

Annual Rainfall Trend Analysis

Figure 4

Seasonal variation of Max Temperature trend Analysis

Figure 5

Annual Max Rainfall

Figure 6

p-values for four Seasons

Figure 7

Seasonal variation of Min Temperature trend Analysis

Figure 8

Annual Min Rainfall