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Spatio-temporal Variability and Trends of Rainfall and Temperature Over Gamo Gofa Zone, Ethiopia

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Authors' contributions

This work was carried out in collaboration between the two authors. Both authors designed the study, wrote the protocol, managed the literature searches, analyzed the data and wrote the manuscript. Both authors read and approved the final manuscript.

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ABSTRACT

This study examined spatiotemporal climate variability and trends of observed rainfall and temperature data from 1991-2010 over Gamo Gofa zone, southern Ethiopia. Normalized anomaly and coefficient of variation were analyzed to observe the variability of climate. Linear regression was used to analyze trends; Mann Kendall trend test was used for testing the significance and ArcGIS was used to map trend magnitudes and the statistical significance. Normalized anomaly of annual rainfalls showed the variability of dry and wet years at all stations. Coefficient of variation analysis indicated that variability of annual and seasonal rainfalls increased from west to east and to the south. Annual, June to August and September to November rainfalls showed both significant decreasing and increasing trends at different stations in the zone. Generally, most of the land area of the zone had experienced insignificant trends for both annual and seasonal rainfalls. Normalized anomaly of mean maximum and minimum temperature showed 2000s were warmer than 1990s at most of the stations. Mean annual and seasonal maximum temperature at all stations in the zone showed warming trends. Significant land of the zone had experienced both warming and cooling trends of minimum temperature for annual and seasonal timescales. These may result in failure of agricultural production that necessitates developing and implementing systematic planning and management activities in the crop calendar.

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1. INTRODUCTION

The climate of Africa is warmer than it was 100 years ago and model-based predictions of future green house gas (GHG) induced climate change for the continent clearly suggest that this warming will continue [1] and, in most scenarios, accelerate. [1] also indicated the likelihood of an increase in annual mean precipitation in East Africa. During the 20th century, a tendency towards more widespread droughts has been observed in many large regions such as the Sahel, southern Africa, central America and south Asia [2]. The current climate change scenarios demand adaptation to temperature increases, changing amounts of available water, climatic instability and increased frequency of extreme weather events.

The trend of increasing temperature, variability in precipitation and increasingly frequent drought is predicted to continue in the tropics through the future [3]. Ethiopia is a victim of such variation and has experienced drought and famine almost every decade, with the resultant disaster on human and livestock population and cause for other negative repercussions [4].

Study conducted by [5] indicated that the Belg (short season rain), Kiremt (longer season rain) and annual rainfall, which are directly affecting agricultural production, exhibited wide variability in Ethiopia. In addition to variations in different parts of the country, the Ethiopian climate is also characterized by a history of climate extremes, such as droughts and flood, and increasing temperature and decreasing precipitation trends.

Mean annual minimum temperature and annual rainfall variability and trend observed over the country during the period 1951-2006 have been reported by [6] in the National Adaptation Program of Action (NAPA) of Ethiopia. The report indicated that there has been a warming trend in the annual minimum temperature over the past 55 years with increasing rate of 0.37℃ per decade. The country has also experienced both dry and wet years over the same period. The trend analysis of annual rainfall shows that rainfall remained more or less constant when averaged over the whole country. According to [7] in Ethiopia, mean annual temperature rose by 1.3℃ or by 0.28℃ per decade during 1960 to 2006 and frequencies of hot days and nights have also showed an increasing trend during these years. Time series studies of rainfall patterns in Ethiopia have been carried out at various spatial and temporal scales by [8] and found a decline of annual and Kiremt (meher) rainfall in eastern, southern, and southwestern Ethiopia since 1982.

The adverse effects of rising trends of temperature and variability of rainfall on agriculture sector are a major concern, particularly given the livelihood dependence on agriculture. The livelihood of the people of Gamo Gofa is dependent on rain-fed small holding farmer's agricultural production which is more vulnerable to the adverse effects of climate variability and change. [9] mentioned that the high lands of Gamo Gofa zone are characterized by nine rainy months which occur from March and October and from October and January. They also indicated that the Southern parts of the zone are characterized by eight rainy months from February to July and from September to October that makes the zone more favorable for rain-fed agriculture. However, according to [10] more than 180,000 people within the zone had suffered from food insecurity due to the prevalence of the 2009 drought. Historical crop production failure and yield variability in the zone is partly attributed to climate instability. This necessitates exploring valuable information in areas of climate variability and trends to enable systematic planning and management. Thus assessments regarding current climate variability and trends which could have much importance in keeping sustainable production systems become more important. Hence the objective of this study was to assess the spatio-temporal variability and trends of annual and seasonal rainfall, maximum and minimum temperatures over Gamo Gofa zone, southern Ethiopia.

2. METHODOLOGY

2.1 Description of the Study Area

The study was conducted in Gamo Gofa zone of Southern Nations, Nationalities and Peoples' Regional State, Southern Ethiopia, about 250 Km from the regional capital Hawassa and about 430 km south of Addis Ababa. It is geographically located between 5°37' to 6°42'N and 36°23' to 37°56'E and between 517m and 4207m above sea level (Fig. 1).

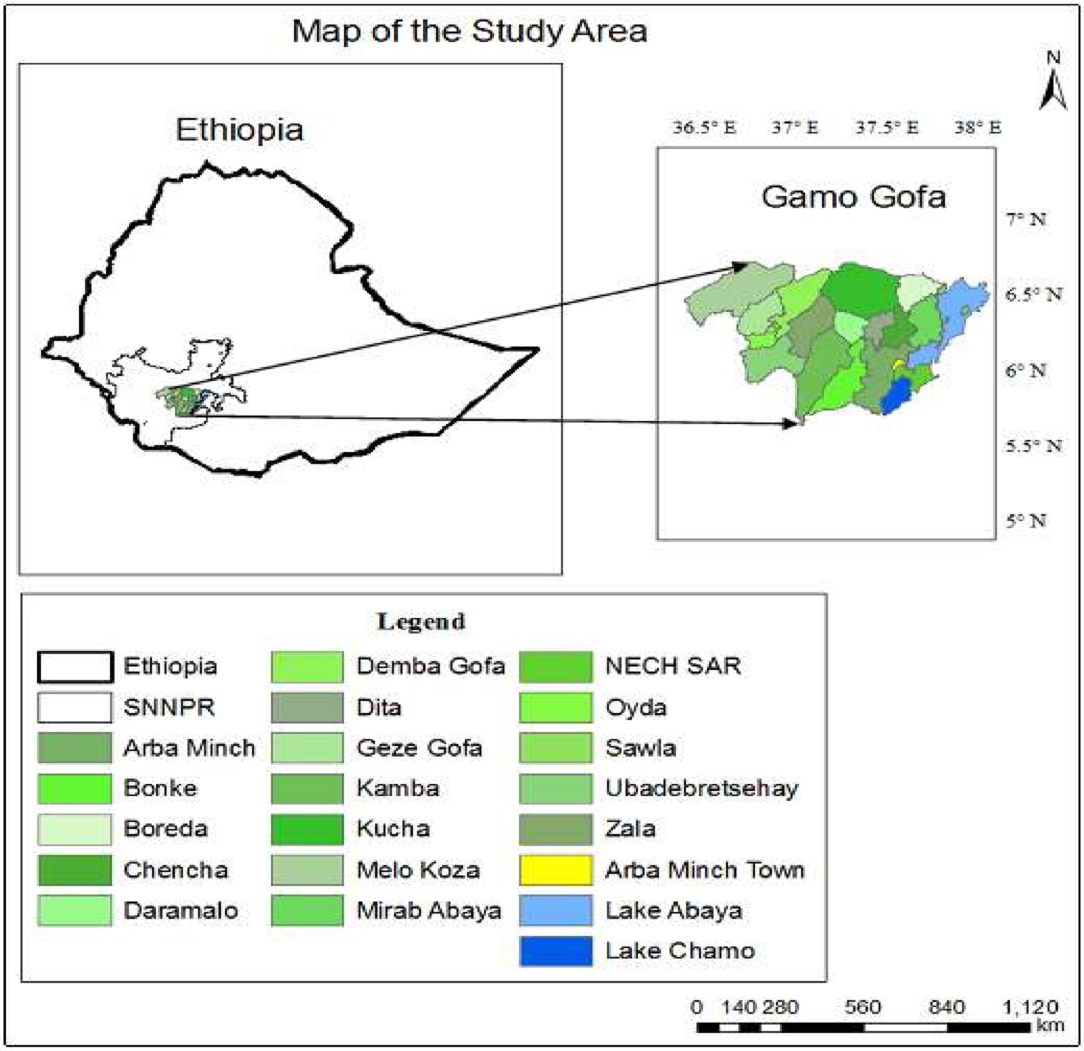

Fig. 1. Map of the study area
(Source: Central Statistical Agency of Ethiopia (2007) and Own clip)

2.2 Data Types and Methods of Collection

Monthly rainfall, maximum and minimum temperature data of stations in the study area were obtained from National Meteorology Agency of Ethiopia. Among the existing meteorological stations in the zone, some stations have data only for rainfall and others are newly established having few years' data for both rainfall and temperatures (Fig. 2). Therefore, 10 stations (Arba Minch, Mirab Abaya, Chencha, Geresse, Kamba, Daramalo, Morka, Lote, Sawla and Bulki) for rainfall and 6 stations (Arba Minch, Mirab Abaya, Geresse, Morka, Sawla and Bulki) for temperature data (1991-2010) were identified for variability and trend analysis in the study period. Additional stations were considered to have adequate distribution of climate data to conduct spatial analysis in the study area. Climate Research Unit time series 3.21 monthly climate data from [11] were used for additional 2 stations (Beto and Melokoza) for rainfall and 6 stations (Beto, Melokoza, Lote, Daramalo, Kamba and Chencha) for maximum and minimum temperatures.

2.3 Data Analysis

2.3.1 Rainfall and temperature variability and trends analysis

Annual and seasonal variability of climate variables of stations in the study area were analyzed using normalized anomaly as used by [12] and coefficient of variations (equation 1). The trends of annual and seasonal rainfall and annual mean maximum and minimum temperatures were analyzed by linear regression as used by [12]. Mann Kendall trend test was used to detect the significance of the trends. The test statistics of datasets for Mann Kendall trend test were calculated by trend software [13].

$$cv = \frac{\sigma}{\bar{x}} \quad (1)$$

Where:

- cv - Coefficient of Variation
- σ - Standard deviation of the climate variable
- $\bar{x}$ - Mean of the climate variable

CV values < 20% indicates less variable, between 20% and 30% indicates moderately variable and >30% indicates highly variable, [14].

2.3.2 Mapping trends and significance of rainfall and temperature

Trend magnitudes of rainfall and temperature were calculated using linear regression lines of datasets and used as inputs to develop trend maps using ArcGIS. The trend maps were used to generate contours of trends using the spatial analyst tool of ArcGIS. Maps of statistical significance of trends were generated using test statistics and superimposed to the contour maps of trends. Test statistics less than 1.563 are considered non-significant, values between 1.563 and 1.862 are considered significant at less than 95% and values greater than or equal to 1.862 are considered significant at greater than or equal to 95%. An Inverse Distance Weighting (IDW) interpolation method with a power parameter of 1 was used for interpolating rainfall and temperature trends and their statistical significance in ArcGIS. The power value was selected comparing the mean prediction error (ME) which approaches zero for perfect interpolation [15]. Both rainfall and temperature trends and significance maps were interpolated at cell size of 1 km by 1 km.

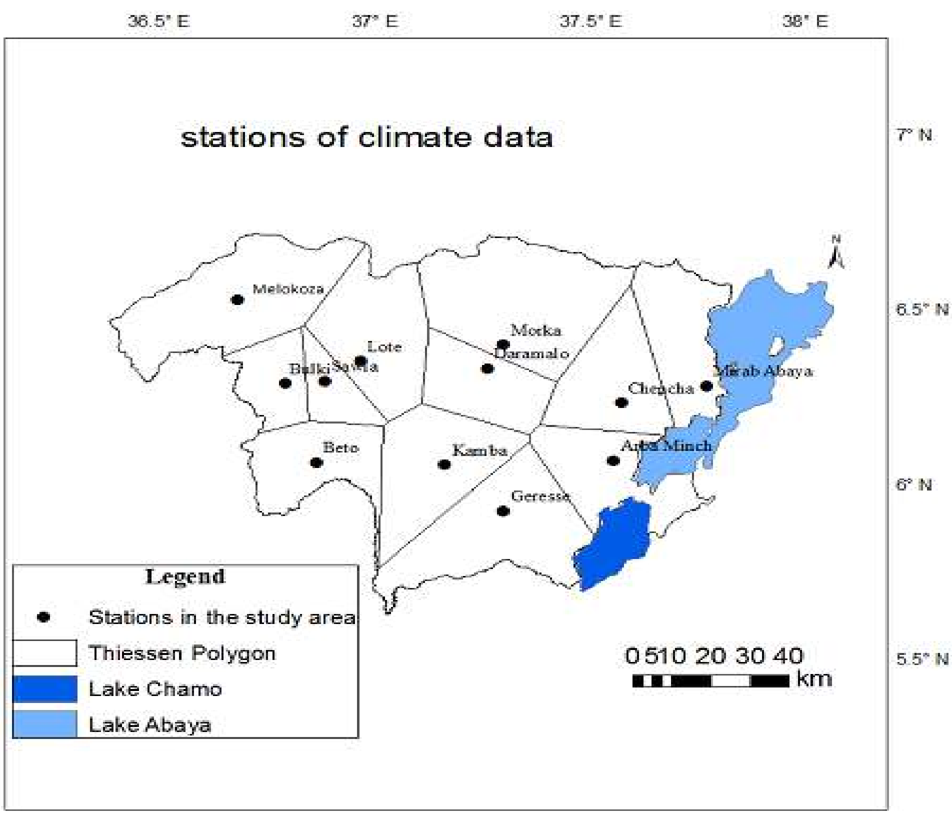

Fig. 2. Meteorological stations & Thiessen polygons of the study area
(Source: Central Statistical Agency of Ethiopia (2007) and Own clip)

3. RESULTS AND DISCUSSION

3.1 Rainfall Variability and Trends at Stations of Gamo Gofa

The normalized anomalies of annual rainfalls in Table 1 show the variability of dry and wet years at all stations in the study area. At Arba Minch and Morka, relatively higher variability was examined in the study period. Continues dry years with rainfall less than average values were observed between 1999 and 2005 at Geresse, Beto, Sawla and Melokoza and during the first half of 1990s at all stations in the zone except at Lote and Bulki. Extremely higher positive rainfall anomalies were observed in 1997 at most of the stations in the zone. The results showed that there is considerable inter-station (spatial) variability of annual rainfall in the study area. Similar to these findings [16] found the presence of inter-annual variability of annual rainfall in western Amhara. Study conducted by [17] using 7 stations in the study area pointed out the variability of annual rainfall within the stations. Coefficients of variation of annual and seasonal rainfalls were increasing from west (e.g Melokoza) to east (e.g. Mirab Abaya) and south (e.g. Geresse) of the zone. Higher coefficient of variation indicates higher variability of the rainfall that would result in failures or reductions of yields of crops in low rainfall years. Table 2 shows trends of annual and seasonal rainfalls per decade and their statistical significance. Significant increasing trends of annual rainfalls were observed at Mirab Abaya, Daramalo and Melokoza. However, significant decreasing trends were examined at Lote and Bulki. Concerning seasonal rainfalls, March to May rainfall had shown significant decreasing trends at Lote and Bulki at confidence level of 90%. June to August rainfall had shown decreasing trends at Chencha, Lote and Bulki and increasing trend at Daramalo with statistical significance. Significant increasing trends were obtained for September to November rainfall at Mirab Abaya and Daramalo. December to February rainfall had experienced significant decreasing trends at Daramalo at 90% confidence level. In comparison with these findings, study conducted over western Amhara by [16] found that annual rainfall has shown significant increasing and decreasing trends at different stations in the study area. [18] found a significant decline in June to September rainfall in different parts of Ethiopia. [8] reported a decline of annual and Kiremt (June to August) rainfall in eastern, southern and southwestern Ethiopia since 1982.

3.2 Maps of Rainfall Trend with Mann Kendall's Trend Test

Maps of decadal trend magnitudes of annual and seasonal rainfalls and their statistical significances are presented in Fig. 3. The map of annual rainfall had shown a decreasing trend with greater or equal to 95% confidence level over 1% of the zonal area. Increasing trends at the east and both increasing and decreasing trends at the west over 36% of the zone had been observed at less than 95% confidence level and remaining area of the zone had experienced insignificant trends for annual rainfall. Increasing trends were observed for September to November rainfall over 2% of the zone in the eastern part with confidence level of greater or equal to 95%; 6% of the zone in the central and eastern part with confidence level of less than 95% and remaining 92% of the zone had experienced insignificant trends.

For June to August rainfall, only 1% of the land area at north western part of the zone had experienced decreasing trends at greater or equal to 95% confidence level; 6% of the zone had experienced decreasing trend at less than 95% confidence level. Overall, it indicated that most of the land area of the zone had experienced insignificant changes for both annual and all seasonal rainfalls. The findings are consistent with those reported by previous studies. [8] have found no significant changes and trends in annual rainfall at the national or watershed level in Ethiopia. Study conducted by [19] has also reported annual and seasonal rainfall decreasing trends with and without statistical significance at different stations/areas in Arid and Semi-Arid areas of Ethiopia.

3.3 Maximum Temperature Variability and Trends of Stations in Gamo Gofa

In Table 3, the normalized anomalies of average maximum temperature of stations show the presence of cool and warm years in the study area. For most of the stations in the study area, 2000s were warmer than 1990s. Higher warming was observed at the end of 2000s at Arba Minch and Mirab Abaya. Moreover, continues warming was seen at most of the stations in 2000s. However, cooler years than the 20 years average were observed in 2010 at Chencha, Kamba, Daramalo, Sawla, Beto and Melokoza.

Table 1. Normalized anomaly of annual rainfall for stations in Gamo Gofa zone

Year	Bulki	Mirab Abaya	Lote	Morka	Arba Minch	Chencha	Sawla	Geresse	Kamba	Beto	Melo Koza	Dara Malo
1991	0.38	-1.64	-0.37	-0.72	-0.99	0.10	0.04	-0.73	-2.15	-0.13	-0.34	-1.58
1992	1.81	-2.07	1.55	-0.40	0.22	-0.73	-0.13	-0.85	-1.01	-0.19	0.26	-0.98
1993	-0.85	0.01	2.83	0.33	-0.40	-0.25	-0.10	-0.61	-0.93	-0.31	0.09	-1.04
1994	0.58	-0.63	1.39	0.67	-0.96	-0.06	-1.04	0.60	1.44	-0.83	-0.90	-0.12
1995	0.61	-0.37	-0.04	-1.04	-0.04	0.06	-0.83	2.03	1.15	-0.57	-0.78	-0.47
1996	0.06	0.21	0.77	0.77	-0.79	-0.36	0.44	2.26	0.67	0.13	0.23	0.58
1997	2.22	2.39	-0.11	1.10	1.93	2.41	2.18	0.36	-0.15	1.44	1.79	2.33
1998	0.16	0.95	0.32	1.10	1.93	2.41	0.84	0.36	-0.15	0.48	0.80	2.33
1999	-0.77	-0.92	0.19	-1.80	-0.97	-1.09	-1.38	-1.31	-0.02	-0.96	-1.30	-0.99
2000	-0.37	0.02	0.06	-0.96	-0.43	-0.20	-0.13	-1.01	-0.29	-0.18	0.08	-0.70
2001	1.04	0.07	-0.07	0.60	0.88	0.64	-1.90	-0.43	0.85	-0.87	-0.67	0.23
2002	-0.40	-0.83	-0.20	-0.91	-0.77	0.18	-2.00	-1.41	-0.89	-1.30	-1.69	-0.35
2003	-0.12	0.06	0.30	0.51	-0.35	-0.96	-0.86	-0.80	0.15	-0.65	-0.88	0.01
2004	-0.39	0.11	-0.46	-1.53	-1.14	-1.42	0.09	-0.38	-1.90	-0.14	-0.18	-0.77
2005	-0.03	0.37	-0.59	-0.39	-0.04	-0.91	-0.14	-0.34	0.95	-0.14	-0.05	0.25
2006	-0.36	1.10	-0.73	1.74	1.16	0.40	1.14	0.87	-0.22	0.52	0.88	0.37
2007	-2.26	0.79	1.00	0.26	1.67	0.80	0.78	0.60	1.43	0.43	0.24	0.45
2008	0.18	-0.64	-0.99	-1.01	0.22	-0.21	0.61	-0.16	0.32	0.42	0.42	-0.31
2009	-0.19	0.94	-1.12	0.67	-0.56	-0.38	-0.02	0.73	0.35	-0.06	0.16	0.31
2010	-1.31	0.07	0.50	1.00	-0.59	-0.44	1.33	0.22	0.39	0.69	0.86	0.41

Table 2. Trends and statistical significance of annual and seasonal rainfall at stations in Gamo Gofa

Station name	Annual		MAM		JJA		SON		DJF	
	Trend	Test statistic	Trend	Test statistic	Trend	Test statistic	Trend	Test statistic	Trend	Test statistic
Arba Minch	31	0.55^{NS}	5	0.1^{NS}	9	0.2^{NS}	15	0.6^{NS}	3	0.6^{NS}
Beto	65	1.46^{NS}	-3	0.3^{NS}	53	0.7^{NS}	9	1.2^{NS}	47	1.5^{NS}
Bulki	-144	1.9^{**}	-92	1.6^{*}	-53	1.7^{*}	4	0.2^{NS}	-3	0.0^{NS}
Chencha	-98	0.52^{NS}	10	0.3^{NS}	-84	1.7^{*}	-79	0.3^{NS}	-5	0.1^{NS}
Daramalo	85	1.95^{**}	8	0.4^{NS}	45	1.7^{*}	50	2.1^{**}	25	1.6^{*}
Geresse	26	0.84^{NS}	8	1.1^{NS}	-143	0.7^{NS}	121	1.2^{NS}	40	0.7^{NS}
Kamba	69	1.3^{NS}	7	0.6^{NS}	47	1.1^{NS}	-26	0.7^{NS}	5	0.2^{NS}
Lote	-116	4.8^{***}	-67	0.9^{NS}	-123	2.6^{***}	-76	0.1^{NS}	-57	1.2^{NS}
Melokoza	60	1.59^{*}	-4	0.1^{NS}	14	0.6^{NS}	10	1.3^{NS}	40	0.8^{NS}
Mirab Abaya	119	2.1^{**}	15	0.0^{NS}	10	0.3^{NS}	65	2.7^{***}	29	1.3^{NS}
Morka	37	0.62^{NS}	-5	0.3^{NS}	15	0.5^{NS}	5	0.8^{NS}	22	0.5^{NS}
Sawla	64	0.6^{NS}	-3	0.3^{NS}	53	0.7^{NS}	9	0.8^{NS}	46	0.5^{NS}

*Trend: Magnitude of trend/decade, NS: Non-significant, * Significant at 0.1 level, ** Significant at 0.05 level, ***Significant at 0.01 level as to Mann Kendall trend test*

Table 3. Trends of annual and seasonal average maximum temperature at stations in Gamo Gofa

Station name	Annual		MAM		JJA		SON		DJF	
	Trend	Test statistic	Trend	Test statistic	Trend	Test statistic	Trend	Test statistic	Trend	Test statistic
Arba Minch	0.09	1.78^{*}	0.05	0.097^{NS}	0.05	0.68^{NS}	0.11	1.33^{NS}	0.06	0.03^{NS}
Beto	0.4	1.78^{*}	0.29	0.81^{NS}	0.4	2.43^{**}	.11	0^{NS}	0.36	0.34^{NS}
Bulki	0.2	3.1^{***}	0.10	2.1^{**}	0.15	4.02^{****}	0.06	0.58^{NS}	0.16	1.36^{NS}
Chencha	0.18	1.59^{*}	0.18	0.68^{NS}	0.06	0.91^{NS}	0.05	0.49^{NS}	0.3	1.51^{NS}
Daramalo	0.24	1.78^{*}	0.28	0.81^{NS}	0.4	2.43^{**}	0.11	0^{NS}	0.26	0.23^{NS}
Geresse	0.24	1.95^{**}	0.16	1.46^{NS}	0.17	3.5^{***}	0.24	2.56^{***}	0.22	1.95**
Kamba	0.38	2.37^{**}	0.40	1.72^{*}	0.2	0.62^{NS}	0.18	0^{NS}	0.25	1^{NS}
Lote	0.18	1.66^{*}	0.27	0.88^{NS}	0.01	0.69^{NS}	0.03	0.097^{NS}	0.36	1.33^{NS}
Melokoza	0.36	2.11^{**}	0.35	1.46^{NS}	0.37	2.1^{**}	0.11	0.03^{NS}	0.39	0.03^{NS}
Mirab Abaya	0.12	0.26^{**}	0.05	0.097^{NS}	0.06	0.26^{NS}	0.12	1.3^{NS}	0.2	0.42^{NS}
Morka	0.17	1.2^{NS}	0.08	0.097^{NS}	0.14	1.2^{NS}	0.05	2^{**}	0.09	0.811^{NS}
Sawla	0.25	2.11^{**}	0.34	1.2^{NS}	0.33	2.17^{**}	0.14	0.2^{NS}	0.24	1.17^{NS}

*Trend: Magnitude of trend/decade, NS: Non-significant, * Significant at 0.1 level, ** Significant at 0.05 level, *** Significant at 0.01 level as to Mann Kendall trend test*

For all stations in the zone, annual and seasonal mean maximum temperature showed warming trends. Except at Mirab Abaya and Morka, all stations had shown significant warming trends for annual time scale (Table 3). For seasonal time scales both significant and insignificant warming trends were observed. Statistically significant trends were observed for June to August season for six stations (Beto, Bulki, Daramalo, Geresse, Melokoza and Sawla). Other seasonal maximum temperature also shown significant warming trends for one to two stations only. The warming trend is as low as 0.01℃/decade at Lote (insignificant) and as high as 0.4ºC/decade at Beto and Daramalo (significant) for June to August. [20] mentioned a 0.1ºC/decade increment of annual average maximum temperature over Ethiopia. [7] reported mean annual temperature rose by 0.28ºC /decade between 1960 and 2006 in the country. [21] found an increase in the difference of average maximum temperature between 2 decades 1987 to 1999 and 2000 to 2011 using 4 stations in the study area indicating the existence of warming trends.

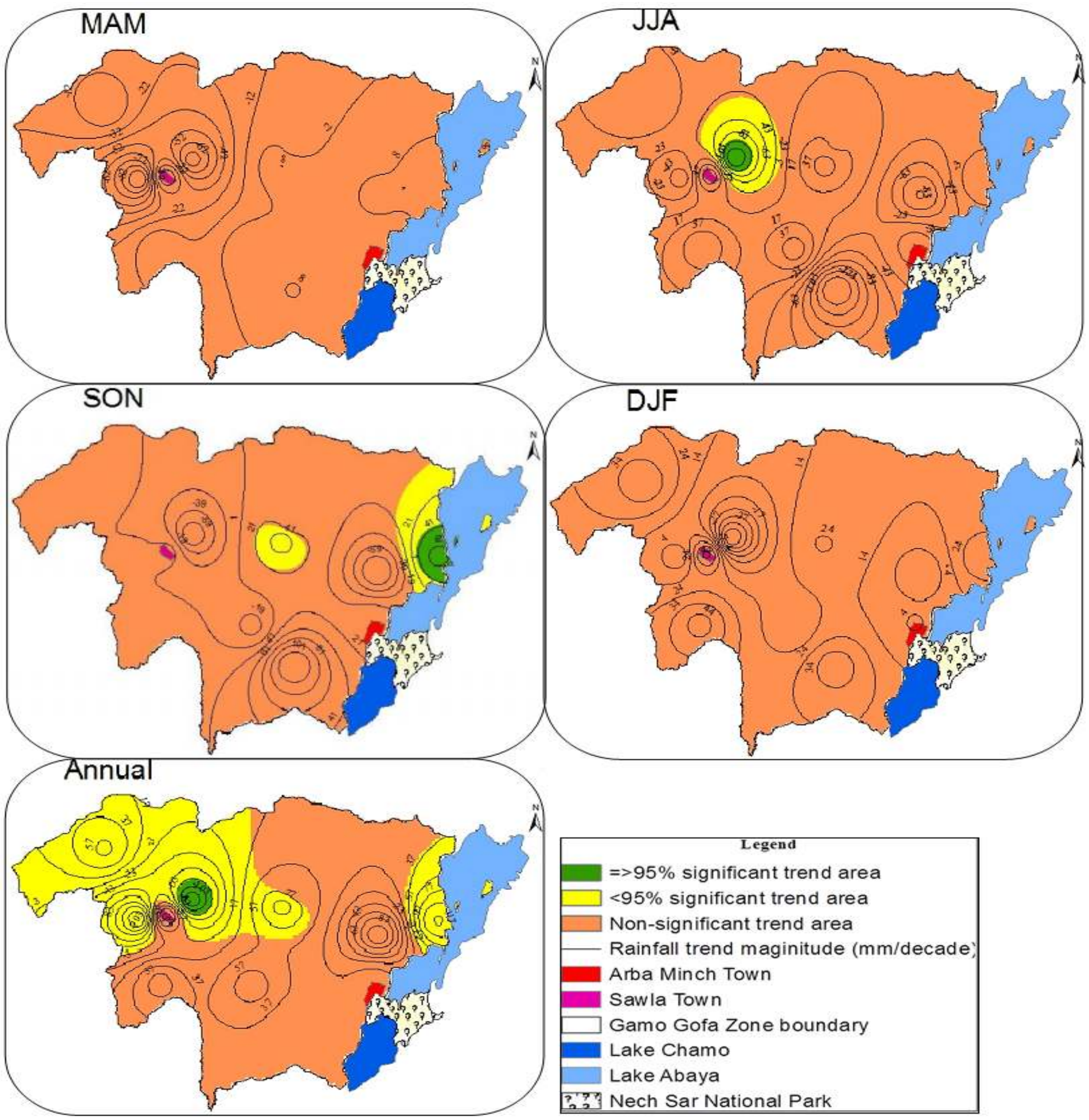

Fig. 3. Spatiotemporal trends in rainfall over Gamo Gofa zone, 1991-2010

3.4 Maps of Maximum Temperature Trends

For annual time scale maps of maximum temperature had shown warming trend over 50% of the north and south western parts of the zone with statistical confidence level of greater than 95%; 29% of the land area of the zone had experienced warming with statistical confidence of less than 95% and remaining 21% area over the northeast of the zone experienced non-significant warming trends. March to May and June to August mean maximum temperatures had shown statistically significant warming trends with greater or equal to 95% confidence level respectively over 2% and 42% of the zone. Statistically significant warming trends with less than 95% confidence level were observed over 13% area for March to May, 20% area for June to August, 2% area for September to November and 2% area for December to February seasons. The remaining part of the zone had experienced warming trends without statistical significance. The study indicated that considerable area of the zone had experienced warming trends of average maximum temperature with statistical significance for annual and June to August season. A study conducted by [16] reported that maximum temperature has experienced both significant and non-significant trends over different areas of western Amhara. [13] obtained both warming and cooling trends of mean maximum temperature for annual and seasonal timescales over upper Blue Nile River Basin of Ethiopia. The results imply that there may have some influences of temperature on especially cold weather crops (like wheat and barley) production and their geographic distributions.

3.5 Minimum Temperature Variability and Trends of Stations in Gamo Gofa

Variability of minimum temperature had shown both warm and cool years over the past two decades in 1991 to 2010. It had shown continues warm years at Mirab Abaya, Geresse, Morka, Lote and Chencha and cool years at Melokoza, Sawla, Beto, Kamba and Daramalo in 2000s than 1990s. Trends of mean annual and seasonal minimum temperature showed that except at three stations in the zone (Arba Minch, Morka and Bulki) statistically significant warming and cooling trends were observed for annual time scale. Significant cooling trends were obtained at two stations (Sawla and Daramalo) while seven stations (Mirab Abaya, Geresse, Melokoza, Beto, Kamba, Lote and Chencha) experienced significant warming trends. The warming was obtained between 0.04ºC/decade at Arba Minch (insignificant) and 0.44ºC/decade at Mirab Abaya (significant). For Seasonal time scales both significant and insignificant warming and cooling trends were observed. [20] mentioned a 0.25ºC\decade increment of annual average minimum temperature over Ethiopia. 0.37ºC/decade increment of annual minimum temperature was reported by [6] over the past 55 years in the country.

3.6 Maps of Minimum Temperature Trends

For annual minimum temperature both warming and cooling trends were observed over 91% area of the zone with statistical confidence level of greater than or equal to 95%. For March to May season, 22% of the zone at western and north western parts had both warming and cooling trends while eastern parts experienced warming trends at greater or equal to 95% confidence level; 14% of the area experienced warming and cooling trends at most of the northern, central and southern parts of the zone at less than 95% confidence level. For June to August season 62% of the zone over northern parts had experienced warming and cooling trends with statistical significance. For September to November season, 24% of the zone showed warming trends at confidence level of greater or equal to 95%; 13% of the zone was experiencing warming at less than 95% confidence level. For DJF, cooling trends at the west and warming trends at east of the zone over 26% of its area were observed with statistical significance. Similar warming and cooling trends were obtained by [13] for both annual and seasonal mean minimum temperature over the upper Blue Nile River Basin of Ethiopia. A study conducted by [8] reported that minimum temperature has experienced significant increasing trends over different areas of western Amhara.

4. CONCLUSIONS

Normalized anomaly of annual rainfalls showed variability of dry and wet years at all stations and high inter-station variations. Annual, June to August and September to November rainfalls showed both significant decreasing and increasing trends at different stations. Generally most of the land area of the zone had experienced insignificant trends for both annual and all seasonal rainfalls. Normalized anomaly of mean maximum and minimum temperature showed 2000s were warmer than 1990s at most of stations in the zone. Mean annual and seasonal maximum temperatures at all stations in the zone showed warming trends. The study pointed out that 79% and 62% land area of the zone had experienced significant warming trends respectively for annual and June to August. Regarding mean minimum temperature, significant cooling trends were obtained at Sawla and Daramalo while significant warming trends were obtained at Mirab Abaya, Melokoza, Geresse, Beto, Kamba, Lote and Chencha. Thus, significant land of the zone had experienced both warming and cooling trends of minimum temperature for annual and seasonal timescales. The result signifies that it may trigger failure of agricultural production that necessitates developing and implementing systematic planning and management activities in the study area and in the country for the major crop calendar.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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