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Spatio-temporal Variability and Trends in Rainfall and Temperature in Anger watershed, Southwestern Ethiopia

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Abstract

Insights to broadly argued research gap on lack of climate studies at micro-scale considering unique features of an area, this paper intended to examine agro-ecological level spatio-temporal trends and variability in rainfall and temperature in Anger watershed of southwestern Ethiopia. The gridded data managed by the Ethiopia National Meteorological Services Agency (NMSA) for 1983-2018 were used. The Mann-Kendall test for trend analysis and different variability measures were used. Questionnaire and FGD data on community perceptions gathered from 214 households and elders were analysed descriptively and qualitatively. The study reveals the consistent increasing trends in temperature; and high variability and insignificant but increasing rainfall trend. The trends and variability show spatio-temporal differences along agro-ecologies. The watershed is characterized by moderate to high rainfall coefficient of variations, significant years of high rainfall concentration, and considerable negative annual rainfall anomalies; that the variability was severe in woinadega followed by kolla agro-ecology. Although, the perceptions on trends, variability and its implications show difference across agro-ecology, the propensity to increased temperature, unclear rainfall trend and significant inter-annual and seasonal variability were witnessed. Unpredictability of rainfall time, concentrations in kiremt, and unexpected rain during harvesting was major challenges resulting multifaceted impacts on the small-scale farmers' livelihoods.

Keywords: *Climate variability, Trend analysis, Variability analysis, Community perceptions*

1. Introduction

Climate change, associated variability in temperature and rainfall is rapidly unfolding challenge for agrarian community; and have been resulting wide range socioeconomic and environmental problems mainly among poor small scale farmers (Aji *et al.,* 2018; Henderson *et al.,* 2018). Although, the trend is inconsistent and characterized by complex geographical dimensions; the tendency is toward increased in temperature and decreased in rainfall since the mid-twenties century (Chen *et al.,* 2013); and significant spatiotemporal variability with general increase in temperature by 0.72 ºC, increasing rainfall by 0.5-1.0% at mid and high latitude to decline at low latitude at the rate of 0.3% (Deliang *et al.*, 2013). For Africa, the trends have been toward increasing temperature and increasing but inconsistent trends in the rainfalls. In the recent decades, the variability in rainy seasons characteristics to more intense and intermittent; for instance, concentrated wetting in the late rainy season. Particularly, significant increases in temperature and spatio-temporal variability in rainfall such as occurrences of dry spells, seasonal droughts and episodes of torrential rainfall with heavy runoff and flooding are recently more frequent in the east Africa than in the past (Biasutti 2019; Ruppel *et al.*, 2014; Serdeczny *et al.,* 2016).

The evidences for Ethiopia indicated less consistency mainly in rainfall trends; and the general trend has been a tendency in lower rainfall, year to year increase in rainfall variability and extremes; and general increase in temperature have been reported in most parts of the country. The seasonal and monthly state of rainfall have been showing remarkable spatio-temporal variability (Amogne et al. 2018; Arragaw and Woldeamlak 2017; Asaminew and Diriba 2015; Befikadu et al. 2019; Convey and Schipper 2011; EPCC 2015; Fazzini, Bisci, and Billi 2015; Feyisa 2017; Jury and Funk 2013; Magarsa and Budiastuti 2020; McSweeney 2012; Melkamu and Getnet 2019; Messay, Degefaa, and Gezahegn 2017; Shiferaw *et al.,* 2014; Solomon et al. 2015; Tagel, Veen, and Van 2013; Wagaye and Endalew 2020; Woldeamlak 2009).

Climate system of Ethiopia is strongly influenced by topography, seasonal migration of the Inter-Tropical Convergence Zone (ITCZ) and associated atmospheric circulations(Dinku et al. 2014; EPCC 2015; McSweeney 2012) Spatially, the country has a diversified climate ranging from semi-arid desert (bereha) type in the lowlands to cool (wurch) type in the mountainous area >3300m amsl; which traditionally classified in to five agro-ecological zones. Mean annual rainfall distribution has maxima (>2000 mm) over the Southwestern highlands and minima (<300 mm) over the South eastern & North eastern lowlands. Mean annual temperature ranges from < 150C over the highlands to > 250C in the lowlands. Ethiopia has three seasons based on rainfall occurrence namely; bega/dry season, belg/short rainy season and kiremt/long rainy season (Few *et al.,* 2015). Particularly, the study area entertains in three agro-ecologies: warm lowland(kolla) having altitude less than 1500m amsl situated in central part of the watershed; midland (woinadega) having altitude 1500m-2300m amsl in northern and southern half of the watershed; and cool temperate (dega) in the mountainous areas of the watershed. These diversified climate state have significant socio-economic and environmental opportunities. However, empirical evidences have been warning that present global climate changes have knocking the ecological and livelihoods systems of the country; and the study area is not exceptional.

The empirical observations conducted at national level implied a significant spatial difference on the extents of the climate variability (Biasutti 2019; Chris et al. 2010; Convey and Schipper 2011; EPCC 2015; Fazzini, Bisci, and Billi 2015; McSweeney 2012); and the magnitudes of impacts on human and natural systems(Emerta 2013; Mintewab, Salvatore, and Alemu 2014; Zenebe *et al.,* 2014) in the country. Therefore, examining the rainfall and temperature trends and variability at micro-scale with unique biophysical characteristics along agro-ecology has paramount importance to understand the spatial variations in change/variability and differential impacts.

The reviewed empirical research for this paper revealed that spatially most of studies were focused in the northern and central highlands; and some in the rift valley and arid and semi-arid parts of eastern and south eastern Ethiopia; while the studies in southwestern highlands and low lands of Ethiopia are overlooked. Moreover, scholars argue that although the knowledge on climate change is growing fast, it is merely organized in the way suitable to integrate with other global change processes in assessing the impacts (Barnett 2020). Among others, the problems are associated with lack of climate studies at micro scale considering unique features of an area, and convoluted concepts and methodologies in integrating the knowledge with site specific non-climatic stressors. Therefore, the study was intended to examine climate situations at agro-ecological level in the watershed focused on comparative analysis trends and variability along agro-ecologies vitally to integrate the knowledge with other site specific non-climate stressors to contribute for the recent research on human dimensions of global change processes impacts (Antwi-Agyei et al. 2018).

Particularly, there are a number of reasons why site-specific climate analysis take due concerns for small scale farmers of Ethiopia. The main natural resources and associated assets are very much the reflection of the unique conditions they have, entail their socioeconomic activities and the main stay economy are sensitive to variability manifested. Thus, identifying agro-ecological based rainfall and temperature trends, seasonal changes and occurrence of extreme events has paramount importance. Specifically, the study was ascertained to analyse the status of rainfall and temperature, the long-term trends and variability across agro-ecologies and assess the community perceptions on trends, variability and the impacts on their livelihoods.

2. Research Methods and Materials

2.1 Background and contexts

Anger river watershed lies in east Wallagga administrative zone extended from 09º12' to 10º00' north and 36º30' to 37º11' east were the focus the study. The area within a single administrative zone was selected to reduce the heterogeneity due to administrative difference; to pinpoint magnitude and spatial variations of vulnerability of household within the same administrative; while the situation is place-based and context specific that the households' exposure to the stressors such as climate variability along agro-ecologies; and the historical socio-economic and natural resources access could be complex if the entire watershed is included in the study.

The study area is composed of various land forms with altitudinal ranges of 1200-3018 meters above sea level. The mean annual temperature ranges between 140c to 250c; and average annual rainfall is also between 1000 mm to 2400 mm. The rainfall shows mono-modal pattern and more than 80% of which occurs between May and October. Numbers of rivers and streams drain the watershed. There are different types of soils found in the zone.

The micro-scale climate, soil types, varied species of forest ecology, wild animals and other natural resources supported vast livelihood options and shaped the socio-economic and demographic characteristics of the region on top of historical national and global change processes. Currently, about 82.3% of total population are rural dwellers directly engaged in agriculture. Different types of crops such as cereal, pulses and oil seeds are produced largely throughout the study area. livestock rearing, beekeeping and direct exploitations of natural resources play a key role in the peasant sector. The area is characterized in poor infrastructure that the road quality/and network density is low; less than half of the rural population has supplied potable water; source of energy is limited to firewood, animals dung, crop residues and charcoal(FED 2014).

2.2 Research methods

2.2.1 Research design

The climate change and variability are reality which permanently exist and impacting the local community when abnormal; and the change become beyond the adaptive capacity of a system (Gray 2017). Thus, study of the change and variability has paramount importance to mitigate, adapt and reverse the adverse impacts. To this end, the paper is designed to examine rainfall and temperature trends, variability and extreme events at agro-ecological level in the study area. The study consists an array of issues from objectively analysing the long-term trends and variability to construct the reality through in-depth explanations of community's perceptions. Thus, the research problems demand mixed research method approach, guided by survey design due to its appropriateness with identified approach and fitness to objectives of the study, the type of data, methods of data collections and analysis. It comprises the systematic gathering and analysis of data through different instruments including gridded data of rainfall and temperature from Ethiopia National Meteorological Services Agency (NMSA) in addition to tools for households' survey.

2.2.2 Sources of data

The multiple eco-system services model (Hennemuth et al., 2015; Nael and Papilaya, 2019) arguments for context specific and objective oriented climate variability and change analysis was applied in the study. Thus, measurements of trends and variability appropriate to evaluate the impacts on the immediate agricultural activities and exploitation of natural resources in the region imply for small scale farmers were chosen.

The gridded data of rainfall and temperature for the study area managed by the Ethiopia National Meteorological Services Agency (NMSA) were used. The data are reconstructed at 10×10 km resolution from weather stations records and meteorological satellite observations by NMSA in collaboration with International Research Institute for Climate and Society to solve the limitations of both sources in climate analysis. The studies on scientific climate data and users for empirical researches recommended gridded data particularly in developing countries. First, weather stations are limited in number, unevenly distributed and situated in urban areas. Second, meteorological satellite observations suffer from heterogeneous time series, short period of observations, and poor accuracy due to low resolutions. Most importantly, our research objective demands accurate representation of the real spatiotemporal variability inputs; which severely limited in the above sources, and spatially interpolated data is subject to large uncertainties(Bigiarini et al. 2017; Dinku et al. 2014). To this end, through discussion with experts in NMSA, the time series data for 35 (1983 to 2018) years for monthly rainfall and the monthly maximum and minimum temperature of the same period was used. Moreover, data for community perceptions on climate change/variability and impacts were gathered from sampled household heads of above 45 years (n=214) drawn from kebeles representing each agro-ecology through questionnaire and elderly farmers through FGD (one group for each agro-ecology were facilitated; having eight members per group).

2.2.3 Methods of analysis

Both methods of trend and variability analysis were used. Trend analysis was conducted by Mann-Kendall statistical test method. The Mann-Kendall test method is non-parametric which has several advantages over parametric and suitable for the study. It does not require the data to be normally distributed, it is appropriate for analysing trends in data over time, and has low sensitivity to abrupt breaks due to inhomogeneous time series(Feng *et al.* ,2016; Tímea, Kovács-Székely, and Anda 2017).

Table 1. Research materials and techniques

Data	Sources	Techniques
monthly rainfall (1983-2018)	Global Precipitation and Climate Centre (GPCC V7), Ethiopian NMSA	Mann-Kendall test
		Rainfall CV, SRA, PCI
monthly max. & min. temperature (1983-2018)	Climate Research Unit (CRU TS 3.23), Ethiopian NMSA	Mann-Kendall test
		standardized temperature anomalies
Questionnaire and FGD	Household survey	Descriptive statistics
		Qualitative method

The Mann-Kendall Statistic measures the trend in the data. Positive (+) values indicate an increase in constituent concentrations over time, whereas negative (-) values indicate a decrease (Mudelsee and Wegener, 2010). The strength of the trend is proportional to the magnitude of the Mann-Kendall Statistic (large magnitudes indicate a strong trend). The Mann-Kendall statistics "S" is calculated by the following formula:

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} sgn\,(Xj - Xi) \quad (1)$$

Xj and Xk are annual value in year j and k, where j>k respectively

$$sgn(Xj - Xk) = \begin{cases} 1\ if\ Xj - Xk > 0 \\ 0\ if\ Xj - Xk = 0 \\ -1\ if\ Xj - Xk < 0 \end{cases} \quad (2)$$

The variance statistic is given as:

$$VAR\ (S) = \frac{1}{18}[n(n-1)(2n+5) - \sum_{p=1}^{q} tp\,(tp - 1)(2tp+5)] \quad (3)$$

Here q is the number of tied groups and tp is the number of data values in the pth group. Finally, the values of S and VAR(S) are used to compute the test statistic Z as follows:

$$Z = \begin{cases} \frac{S-1}{\sqrt{VAR(S)}} if\ S > 0 \\ 0 \quad if\ S = 0 \\ \frac{S+1}{\sqrt{VAR(S)}} \ if S < 0 \end{cases} \quad (4)$$

The presence of a statistically significant trend is evaluated using the Z value. A positive (negative) value of Z indicates an upward (downward) trend. The statistic Z has a normal distribution.

Among methods of variability measures the coefficient of variations, standardized anomalies/percentage departure from mean and precipitation concentration index were applied.

Coefficient of Variations (CV) was used to evaluate the variability of rainfall in the study area along different agro-ecology. A higher value of CV is the indicator of larger variability, and vice versa which is computed as:

$$CV= σ/μ*100 \quad (5)$$

Where; CV is the coefficient of variation; σ is standard deviation and μ is the mean precipitation. The degree of variability of rainfall events are assigned as less variable (CV < 20), moderate (20 < CV <30), and high (CV >30) (Befikadu *et al.,* 2019; Dinku *et al.,* 2014).

Precipitation Concentration Index (PCI) was used to examine the variability or heterogeneity pattern of rainfall at annual or seasonal scale. The annual PCI is computed as follows:

$$PCI_{annual} = \frac{\sum_{i=1}^{12} Pi^2}{(\sum_{i=1}^{12} Pi)^2} \quad (6)$$

Where: Pi = the rainfall amount of the ith month. The PCI values for uniform monthly distribution of rainfall (low precipitation concentration) is less than 10, values between 11 and 15 denote moderately distributed rainfall concentration, 16 to 20 indicates high concentration, ≥ 21 indicate very high concentration.

The standardized anomalies of rainfall were used to examine the nature of the rainfall trends, to identify the dry and wet years and to assess frequency and severity of droughts.

$$Z = \frac{(Xi-\bar{X})}{s} \quad (7)$$

Where, Z is standardized rainfall anomaly; Xi is the annual rainfall of a particular year; $\bar{X}$ is a long term mean annual rainfall over 35 years and 's' is the standard deviation of annual rainfall over 35 years. The drought severity classes are: extreme drought (Z < -1.65), severe drought (-1.28 > Z > -1.65), moderate drought (-0.84 > Z > -1.28) and no drought (Z > -0.84) (Amogne *et al.,* 2018)

3. Results and Discussions

The Analysis of 35 years mean monthly rainfall and monthly minimum and maximum temperatures from about 166 grid points were used to cover the watershed. The points were taken based on area proportion of the agro-ecologies and represented 10×10km areas. Accordingly, 94 for kolla, 13 for dega and 59 points for woinadega.

The spatial variations in distribution of annual rainfall, and mean annual minimum and maximum temperature were observed in the watershed (Figure 1). The woinadega areas in the northern parts of the watershed particularly Gida Ayana and Kiramu districts experienced highest mean annual rainfall; while kolla in southern part of Gida Ayana and western part of Kiramu; and woinadega in Guto Gida, Limu, northern Bila Sayo districts in central and southern parts of watershed have relatively medium annual rainfall pattern and southwestern parts of Sibu Sire and Bila Sayo districts showed lowest mean annual rainfall of the watershed. The lowest mean annual minimum and maximum temperature were observed in dega areas particularly around Ilfata mountain of Wayu Tuka and highlands of Gida Ayana and Kiramu districts; while extensive part of kolla agro-ecology shows highest mean annual minimum and maximum temperature in the watershed (Figure 1).

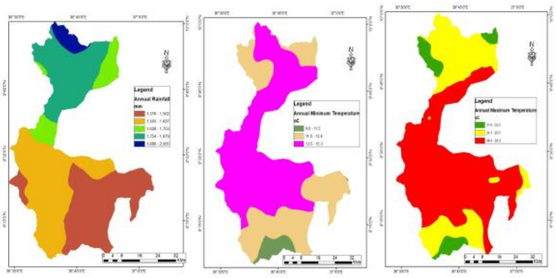

Figure 1: Spatial distributions of annual rainfall, annual minimum and annual maximum temperature in Anger watershed from left to right respectively

3.1 Rainfall patterns, trends and variability across agro-ecologies

Rainfall pattern and trends

The watershed receives mean annual rainfall of 1577mm which ranges from 1493mm in dega to 1873mm in woinadega while 1520mm in kolla agro-ecology. Kiremt (JJAS) is the major rainy season for all agro-ecology, contribute 56.2%, 55.2% and 56.0% of total annual rainfall for dega, woinadega and kolla respectively. Nearly, half amount of annual rain in woinadega contributed by rain in two months (July and August) while the distribution is relatively uniform among rainy months of dega and kolla (Table 3).

The trends of rainfall show substantive spatio-temporal differences in the watershed (Table 2). On monthly base, March and December shows decrease in rainfall trend; while January, May, June and November exhibit increasing trends for the entire watershed. However, significant increase ($p<0.05$) was observed in June and September for dega; while both woinadega and kolla experienced significant increase ($p<0.05$) only in September. This implies that September is the only month with significant increase in rainfall in the entire watershed. Although, July contributes highest percentage of annual rainfall for the entire watershed, the decreasing trend was recorded in kolla and dega; but significant ($p<0.05$) in dega agro-ecology in the month. However, it doesn't show decreasing impact on the aggregate kiremt rainfall of the agro-ecology.

Table 2: Rainfall trends across agro-ecology in Anger watershed (1983-2018)

Note: *, ** and ** statistically significant at 0.1, 0.05 and 0.01 alpha level of significance respectively.

The trends of rainfall across agro-ecologies on seasonal base show remarkable differences. The belg (MAM) rain shows increase for both dega and kolla; while decrease for woinadega, but not statistically significant.

Month/ Season	Agro-ecology					
	Dega		***Woinadega***		***Kolla***	
	MK-test	Sen's Slope	MK-test	Sen's Slope	MK-test	Sen's Slope
Jan	0.774	0.00	0.757	0.00	0.996	0.03
Feb	-1.045	-0.08	1.045	0.02	-0.374	-0.02
Mar	-0.503	-0.34	-0.308	-0.13	-0.130	-0.05
Apr	0.535	0.45	-0.438	-0.53	0.276	0.26
May	0.989	1.45	1.378	2.53	0.681	1.09
Jun	**1.719***	1.42	0.519	0.62	1.151	0.86
Jul	**-2.092***	-1.69	0.892	0.95	-1.476	-0.99
Aug	0.130	0.15	1.605	1.89	-0.438	-0.25
Sept	**2.044****	1.23	**2.124****	2.28	**1.800***	0.92
Oct	0.373	0.38	0.000	-0.03	-0.049	-0.06
Nov	0.324	0.14	1.492	0.59	0.535	0.23
Dec	-0.462	0.00	-0.989	-0.07	-0.804	-0.06
Belg	0.276	0.45	-0.178	-0.36	0.114	0.11
Kiremt	0.016	0.05	**1.854***	1.76	**1.776***	0.33
Annual	1.168	0.25	**2.368****	0.73	0.778	0.17

but significant only in woinadega agro-ecology (Table 2).

The findings for the trends of kiremt were agree with the results from great rift valley basins, central highlands, Amhara region, north central highland and north eastern Ethiopia((Amogne *et al.* , 2018; Arragaw and Woldeamlak 2017; Fitih *et al.,* 2019; Wagaye and Antensay 2020; Woldeamlak 2009). However, most of them reported negative trends for belg which fit with the condition in woinadega in our study area; In general, spatially disaggregated analysis of rainfall trends along agro-ecologies revealed the persistence of significant difference contributed by variations at micro scale in the watershed.

Rainfall variability

Variability measures are important to comprehend monthly, seasonal and annual variations and distribution of rainfall which has paramount importance due to the fact that rain fed agrarians are sensitive to these variabilities. To this end, rainfall coefficient of variations (Table 3); annual precipitation concentration index and annual standardized rainfall anomaly (Table 4) and seasonal standardized rainfall anomaly (Figure 2) were analysed for all agro-ecology separately and comparison was made.

Except for June, July, August and September (CV<20); all months have shown high rainfall variations with considerable difference across agro-ecologies. Moreover, the variations observed in January, February and December in kolla and woinadega was exceptionally highest with remarkable difference along the cases; because these months are the driest (i.e., consisted in bega season) in the watershed.

Table 3: Agro-ecology based rainfall coefficients of variability in Anger watershed (1983-2018)

Month	**Agro-ecology**								
	Dega			**Woinadega**			**Kolla**		
	Mean	SD	CV (%)	Mean	SD	CV (%)	Mean	SD	CV (%)
January	9.2	11.9	129.6	3.3	6.0	180.7	5.9	7.8	132.2
February	9.6	13.6	142.0	5.8	9.5	163.9	7.6	10.1	132.3
March	47.6	35.1	73.7	30.2	27.2	90.0	44.5	33.7	75.7
April	73.1	48.8	66.8	60.3	53.1	88.1	64.4	41.9	65.0
May	166.0	72.2	43.5	214.0	97.3	45.5	174.0	69.8	40.1
June	274.4	52.4	19.1	310.2	59.4	19.1	264.0	33.9	12.9
July	284.4	50.2	17.6	374.1	46.2	12.3	302.1	38.3	12.7
August	283.6	53.9	19.0	369.4	56.4	15.3	293.4	48.4	16.5
September	193.5	31.8	16.4	342.5	57.3	16.7	220.0	31.5	14.3
October	105.1	71.3	67.8	124.8	69.1	55.3	104.2	68.5	65.7
November	27.4	23.9	87.4	27.7	21.3	77.0	27.2	19.6	72.0
December	14.0	24.9	177.8	10.3	14.3	139	12.9	21.3	165.2
Belg	95.6	52.0	61.3	101.5	59.2	74.5	94.3	48.5	60.3
Kiremt	259.0	47.1	18.1	349.1	54.8	15.9	269.9	38.0	14.1

The kiremt was characterized with increase in rainfall for all agro-ecologies, but significant at p<0.1 for woinadega and kolla. Moreover, there is increase in mean annual rainfall for entire watershed

Conversely, kiremt was characterized by less variability for all agro-ecologies (CV<20) while belg experienced high variability with notable difference between dega and kolla (CV≈60) on one hand and woinadega (CV=74.5) on the other hand (Table 3). Although, the highest coefficient of variations observed from December to February was agree with previous results (Amogne et al., 2018; Ashenafi, Bazezew, and Kebede 2013; Befikadu *et al.,* 2019; Birhan 2018; Daniel 2011; Fazzini, Bisci, and Billi 2015; Feyisa 2017; Fitih *et al.,* 2019; Solomon *et al,.* 2015; Woldeamlak 2009) the time is more extended in other parts of Ethiopia mostly from October to February in north, north central, central, southern, rift valley and north eastern.

The watershed is characterized by moderate and high rainfall concentration with considerable difference across agro-ecology (Table 4a). High concentration was observed in woinadega followed by kolla. The dega agro-ecology is relatively characterized by moderate rainfall concentration. The same spatial variations in rainfall concentration were observed in south and south-eastern Ethiopia (Magarsa and Budiastuti 2020; Messay, Degefaa, and Gezahegn 2017) comparable to dega of our study area; while the irregularities and high concentration resembling woinadega were observed in north, north central and central rift valley of Ethiopia (Amogne et al. 2018; Melkamu and Getnet 2019;Feyisa 2017).

Table 4: Rainfall (PCI and SRA) across agro-ecology in Anger watershed

	Index	Description	Proportion of years along agro-ecology (%)		
			Dega	**Woinadega**	***Kolla***
(a) Precipitation Concentration Index (PCI)	< 10	Low concentration	3.1	3.1	0
	10 to 15	Moderate concentration	68.8	31.3	56.3
	>15 to 20	High concentration	28.1	56.3	43.7
	> 20	Very High concentration	0	9.4	0
(b)Standardized Rainfall Anomaly	≥ -0.84	No drought	90.6	71.8	93.7
	<-0.84 to -1.28	Moderate drought	6.3	12.5	6.3
	≤-1.29 to -1.65	Severe drought	3.1	6.3	0
	< -1.65	Extreme drought	0	3.1	0

Although, the proportion of positive anomalies in the watershed ranges from 28.3% in kolla, 34.8% in dega and 37.0% in woinadega; the annual standardized rainfall anomalies show a moderate to extreme drought in few years in all agro-ecologies (Table 4b). It revealed that no drought situations (SRA ≥ -0.84) were observed for most of years in the climatologic time in the watershed. The 1986 was the year of extreme drought (SRA < -1.65) for both woinadega and dega; while and severe drought (SRA ≤-1.29 to -1.65) was happened in 2002 in dega and in 1991 and 2009 in woinadega agro-ecology. However, except the moderate droughts in 1984 and 1995, no any extreme and severe droughts were recorded in the kolla agro-ecology (Table 4b).

The annual standardized anomalies indicate extreme and severe drought in woinadega implied only moderate droughts for either belg or kiremt of the years. Nevertheless, the moderate to severe negative anomalies observed (1988, 1990, 2002, 2003, 2004 and 2012) in belg season; and (1989, 1992, 1995, 1998, 2000, 2008 and 2014) in kiremt of woinadega while annual anomalies show no droughts (SRA ≥ -0.84) for these years. Similarly, the extreme and severe drought of 1986 and 2002 in dega observed in annual anomalies were implied the moderate drought in the year for belg and kiremt respectively. However, the moderate to severe negative anomalies recently observed (1983, 1988, 1998, 2003, 2012, and 2013) in belg season; and (1985, 1994, 1999, 2001 and 2011) in kiremt of dega while annual anomalies show no droughts (SRA ≥ -0.84) for these years. Therefore, although kiremt and belg negative anomalies and drought index were relatively higher in most of the years; the annual anomalies show fewer dry conditions in both dega and woinadega. Contrary, the kolla agro-ecology where extreme and severe droughts were not recorded for annual anomaly has experienced significantly high negative anomalies in kiremt and belg for the same years. For example, the extreme drought (SRA < -1.65) in 1999 and severe drought (≤-1.29 to -1.65) in 1997 and 1999 were recorded for kiremt. Similarly, several years of extreme and severe droughts in belg were observed (1983, 1988, 2012, and 2013) while annual negative anomalies are either highest (>-0.5) or positive in these years.

Most of the years identified as severe and extreme droughts in the study area were mentioned in the other parts of Ethiopia. Moreover, below the average long term was recorded for more than half of the years (1975-2003) in Amhara region (Woldeamlak 2009); negative standardized rainfall anomalies were observed for >50% of years in central highland and in the northern Ethiopia(Arragaw and Woldeamlak 2017; Birhan 2018; Wagaye and Antensay 2020). Nevertheless, the annual anomalies have direct relationship with anomalies in the kiremt and belg seasons in some parts of Ethiopia indicated above unlike the observed results in the Anger river watershed.

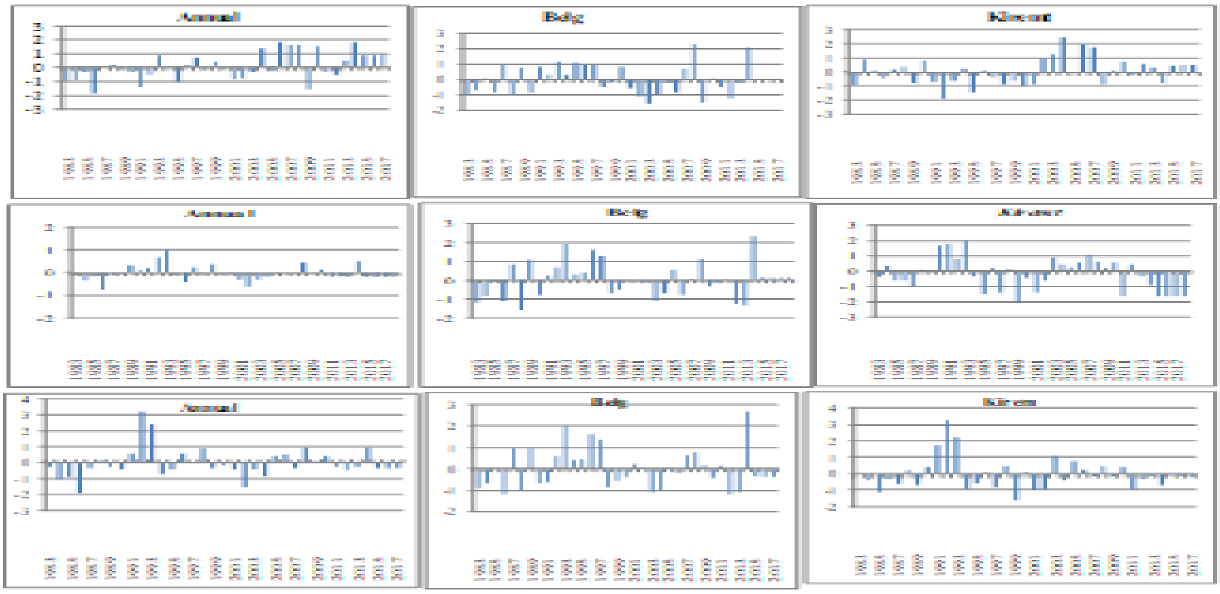

Fig 2. Annual and seasonal (belg and kiremt) standardized rainfall anomalies along agro-ecologies (woinadega, kolla and dega from top to down)

3.2 Temperature trends and variability

The MK trend test result revealed that maximum and minimum average temperatures have been increasing through the time at different significance level for all agro-ecologies (Table 5). However, the magnitude was different across agro-ecologies. The trend in mean maximum in dega and kolla shows significant increase for February, March, June, July and August (p<0.01 and <0.05) while significant increase in mean minimum trend was observed from July to November in both areas. The woinadega is characterized with increasing trends in both maximum and minimum for all months at different significance level except for mean maximum of August (Table 5). In general, the temperature trends show an increase for the watershed with considerable spatio-temporal differences.

Mean annual based temperature anomalies was analyzed to identify the characterstics in each year against the aggregate for climatologic time (Figure 2) to pinpoint the spatio-temporal variation in the years of extreme mean annual temperature conditions in the climatologic time and along agro-ecologies.

The years from 1983 to 1985 was characterized with high negative anomalies for all agro-ecologies due to relatively low mean annual temperature recorded in the years. Since then, inconsistent temporal trends were observed in all agro-ecologies at different extents approximately till 2000/2001 for dega and kolla and till 1994 for woinadega. However, except for 2008 when the lowest mean annual temperature of watershed was recorded in the climatologic time, the anomalies become positive without any interrupt decrease in mainly for dega while some interrupting negative anomalies were observed for woina dega and kolla (Figure 2). The result revealed the spatio-temporal variation in the years of extreme temperature conditions in the watershed.

Table 5. MAKESENS trend analysis of temperature across agro-ecologies in Anger river watershed (1983-2018)

	Mean Max-temp.						Mean Min-temp.					
	Dega		*Woinadega*		*Kolla*		*Dega*		*Woinadega*		*Kolla*	
Months	MK-test	Sen's Slope	MK - test	Sen's Slope	MK-test	Sen's Slope	MK-test	Sen's Slope	MK-test	Sen's Slope	MK-test	Sen's Slope
January	2.19	0.038	**2.48**	0.035	2.09	0.031	2.79	0.030	**2.22**	0.0345	0.98	0.013
February	**3.61**	0.091	**3.94**	0.060	**3.55**	0.065	1.42	0.026	**2.18**	0.0442	1.08	0.017
March	**3.47**	0.068	**4.13**	0.056	**3.00**	0.047	1.37	0.020	**3.29**	0.0559	0.66	0.013
April	1.82	0.048	**2.27**	0.049	1.61	0.050	1.16	0.019	**1.99**	0.0437	0.63	0.012
May	1.17	0.030	**2.23**	0.056	2.12	0.060	1.26	0.021	**2.54**	0.0447	0.69	0.014
June	**3.16**	0.059	**3.77**	0.053	**4.31**	0.066	**2.40**	0.024	**4.07**	0.0351	**2.91**	0.027
July	**3.27**	0.057	**2.80**	0.039	**3.87**	0.056	**3.78**	0.046	**5.01**	0.0424	**3.81**	0.033
August	**2.82**	0.039	1.81	0.025	**2.19**	0.029	**3.44**	0.034	**3.90**	0.0276	**3.09**	0.027
September	1.88	0.034	**2.64**	0.031	**3.00**	0.037	**4.56**	0.045	**3.84**	0.0312	**4.33**	0.037
October	1.80	0.034	**2.87**	0.037	1.84	0.032	**3.57**	0.040	**3.12**	0.0410	**3.19**	0.032
November	1.51	0.020	**2.33**	0.022	1.57	0.015	**4.08**	0.050	**3.68**	0.0481	**3.26**	0.038
December	0.60	0.013	**2.22**	0.025	1.61	0.013	0.47	0.008	**2.28**	0.0340	0.83	0.013
Average	**3.81**	0.043	**4.10**	0.042	**4.33**	0.036	**2.92**	0.032	**3.51**	0.0372	**2.32**	0.023

Bold value indicates statistically significant results at P=0.01 and 0.05

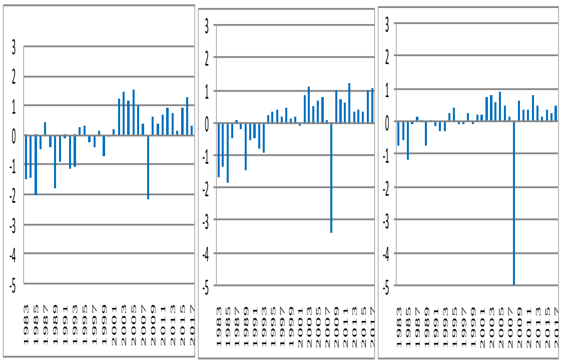

Fig 3. Mean annual based temperature anomalies in dega, woinadega and kolla from left to right

The overall trends of temperature which revealed increasing pattern were agrees with the findings in the other parts of Ethiopia (Arragaw and Woldeamlak 2017; Magarsa and Budiastuti 2020; Messay, Degefaa, and Gezahegn 2017; Wagaye and Endalew 2020); while agro-ecologies based spatial analysis in central, southern and northern Ethiopia (Ashenafi *et al,.* 2013; Befikadu *et al.,* 2019; Birhan 2018)showed highest significant increase kolla; unlike in our case where significant increase in trends were observed for almost all months of woinadega.

In general, the anomaly and trends analysis show steadly increasing in temperature with delineated spatio-temporal variations.

3.3 Perceptions on climate variability

Households' perception on trends of rainfall is more complicated compared to perception on temperature along agro-ecologies. In kolla remarkable percentage of respondents explained the trend as undetermined and increasing. However, significant percentage in dega and woinadega explicated on decreasing trends. However, most of households in all agro-ecologies agreed on increasing temperature in their area. This revealed that, the community has clear perception on temperature trends; while rainfall trend was relatively less clear for the community, mainly in kolla (Figure 3).

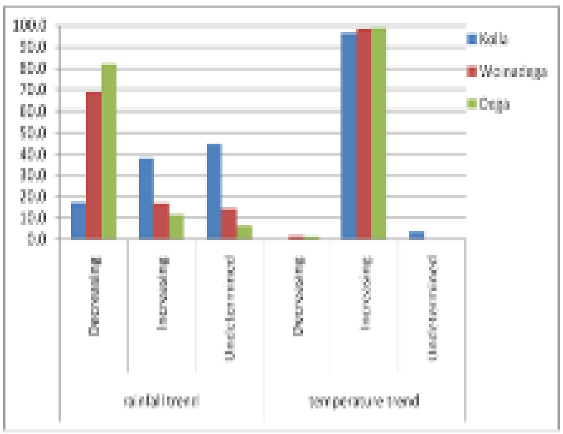

Fig 4. Community perception on trends of rainfall and temperature in the last 30 years across agro-ecology

Moreover, the woinadega and kolla discussants explained that the temperature increases and the extremes have been observed on diurnal, monthly and seasonal pattern. Although, they explained increased in overall trends of temperature, the condition in kiremt season was exception for dega discussants mainly the recent extreme high night temperature. These were in line with the spatial difference in trends of mean maximum and minimum temperature observed in the study area. Although, dega was relatively least in numbers of months with significant increase; all months of kiremt season shows significant increase for both mean monthly minimum and maximum temperature.

The unpredictability of rainfall time (mostly late onset of belg rain), concentrations, and unexpected rain during harvesting were major challenges elevated by discussants in all agro-ecologies. Particularly, they explained the late rain multifaceted impacts on their livelihoods such as reducing productions and productivity of "dafee " crops which has significant implication for households' food security in kiremt; diminishing of grazing land due to elongated dry season; and late belg rain results an increase in concentration for the next kiremt. Although, heavy rainfall in kiremt is climatic attribute of the study area according to the group discussants, the recent rainfall concentration in June and July were argued as disastrous which have been aggravate soil degradation, crop destructions because of associated storm, and unsuitability for some crop's germination and growth.

Moreover, the kolla discussants explicate the increasing in unpredicted rain during harvesting period. The impacts of rainfall in late November on production of crops mainly sesame and maize which are the most important crops in the kolla of Anger river valley were attentive. In general, the agro-ecological based perception study in the watershed show remarkable difference in perceptions on trends, variability and impacts of climate variability among households reside in different agro-ecologies. Although, the research on the issues didn't consistently assessed perception aspects along designed spatial classifications in Ethiopia rather merged them in the perception studies, examined the determinants of perceptions and concluded for the entire study area regardless of place difference(Amogne et al. 2018; Befikadu et al. 2019; Gutu, Emana, and Ketema 2012), the studies conducted in different parts of the world relatively claim for spatial aspects of perceptions (Boissière et al. 2013; Chibinga et al. 2010; Kashaigili et al. 2014).

4. Conclusions

Insights to broadly argued research gap on lack of climate studies at small geographic region by considering unique features of the area, deficiency of climate change studies for southwestern Ethiopia and specific to the study area; this research is intended to examine spatio-temporal trends and variability in rainfall and temperature in Anger watershed of southwestern Ethiopia. Ultimately, the research was designed to integrate the result with the studies on other global change processes and changing socioeconomic, political and organizational conditions in the community to understand the possible vulnerability pathways and adaptation responses of small-scale farmers in the study area. Examining the trends and variability of the elements of climate at micro scale having unique biophysical and socioeconomic characteristics has paramount importance to understand the system differential vulnerability to the changes; identify adaptation strategies within change processes; and to explore the causal linkage of adaptation constraints so as to recommend options suited to the identified case studies to enhance resilience of small-scale farmers in the study area.

About 166 grid points were used to cover the watershed for rainfall and temperature gridded data from 1983 to 2018. The watershed receives mean annual rainfall of 1577mm mostly contributed by kiremt rain with no significant difference in patterns among agro-ecologies. The trends of rainfall show substantive spatio-temporal differences in the watershed on monthly, annual and seasonal bases. However, there is general increase in annual rainfall for entire watershed but significant only in woinadega agro-ecology.

The trends of rainfall on seasonal base across agro-ecology show some remarkable differences. The kiremt rain shows increase for entire watershed but significant for woinadega and kolla agro-ecologies while belg rain show non-significant increase in dega and kolla; and decrease in woinadega.

Unlike the trend, the result of rainfall coefficient of variation, concentration index and anomalies show remarkable variability; and the situation has spatial aspects in the watershed. All months excepts rainy months of kiremt (JJAS) have shown moderate to high rainfall coefficient of variations; while dry months of bega (NDJF) shows exceptionally highest for all agro-ecologies with considerable difference across agro-ecologies. Although, low coefficient of variations was confirmed for kiremt; remarkable spatial difference was observed that; relatively highest variability was recorded in woinadega followed by kolla agro-ecology. The moderate to high rainfall concentration with considerable difference across agro-ecologies were observed in the study area. High concentration was observed in woinadega followed by kolla; while dega is relatively characterized by moderate rainfall concentration. On the basis of the annual anomalies, rainfall shows moderate to extreme drought in few years in all agro-ecology. The 1986 was the year of extreme drought for both dega and woinadega while severe drought was happened in 2002 and 2004 in dega and 1991 and 2009 in woinadega agro-ecology. The kolla agro-ecology weren't experience any extreme and severe drought in annual standardized rainfall anomalies. However, these negative annual anomalies weren't implied for kiremt and belg droughts in the study area that most of moderate to extreme droughts in these seasons were observed in significant numbers of years dissimilar with the years when severe and extreme annual anomalies-based drought were recorded.

The temperature trends show an increase in both maximum and minimum temperature with spatiotemporal variations which is among the manifestations of global climate change. The increasing situation is severe in woinadega where trends for both mean annual maximum and minimum for all months at different significance level shows increment except for mean maximum of August.

The small-scale farmers in the study area have clear perception on status and trends of temperature; while relatively blurred on rainfall conditions. Moreover, significant difference was observed among agro-ecology regarding perception on rainfall trends and variability while temperature was perceived as increasing for all agro-ecology. Most of kolla community perceived the trend of rainfall as undetermined and explained the situation as highly variable; than those from dega and woinadega.

Accordingly, unpredictability of rainfall time (mostly late onset of belg), concentrations, and unexpected rain during harvesting were major challenges in the watershed. These have multifaceted impacts on their livelihoods such as reducing production and productivity of belg crops; soil degradation and crop destructions because of heavy rainfall and associated storm in kiremt; unpredicted rain in late November have been devastating crops under harvesting.

Although the overall trend observed for rainfall has increasing tendency in southwestern highlands of Ethiopia; these couldn't grant positive climate situation while inter-annual, seasonal, and monthly variability was significantly witnessed in the study area; which has potential to hamper livelihoods of local community. Small scale farmers' worry was toward inconsistency of rainfall (onset and off-set), seasonality and fuzzy optimum adequacy; increasing in extreme events such as storms and heavy rainfall; and extremely increasing trends of temperature; rather than overall trends in rainfall. Therefore, future research works focusing on comprehensive variability measurements including other elements of climate is important. Moreover, in addition to scientific contribution for climate science, the climate analysis seems rewarding when take place at micro-level and applied to identify confined status. Most of vulnerability and adaptation studies in Ethiopia have been take place by adopting large scale empirical data on recent trends, experts/and community perceptions; and even without these data claiming climate variability as inevitable natural processes. However, probing the issues to the change without site specific micro-scale knowledge on the status, trends, magnitude, spatial variations and distributions with parameters implied for the livelihoods systems of a community would affect development practitioners' interventions to enhance the resilience, and recommend appropriate adaptation options and implement the strategies.

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