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GRADUATE PROGAM

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MSc Thesis

By

BELAY MULU TEGEGNE

January. 2020

Bahir Dar

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BELAY MULU TEGEGNE

SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE (MSc.) IN “CLIMATE CHANGE AND DEVELOPMENT”

Main Advisor-MINTESINOT AZENE (PhD)

Co-Advisor- ZERIHUN YOHANNES (PhD)

January. 2020

Bahir Dar

THESIS APPROVAL SHEET

As member of the Board of Examiners of the Master of Sciences (M.Sc.) thesis open defense examination, we have read and evaluated this thesis prepared by Mr. Bela Mulu entitled "**Effects of Climate Variability on Crop Diversity Over the Agroecological Zones of Gumara Watershed, North West Ethiopia**. We hereby certify that; the thesis is accepted for fulfilling the requirements for the award of the degree of Master of Sciences (M.Sc.) in Climate Change and Development.

Board of Examiners

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Name of Chair Person	Signature	Date

DECLARATIONS

This is to certify that this thesis entitled "**Effects of Climate Variability on Crop Diversity Over the Agroecological Zones of Gumara Watershed, North West Ethiopia**" submitted in partial fulfillment of the requirements for the award of the degree of Master of Science in "Program" to the Graduate Program of College of Agriculture and Environmental Sciences, Bahir Dar University by Mr. Belay Mulu, (ID. No. BDU1018604) is an authentic work carried out by him under our guidance. The matter embodied in this project work has not been submitted earlier for award of any degree or diploma to the best of our knowledge and belief.

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Signature_________________________ Date_______________________

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ABSTRACT

Ethiopia is a home for a number of food crop varieties suited to the dry and high temperature conditions. It varies from Denakil Desert to cool wet alpine highlands in climate variability. The vigorous indigenous crops were growing in a diversified manner in their agroecological suitable area across Ethiopia as well as Gumara watershed. But starting from some years back, the diversely growing of those crops are affected by climate variability. The study area is one of the richest areas in indigenous crop types and faced with the aforementioned problem. Thus, the study aimed to analyse the trend of climate and the decadal dynamics of the crop diversity in the watershed. The Gridded Satellite and observed historical climate data from 1987-2016 period and crop-climate history were the data sources. Using the Mann-Kendall test and Sen's Slopes estimator, for trend, rating of Food and Agriculture Organization crop-climate requirement, for crop diversity dynamics were employed methods of data analysis respectively. The result indicated non-significantly increasing of decadal Kiremit rainfall in 27mm at Weyna Dega and 43mm at Dega agroecological zones. The kiremit season temperature variables are in a statistically significant increasing trends at all zones. In general, 0.4^{o}c of decadal increments of minimum and maximum and 0.5^{o}c of mean temperature increment is recorded in the watershed. The recent period of decadal increment in maximum temperature negatively affecting most selected indigenous crops at the lower elevation and helps to move the crops forward to the higher elevation. The local farmers perception results agreed with the historical climate data analysis. Improved crop verities shall be introduced to the watershed agroecological zones. The traditional agroecological zone classification system of Ethiopia must be systematically updated. In order to detect the detail information on crop-climate associations/ effects of climate variability on crop diversity, the yearly analysis rather than decadal analysis; shall be suggested respectively for governments and future researches.

Key Words: - Effect, Climate Variability, Indigenous Crop, Crop Diversity, Agroecological Zones.

Table of Contents

List of Abbreviations/Acronyms

AEZ	Agroecological zone
ANRS	Amhara National Regional State
Ave.	Average
CHIRPS	Climate Hazards Group InfraRed Precipitation with Stations
CSA	climate-smart Agriculture/Central Statistical Agency
CV	Coefficient of Variability
ETo	Potential Evapotranspiration
FAO	Food and Agricultural Organization
FGD	Focus Group Discussion
GHG	Greenhouse Gases
IISAS	International Institute of Applied System Analysis
IPCC	Intergovernmental Panel for Climate Change
KII	Key Informant Interview
LGP	Length of Growing Period
m.a.s.l.	meter above sea level
MoA	Minister of Agriculture
NAMA	Nationally Appropriate Mitigation Action
NAPA	National Adaptation Program of Action
NMSA	National Metrological Services Agency
NS	Not Suitable
Rf	Rainfall
SOS	Start of the rainy Season
SRTM-DEM	Shuttle Radar Topographic Mission- Digital Elevation Model
T max	Maximum temperature
T min	Minimum Temperature
Temp.	Temperature
UNDP	United Nation Development Program
UNFCCC	United Nations Framework Convention on Climate Change
USAID	United State Agency of International Development
WMO	World Meteorological Organization
XLSTAT	Statistical Software for Excel

List of tables

List of Figures

List of Appendix

Chapter One: INTRODUCTION

1.1 Background and Justification

Warming of the climate system is unequivocal, as now evident from observations of increases in global average air and ocean temperatures, widespread melting of snow and ice and rising global average sea level (Pachauri *et al.*, 2014). Climate is the most important factor that governs food production and causes of variability in socio economic and environmental systems related to the availability of water resources in its changing state (Koudahe *et al.*, 2018; Pachauri *et al*., 2014). According to the International Panel for Climate Change Working Group report, the change referred as a change in average weather conditions or long-term variation in climate variables (Pachauri *et al*., 2014).

Since the early 1990s the Intergovernmental Panel for Climate Change (IPCC) has provided evidence of accelerated global warming and climate change. The global average temperature in the last 100–150 years has increased by 0.76^{o}C (0.57–0.95^{o}C) cited by Traore *et al.* (2013). Altered frequencies and intensities of extreme weather is expected to have mostly adverse effects on natural and human systems (Pachauri *et al.*, 2014).

Agricultural production, including access to food, in many African countries is projected to be severely compromised. This would further adversely affect food security and exacerbate malnutrition (Pachauri *et al*., 2014). On the other hand, according to FAO and World Bank report, the whole world needs agriculture, because agriculture does not only feed the entire human race but also produces fiber for clothing, feed for livestock and bio-energy. In the developing world agriculture contributes significantly to the gross domestic product, leads the way in reducing poverty and accounts for the lion's share of employment opportunities (Agbossou *et al.*, 2012).

By 2020, in some countries, yields from rain-fed agriculture could be reduced by up to 50% (Pachauri *et al*., 2014). Specifically, Africa is highly vulnerable to future climate change and variability, and Ethiopia is often cited as one of the most extreme examples (A. a. B. Alemayehu, Woldeamlak 2016) because, between 80-95 percent of Ethiopia's agriculture is rain-fed and the nature of Ethiopia's agriculture, primarily rain-fed means that production is sensitive to the fluctuations of rainfall, then the economy is highly exposed to climate variability and extremes (Sadoff, 2019; Taye *et al.*, 2013; UNDP, 2011).

Current climate variability also has a significant influence on crop production in the area and any unfavorable change in the local climate in the future will have serious implications for household level food security in the country(A. a. B. Alemayehu, Woldeamlak 2016). Because Ethiopian economy is already dependent on rainfall and its pattern (Taye et al., 2013).

Various analysts reasoned that the persistence of the subsistence nature of Ethiopian agriculture is partly due to the lack of proper understanding of the agroclimatic resources of the country. Agroclimatic zone is a land unit, in terms of major climate and growing period that is climatically suitable for a certain range of crops and cultivars. Agroclimatic zonation schemes are standard tools for prioritizing agricultural research because they offer relevant available information about the target environments (Ganaie *et al.*, 2014). The reason that agroclimatic zone understanding is that, climate plays important role in influencing land cover, viz., natural vegetation or land use and dictates a large extent what the natural vegetation is and which crops can be grown; additionally, it is mainly responsible together with soils for yearly variation in yields (Ganaie et al., 2014).

Of the climatic factors, the two limiting climatic elements i.e. the number of days in which adequate moisture is available for growth and development of plants and conducive temperature for adaptation of a certain (botanical) community of plants and animals are given high priority and due considerations (Hurni, 1998).

Owing to its large altitudinal variation, Ethiopia is a home for a number of food crop varieties suited to the dry and high temperature conditions of the lowlands and the wet and cooler temperature conditions of the highlands (Di Falco *et al.*, 2010). Based on the their agroclimatic suitable zone, a large number of crops are grow in a diversified manner in Ethiopia that include cereals (Tef, Wheat, Barley, Corn, Sorghum and Millet); pulses (Faba Bean, Chickpea, Haricot bean, Field Pea, Lentil, Soybean, and Vetch); oilseeds (linseed, noug, gomenzer, sesame, and groundnuts), vegetables (pepper, onion, tomato, carrot, cabbage, and kale), root and tubers(potato, Enset, Sweet-potatoes, beets, yams); fruits (apple, peach, plum, grape, banana, citrus, papaya, pineapple, mango and avocado); fibers (cotton and sisal); stimulants (coffee, tea, chat and tobacco) and sugarcane (Benin *et al.*, 2003; Gorfu, 2012).

Crop biodiversity is the foundation of food production and supply (Di Falco et al., 2010). But, due to the changing climate from time to time the climatic zones that control species distribution will move pole ward and to higher elevations, consequently the species diversity will shift as the climate zone and then the local diversity shift will be faced with diversity degradation and new species will also emerges (IPCC, 1990). In order to challenge the complex climatic impacts on crop production farmers and breeders are practically use biodiversity to adapt crops to different and changing production environments (Di Falco et al., 2010). But it is impossible to get a solution without the proper understanding of the current and future climate change impacts on the agroecological and agroclimatic zones at local/ watershed level. Because Agroecological Zones (AEZs) based measures answer and play an important role to predict how impacts will be dispersed across the landscape (Seo, 2011). Furthermore, its impacts are exaggerated in the diversified agroecological zones and the vulnerability of the system in this diversity will increased. The most sensitive areas will be where species are close to their biological limits in terms of temperature and moisture (IPCC, 1990).

Concerning in the attempt of investigating the effects of climate variability on crop diversity over the agroecological zones at watershed level, this thesis was initiated to analyse the trends of climate variables; to analyse the decadal dynamics of crop diversity due to climate variability; and to assess adaptation strategies in the study area as a specific objectives.

1.2 Statement of the Problem

Previous studies on the effects of climate change on biodiversity were focused on the future impacts of climate change at large scale/global and regional level; e.g. (Ackerly, 2012; Coll *et al.*, 2013; Howden *et al.*, 2003; Hui, 2013; Lane andJarvis, 2007; Pérez, 2008). In their analytical predictions the result of the effect is different for different regions and species diversities, for example; Lane and his friend noted that, Europe will experience the largest gain in suitable areas for cultivation and high production in a number of crop species beyond the present situation from increasing temperature. Whereas, the Sub-Saharan Africa and the Caribbean are projected to suffer in a decline in land area suitable for cultivation and cereal crops will decrease markedly (Lane andJarvis, 2007). But each region has different resources to support the existing life within it (Aguilar *et al.*, 2015), because the condition at local level didn't be follows the national patterns of both biotic and abiotic resources. For instance, changes in temperature and precipitation differ among different places, the effects of climate change on biodiversity may vary spatially and temporally (Hui, 2013).

The species movements and their diverse societal and environmental impacts, awareness of 'species on the move' should be incorporated into local, regional and global assessments as standard practice (Pecl *et al.*, 2017). The differential effects of climate change on farms in various agroecological zones have not yet been quantified (Seo, 2011). Additionally, he had discussed farms in different agroecological zones clearly face different conditions for farming. In order to make a solution for the problem, small-scale projects such as the case studies need to be scaled up and multiplied to encourage the direction of large-scale funding towards local solutions (Swiderska, 2008).

Further analysis is needed to identify priority species and areas to target for climate adaptation strategies, particularly for improved climate change- tolerant varieties (Lane andJarvis, 2007). Additionally, they indicated that, rich species and genetic diversity that exists in landraces and local knowledge should be exploited and used to guide crop variety selection.

Hussain and his friend on their irrigation-based impact of climate change on crops' productivity across selected agroecological zones analysis. They also recommended for future studies to consider the effect of geographic variables such as altitude and the crop season climatic variables i.e. the rainfall and temperature as well as soil moisture availability for crop growth and development within and across the agroecological zones. Because over the time, these climate variables may affect cropping pattern across the agroclimatic zones through altering the sowing and harvesting period of crops (Hussain andBangash, 2017). On the other hand, Katwal *et al.* (2015) was attempted to address the impacts of climate change on indigenous cereal crops based on the community perception alone without the metrological data and the crop-climate relationship analysis in Bhutan district. The shift of the geographic distribution of cereal production due to climate change and how productivity may shift under multiple climate change scenarios in Ethiopia was done by Evangelista *et al.* (2013).

Gumara watershed is rich in agroecological zone (elevated from 1784-3800 m.a.s.l) and crop diversity in a small square kilometer (Melke, 2015).. But now, these indigenous crop diversity situations have observed as instable and degraded on their original places within the watershed agroecological zones and couldn't find such crops diversifications as the previous times. (Consequently, the agroecological zones are make hospitable for some new crops species and farmers also gradually adapt those new species). Thus, the instability and degradation problem may due to climate variability and change as stated by different scholars at global and regional level. The reason why the local farmers are shifting to improved varieties should be analysed and interpreted to set proper adaptation strategies for the vigorous indigenous crops of the Gumara watershed.

To date, however, studies on the potential effects of climate variability on crop diversity at watershed level are still very limited. In the partial fulfilment of the above gaps of previous researchers, this thesis has initiated as entitled and settled objectives at the watershed level. As the climate factors play an important role in spatial distribution and production of crops, based on high resolution /4kmx4km Chirps source/ gridded Satellite historical climate data, crop history and the local people knowledge /KII/ within a watershed agroecological zones, this thesis investigated the effect of climate variability on crop diversity over the agroecological zones of gumara watershed, northwest highlands of Ethiopia. Then, in addition to knowing the recently adaptation mechanisms of local farmers, analysing the trend of climate, which climate factor affect the crop diversity and which crop species are more sensitive to this climate variability is crucial to address the problem through suggestions and recommendations of proper adaptation strategies.

1.3 Objectives

1.3.1 General Objective

The general objective of this study was to investigate the effect of climate variability on crop diversity over the agroecological zones of Gumara watershed, northwest highlands of Ethiopia.

1.3.2 Specific Objectives

The specific objectives of the research were: -

1. To analyse the trends of climate variables in the agroecological zones of study area; and
2. To analyse the decadal dynamics of crop diversity due to climate variability in the study area;

1.4 Research Questions

1. What is the trends of climate variability within the agroecological zones of Gumara watershed? and

2. What is the decadal effect of climate variability on crop diversity in the agroecological zones Gumara watershed?

1.5. Scope and Limitations of the Study

Indigenous crops are observed in decreasing its diversity from AEZ to AEZ and time to time due to different affecting factors. Among these factors long time climate variability may be the major influencing factor. Then, based on the primary and secondary data, this paper analysed the climate variability effects on crop diversity over the agroecological zones at watershed level (i.e. Gumara watershed). As such, many crop types are grown in the watershed, cereal crops like Tef, maize, Barley and Wheat (Melke, 2015). Due to the resources (time, finance and man power) limitations, this thesis was purposively selected some crop species that are dominant in some previous year periods for the assessment of shifts and crop diversity situations under the changed/variable/ climate within the watershed agroecological zones.

1.6 Significance of the study

The relationships between climate variability and cop diversity within different agroecological zones, watershed as well as in the regional and national level is lacking yet. Studies to attempt the effect of climate change and variability in different climatic resource region is crucial rather than studies that generalize the whole Ethiopian climatic regions as a single unit. Because, according to Aguilar et al. (2015), all resource regions not followed the national pattern or the same crop diversity. Research documenting changes in crop species diversity is lacking. This paper provided some important information about the climate variability effects on crop diversity within different agroecological zones of the study area.

The result had provided some crucial adaptation strategies policy makers, local community, governmental, nongovernmental organizations to implement their agricultural development practices by following the research finding introduced by this paper in Gumara watershed. On the other hand, researchers may take some important guiding points and recommended gaps on the analysis of climate variability effects on crop diversity on a specific area.

Chapter Two: LITERATURE REVIEW

Chapter Three: RESEARCH METHODLOGY

3.1 Study Area Description

3.1.1 Location

Gumara watershed, drained by Gumara Rivers, is located in to the east direction of Lake Tana, south Gondar zone of the Amhara National Regional State between latitude of 11° 35' and 11° 55' N and longitude of 37° 40' and 38° 10' E, at 624 KM North of Addis Ababa (Chakilu andMoges, 2017; Melke, 2015). The elevation of the watershed ranges from 1784 m.a.s.l. at the lake to 3800 m.a.s.l. at the highlands, with slopes ranging from 0% to more than 70%. The total main stream length from its origin (near mount Guna) is approximately 132.5 km before the river joins Lake Tana. The total area of the watershed covers about 1639 km^2. It is part of the Lake Tana sub-basin which is situated on the Eastern side of Lake Tana and contributes significant inflows to the Lake. It drains *Dera*, *Farta*, *Fogera* and some part of *Estie Woredas* (Chakilu andMoges, 2017).

3.1.2 Climate condition

There are some meteorological stations within the study area and its surroundings such as Bahir Dar, Debre Tabor, Amedber, Woreta, Amde Genet, Nifas Mewucha, Wanzaye and Gassay which are monitored by Ethiopian Meteorological Agency. Among these Bahir Dar, Debire Tabor and Nefas Mewucha stations of relative humidity, sunshine hour and wind speed data used to calculate the potential evapotranspiration conditions of the watershed agroecological zones. The annual climate may be divided in to two, rainy and dry season. The four rainy months/ kiremit cover 84 percent of the total annual rainfall. While the remaining months, being from October to May has a total rainfall of about 16% of the mean annual rainfall. Previously, 85 and 15 percent of the kiremit and other months rainfall contributions respectively by Melke (2015). Referring the Ethiopian Metrological Service/EMSA/, the climatic type is generally humid in 20.5^{o}c the mean annual temperature and 1300mm of the average total annual rainfall (Wubie *et al.*, 2016). Wetlands/swamp areas are commonly existent on the lower banks of Rivers, mainly of River and near Lake Tana (Melke, 2015).

Table 3.1. Traditional Agroecological Zones and Physical Characteristics

Zone	Altitude (m.a.s.l.)	Rainfall (mm/year)	Average annual temperature (o C)	Length of Growing Period (days)
Wurch (upper highlands	>3200	900-2200	< 11.5	211-365
Dega (highland)	2,300-3,200	900-1,200	17.5/16-11.5	121-210
Weyna Dega (midland)	1,500-2,300	800-1,200	20.0-17.5/16	91-120
Kola (lowland)	500-1,500	200-800	27.5-20	46-90
Bereha (desert)	<500	< 200	>27.5	0-45

Source, Hurni, 1998

3.1.3 Socioeconomic conditions

According to the 2013 Central Statistical Agency (CSA) report, the total population of the Watershed accounts 487,576 cited in Wubie et al. (2016). Agriculture is the main livelihood activity in the watershed. According to the Central Statistical Agency (CSA) report in 2001, 91% of the total cultivated area was cropped during the meher/Kiremit/ season in 2000/01 cropping year (Woldeamlak, 2009). The major cereals crops grown in the watershed are Tef, maize, Barley, Wheat and Finger Millet as well as oil seeds lie Linseed/Telba/ and Niger Seed/noug/.

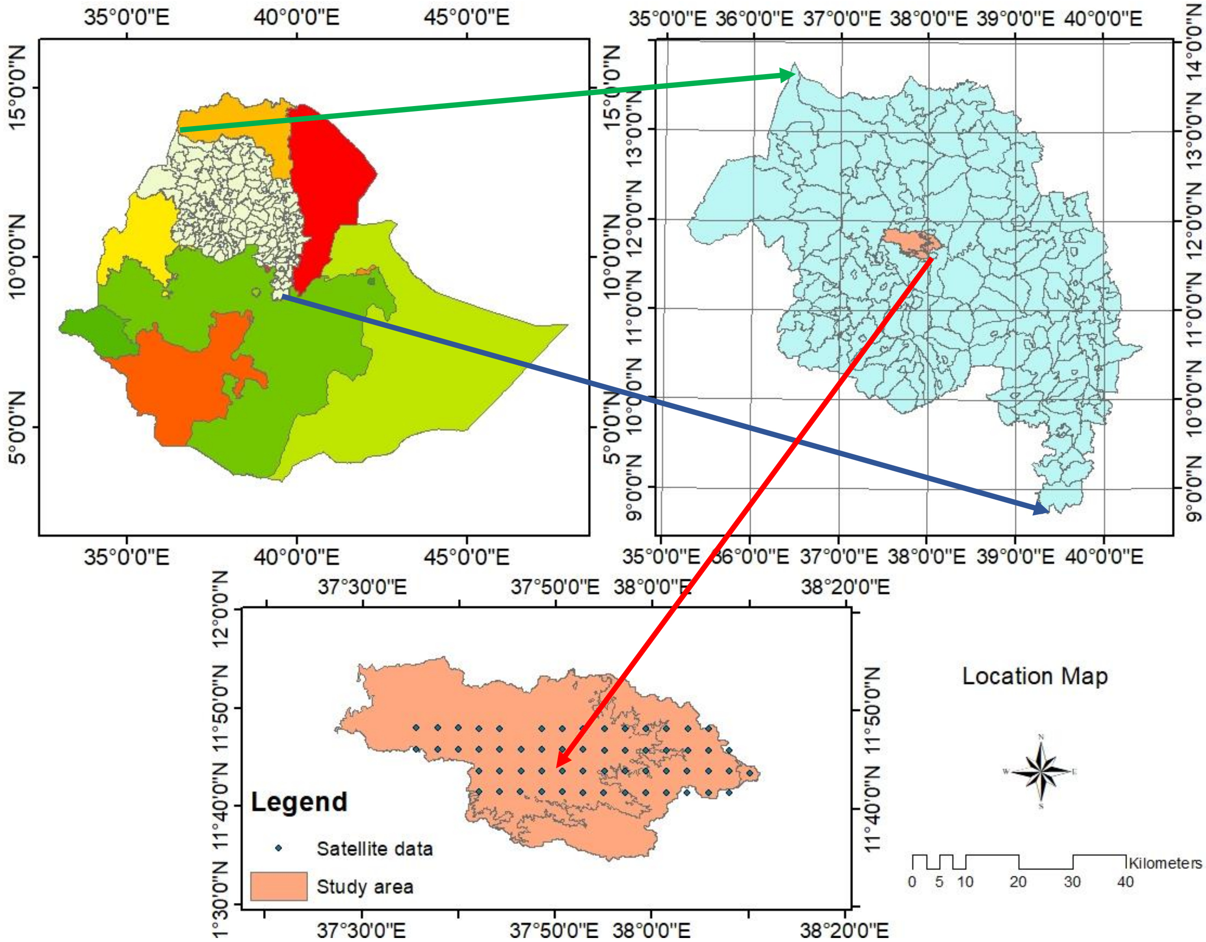

Figure 3.1. Map of Study Area

Source: Extracted from Amhara region Shape file (2019)

3.2 Methods of Data Collection and Sources

To identify any changes in the climate, it was necessary to compare the climate statistical parameters (precipitation and temperature) for the three different climate periods from the 30 years' data (Asai, 2017). Based on the annual average climate data the decadal climate dynamics of the study area were done (Asai, 2017; Taye et al., 2013). The 31-years (1986-2016) CHIRPS sourced (4km*4km) gridded satellite climate data (daily rainfall and temperature) were collected at National Metrological Services Agency/ NMSA/. The Gridded climate data are a reconstructed data based on records of gauge stations and metrological satellite observations. The gridded data set is very useful in view of the fact that weather stations are limited in number, unevenly distributed and have a missing data problem and a short period of observations (Asfaw *et al.*, 2018). Among other satellite data source, the CHIRPS satellite data source was evaluated and preferred by different previous scholars in East Africa (Gebrechorkos *et al.*, 2018) and Ethiopia Tekeze-Atbara basin by (Gebremicael *et al.*, 2017). Especially in the nearby of our study area of the Upper Blue Nile River Basin evaluated by Bayissa *et al.* (2017).

According to the Food and Agriculture Organization discussion, the big challenge to calculate the evapotranspiration of the zones was to find other climate variables such as relative humidity, sunshine hour and wind speed data in the area where the rainfall and temperature data are collected. Although the solution had suggested by FAO (1996) itself as we can collect those data from the neighboring stations through interpolation/linear regression/ mechanism and used by Surendran *et al.* (2015).

Then, we collected these data from Nefas Mewcha, Debre Tabor and Bahir Dar stations for Wurch, Dega and Weyna Dega agroecological zones respectively for the purpose of length of growing period calculation. The agroecologically neighboring observed metrological data for the purpose of comparison with gridded satellite data was used by Esayas *et al.* (2018).

3.3. Sampling Techniques

Firstly, dominantly growing indigenous crop types in the past 15-20 years in the watershed were identified from the previous literatures and the administration of South Gonder Zone agricultural sector experts. Thus, based on the crop types abstained, their botanical/scientific names were identified in FAO (1989) and used for crop-climate relationship analysis.

Table 3.2. Indigenous crop types in the watershed

No.	Name Crop type	Botanical/Scientific name
1	Maize	Zea mays
2	Tef	Eragrostis abyssinica
3	Barley	Hordeum vulgare
4	Wheat	Triticum aestivum

5	Finger Millet	Eleusine coracana
6	Linseed (flax for oil seed)	Linum usitatissimum
7	Niger seed	Guizotia abyssinica

Source, (FAO, 1989)

The watershed Gumara Watershed was classified into agroecological zones using Arc GIS 10.4 software as the system used by Ahmed et al. (2009). Using the GIS10.4 Software, the 4km*4km resolution Gridded satellite climate data obtained from National Metrological Service Agency /NMSA/ were displayed to the watershed area and grouped the data into elevational class called agroecological zones through the Food and Agriculture Organization of United Nations (FAO, 1989). In each agroecological zones; Weyna Dega, Dega, and Wurch zones, there were 39, 18 and 1 gridded data shares respectively. According to Gorfu and his friend there is a 0.6^{o}c and 0.7^{o}c change in temperature in each 100-kilometer elevational differences in Ethiopia (Gorfu and Ahmed, 2012).

In order to eliminate this temperature difference in each 100-kilometer due to elevation, we considered the grouping of these gridded data in less than and equals to 81 kilometers within the average samples' altitude coverage. Hence, to characterize the agroecological zones climate trends, these gridded data in the zones were also grouped in to the manageable average size of 6, 6, and 1 for Weyna Dega, Dega and Wurch respectively.

3.3.1**.** The climate data sampling technique

According to Hurni (1998) the traditional elevational coverage of the watershed ranges from Weyna Dega zone (1784–2300 m.a.s.l), Dega zone (2301-3200) and Wurch zone (3201–3800 m.a.s.l). Based on the area coverage of each agroecological zone within the total area 1639 Km2 of watershed, each agroecological zone covers 1103.6, 357.4 and 178 Km2 at Weyna Dega, Dega and Wurch zones respectively.

The watershed had 58 gridded points. Based on GIS10.4 Software using SRTM-DEM, there were three elevational differences /agroecological zones/ in the watershed. Both Weyna Dega and Dega agroecological zones had grouped into 6 average gridded points/parts/ and 1 for Wurch zone were used to analyse climate trend by (Mann Kendal test and Sen's Slop estimator) and coefficient of variability (CV) analysis purposes. In order to eliminate the temperature changes in each 100km difference in Ethiopia. We classified and grouped the AEZs rainfall and temperature data into manageable average gridded data less than 81 km differences between the start of lower elevation to the end of higher elevation. Thus, based on the principle discussed by Gorfu and Ahmed (2012), Table 3.3 illustrated that, the averaged ranges of gridded data that contains less than 100km elevational differences between the gridded points in each agroecological zone parts.

Table 3.3. Discussion Keys for the climate trends at the zone's part

AEZs	Parts of the AEZs and its Gridded Points Altitude Coverage /m.a.s.l.						AEZs total Coverage/ m.a.s.l.
	1st part (Lower)		2nd part (Middle)		3rd part (Upper)		
	Lower-lower part	Lower-upper part	Middle-lower part	Middle-upper part	Upper-lower part	Upper-upper part	
Weyna Dega	1792-1878	1896-1930	1950-2004	2021-2106	2120-2169	2172-2285	1792-2285
Dega	2300-2363	2389-2564	2604-2637	2641-2713	2767-2821	2881-2939	2300-2939
Wurch	3200-3372	-	-	-	-	-	3200-3372

Sources; Our calculation based on Gorfu and Ahmed (2012)

The 6 averaged gridded points that were used to characterize climate trends at the Weyna Dega and Dega zones had reduced/aggregated into three (lower, middle and upper) parts to analyse the effects of climate variability on crop diversity across the agroecological zones in a decadal basis as the following table (Table 3.4).

Table 3.4. AEZ parts and mean elevational coverage for crop diversity dynamics analysis

Agroecological Zone	Agroecological parts and its altitude coverage (m.a.s.l)		
	Lower	Middle	Upper
Weyna Dega	1835-1913	1977-2064	2146-2229
Dega	2348-2561	2622-2641	2814-2903
Wurch	3372	-	-

Sources; Our calculation average elevation of parts of table 3.3.

3.5. Data Set and Quality Control

3.5.1. Outlier detection

The Tukey fence was used to screen the outliers greater than a threshold value that can affect the detection of inhomogeneity (Ngongondo *et al.*, 2011).

The data range is represented as:

[Q1 -1:5×IQR, Q3+1:5×IQR] …………………………………… (2)

where Q1 and Q3 are the lower and upper quartile points, respectively and IQR is the interquartile range. Values outside the Tukey fence are considered as outliers. In this paper, such outliers were set to a limit value corresponding to 1.5×IQR. Below the lower and above the upper limit considered as outlier and rejected.

3.6. Methods of Data Analysis

The data collected from all sources were analysed through qualitative and quantitative approaches. The data analysis was undertaken using XLSTAT software and excel spreadsheet. The perception of experienced small-holder farmers on rainfall and temperature change/variability/ and the effects on their local indigenous crop that they grow in their local area and adaptation measures they used collected through KII and FGD were analysed using descriptive statistics and qualitative analysis respectively.

3.6.1. Length of growing period /LGP/ calculation

We examined the main crop growing season/main rain season/ (Jun-September) for the crop-climate relationships. We followed the crop-moisture availability/LGP/ conditions of the area related to crop-moisture requirement during their growing season based on the (FAO, 1989) specifications.

According to the United Nation Development Program Food and Agricultural Organization (FAO, 1989) the Length of Growing Period/LGP/ analysis can be assessed by two alternative methods, such as; calculation from rainfall and PET data and from the growing period zone map of Ethiopia. As discussed by FAO (1989), due to its potentially much more accurate than the reading LGP from the map; we followed the "calculation from rainfall and PET data" methods of analysis. Thus, in order to calculate the Length of Growing Period/LGP/ the PET were calculated through Penman Monteith CROPWAT8.0 Software using the minimum and maximum temperature, relative humidity, sunshine hours and wind speed as an input data (FAO, 1998). Length of growing period were determined by the precipitation data that are greater than the half of potential evapotranspiration (FAO, 1989).

The FAO Penman-Monteith method is recommended as the sole ETo method for determining the potential evapotranspiration. CROPWAT.8 software we used to compute ETo as;

$$ETo = 0.408 * \Delta = \left((Rn - G) + y * \frac{\frac{900}{T+273} * U2(es - ea)}{(\Delta + y * (1 + 0.34 * u2))} \right) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (7)$$

Where;

ETo: reference Evapotranspiration (mm/day)

Rn: Net radiation at the crop surface (MJm-2 day-1)

T: Mean daily temperature at 2m height (°C)

Es: saturation vapor pressure (kPa),

Ea: actual vapor pressure (kPa),

Es-Ea; saturation vapor pressure deficit (kPa)

Δ: slope vapor pressure curve (kPa °C)

G: soil heat flux density (MJm-2 day-1)

ý: Psychometric constant (kPa).

U2: wind speed at 2m height (ms-1)

3.6.2. Climate Trend Analysis

The Mann Kendall test and Sen's Slope estimator

The Mann Kendall test were used to detect the trend of climate variables (rainfall, temperature and length of growing periods) and the magnitude were analysed by Sen's slope estimator. Mann–Kendall's test is a non-parametric method, which is less sensitive to outliers and tests for a trend in a time series without specifying whether the trend is linear or non-linear (Asfaw et al., 2018; Bekele et al., 2016; Partal andKahya, 2006; Yue *et al.*, 2002). The initial value of the Z test statistics /S/ is assumed to be zero, implying no trend. If a data value from a later time period is found to be greater than the data value from an earlier time period, then statistics /S/ is incremented by one. On the other hand, if the data value from the later time period is lower than that of the earlier period, the Z test statistics S is reduced by one. The overall result of all increments and decrements provides the final S value, which lies between -1 and +1. The null hypothesis of the Z test is no change has occurred during the time (no trend). Whereas the alternative hypothesis of the Z test is a significant change has occurred over the time. Mann Kendall and Sen slop tests are widely known and used by different authors to detect the trends of meteorological variables (Asfaw et al., 2018; Bekele et al., 2016; Degefu andBewket, 2014; Kiros et al., 2016; Seleshi andZanke, 2004).

The Mann–Kendall test statistics are given as follows (Bekele et al., 2016; Longobardi andVillani, 2010; Salmi *et al.*, 2002).

$$S = \sum_{i=1}^{n-1} \sum_{j=i+1}^{n} \mathrm{sgn}(xj - xi) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (8)$$

The application of trend test is done to a time series xi that is ranked from i= 1, 2…n-1 and xj, which is ranked from j=i+1, 2…n. Each of the data point xi is taken as a reference point which is compared with the rest of the data point's xj. Then;

$$sgn = (xj - xi) = \begin{cases} +1 if (xj - xi) > 0 \\ 0 if (xj - xi) = 0 \\ -1 if (xj - xi) < 0 \end{cases} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (9)$$

Where xj and xi are the annual values in years j and i (j>i) respectively.

It has been documented that the number of observations is more than 10(n ≥ 10) the statistic 's' is normally distributed with the mean value of zero and variance is calculated using Equation

$$Var\ (S) = \frac{n(n-1)(2n-5)-(x+a)^n = \sum_{t=1}^{m} (\mathrm{ti}(\mathrm{ti}-1)(2\mathrm{ti}-5)}{18} \text{……………………… (10)}$$

Where n is the number of observation and ti are the sample time series. The test statistics Z is as follows;

$$Z = \begin{cases} \frac{S-1}{\sigma} if\ S > 0 \\ 0 if s = 0 \\ \frac{S+1}{\sigma} if S < 0 \end{cases} \text{………………………………………………………. (11)}$$

The decision to either reject or accept the null hypothesis is then made by comparing the calculated Z with the critical value at a chosen level of significance.

Sen's Slope Estimator is also a non-parametric test by which the true slope (change per year) of a trend is estimated (Salmi et al. 2002; Bekele et al., 2016). Sen's test is used when the trend is assumed to be linear, i.e.

$$f(t) = \delta t\ +\ B \text{………………………………... (12)}$$

where f(t) increasing or decreasing function of time, i.e. the trend δ the slope and B intercept (constant). The slope of each data pair δi is calculated as:

$$\delta i = \frac{Xj-xk}{j-k} \text{……………………………………… (13)}$$

where j>k and, if there is n number of xj in the time series, we get as many as N $\frac{n(n-1)}{2}$ slope estimates of δi.

Then the values of Qi are ranked from small to large; the median of which is the Sen's slope (δ):

$$\delta = \begin{cases} \delta \left[\frac{N+1}{2}\right]\ if\ N\ is\ odd \\ (\delta \left[\frac{1}{2}\right] \delta \left[\frac{(N+2)}{2}\right]\ if\ N\ is\ even \end{cases} \text{……………………………………… (14)}$$

3.6.3. Analysis of coefficient of variability/CV/

The Coefficient of Variability/CV/ is a unit-less normalized measure of dispersion of a probability distribution. It expresses the standard deviation as a fraction of the mean and is useful when interest is in the size of variation relative to the size of the observation. It is expressed as the ratio of the standard deviation to the mean (Araya *et al.*, 2011; Bekele et al., 2016).

$$CV = \left[\frac{S}{X}\right] * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots .(15)$$

where CV is the coefficient of variation; X is the average long-term rainfall and S is the standard deviation of rainfall. The CV was used to compare the long-term variation of wet season rainfall to that of individual years. The result of coefficient of variability (CV) had expressed in percentage and the degree of variability of rainfall events were classified based on (Hare, 2003) as; when CV < 20% =less/slightly variable, CV from 20% to 30%= moderately variable and CV > 30% = highly variable.

3.6.4. Analysis of decadal effects of climate variability on crop diversity

All climate variables are not equally supporting and affecting the crops at the same time and place. Thus, in order to analyse the effects, three discussion points (parts) and (decadal periods) were undertaken as (lower, middle and upper) and [(1987-1996), (1997-2006) and (2007-2016)] of the zones and periods. Finally, through the mean part i.e. Weyna Dega, Dega and Wurch zones of the watershed; the number of crops/richness/ suitably growing indigenous crops are identified and determined in terms of number in a decadal basis in each agroecological zones.

However, the main analysis of number of suitably growing crops are identified and numbered. The minimum and maximum temperature and moisture requirement of crops were used to discuss as which variable were affecting more. The crop-temperature suitability analysis with each variable/minimum and maximum temperature/ may provide a proper insight rather than the analysis with mean value alone.

Rating Method

The Food and Agricultural Organization of United Nation FAO (1989) specified the crop-climate suitability conditions. In this thesis we used this specification ranges to analyse the crop growing season and climate variability effects on crop diversity (crop diversity dynamics) through rating the decadal climate data to the crop suitability ranges in the study area agroecological zones. Thus, the decadal number of selected crops dynamics in the agroecological zones were analysed. The following tables (Table 3.5 and 3.7) presents the main climate variables such as moisture and temperature for crops suitability ranges respectively, which determines the distribution and occurrences of crops in an area specified by FAO (1989). On the other hand, Table 3.6 and 3.8. depicts the recorded decadal climate moisture and temperature data respectively. We used these tables for all zones in the crop richness and crop diversity dynamics analysis. The suitability range rating with the selected crops in each agroecological zones are made in the decadal bases in the period of 1987-2016 through calculated moisture availability (Length of Growing Period) instead of amount of rainfall, and the temperature variables.

Table 3.5. The FAO Crop-Moisture Suitability Range

Crop types ↓	Mean Moisture Requirement /Days/ at the mean elevation of the zones			Minimum LGP Requirement			Maximum LGP Requirement		
	Weyna Dega (2000masl)	Dega (2500masl)	Wurch (3000masl)	Weyna Dega (2000masl)	Dega (2500masl)	Wurch (3000 masl)	Weyna Dega (2000 masl)	Dega (2500 masl)	Wurch (3000 masl)

Suitability ranges →	S1	S1	S1	S2	S2	S2	S2	S2	S2
Maize	140-255	245-360	>285	120-140	255-245	NS	255-300	310-360	350-360
Tef	95-230	145-280	180-315	80-95	130-145	165-180	230-255	260-285	280-305
Barley	105-240	155-290	190-325	90-105	140-155	175-190	240-260	240-260	140-260
Wheat	115-240	165-290	200-325	100-115	150-165	185-200	240-265	240-265	240-265
Niger Seed	120-155	120-155	120-155	110-120	110-120	110-120	150-210	150-210	150-210
Linseed	130-240	160-270	180-290	110-130	140-160	160-180	240-270	240-270	240-270
Finger Millet	90-120	160-280	NS	75-90	145-160	NS	NS	NS	NS

Source; FAO, 1989.

Table 3.6. The calculated decadal LGP at the zones

Decadal Periods	Agroecological Zones LGP		
	Weyna Dega	Dega	Wurch
1987-1996	150	190	168
1997-2006	156	165	165
2007-2016	156	180	180

Source: Our calculation from Penman-Monteith (CROPWAT)

Table 3.7. The FAO Crop-temperature suitability range of selected crops

Minimum Temperature Requirement					Crop Types	Maximum Temperature Requirement					Mean temperature requirement
Ns	S4	S3	S2	S1		S1	S2	S3	S4	Ns	Mean
<12	12-14	14-15	15-16	16-26	Maize	16-26	26-30	30-34	34-38	>38	16-26
<11	11-12	12-14	14-15	15-21	Tef	15-21	21-22	22-23	23-25	>25	15-21
<5	5-7	7-9	9-11	11-24	Barley	11-24	24-27	27-28	28-30	>30	11-24
<10	10-	11-	12-	14-	Wheat	14-	24-	27-	28-	>30	14-24

	11	12	14	24		24	27	28	30		
<12	12-13	13-15	15-17	17-23	Nigger Seed	17-23	23-24	24-26	26-29	>29	17-23
<10	10-12	12-14	14-16	16-24	Linseed	16-24	24-26	26-28	28-30	>30	16-24
<14	14-15	15-16	16-17	17-30	Finger Millet	17-30	30-35	35-38	38-40	>40	17-30

Source; (FAO, 1989)

Table 3.8. Spatial and temporal crop growing season temperature values in the agroecological zones

AEZ Parts	Decadal Periods	**W/Dega Temperatures**			**Dega Temperatures**			**Wurch Temperatures**		
		T min	T max	T mean	T min	T max	T mean	T min	T max	T mean
1 (lower)	1987-1996	11.9	24.7	18.2	9.8	21.3	15.5	8.9	20.2	14.5
	1997-2006	12.5	25.7	19.0	10.1	22.0	16.0	9.2	20.7	15.3
	2007-2016	13.7	25.3	19.4	10.5	22.3	16.1	9.8	21.3	16.4
2 (middle)	1987-1996	11.3	23.3	17.5	9.7	20.7	15.2	-	-	-
	1997-2006	11.9	24.1	18.2	10.1	21.3	15.6	-	-	-
	2007-2016	12.8	24.1	18.7	10.5	21.7	16.0	-	-	-
3 (upper)	1987-1996	10.6	22.9	16.7	9.3	20.5	14.9	-	-	-
	1997-2006	10.9	23.6	17.2	9.6	21.0	15.3	-	-	-
	2007-2016	11.6	23.7	17.7	10.0	21.5	15.5	-	-	-

Source; Base on Hurni (1998); our spatial and temporal calculation (2020)

Chapter Four. RESULTS AND DISCUSSION

4.1. Results of Data Set and Quality Controls

The Tukey fence was properly detected/screened the outliers greater than (Q3) and less than (Q1) the threshold value that can affect the detection of inhomogeneity. Values outside the Tukey fence were considered as outliers/anomalies and removed from the data before the aggregation of the daily gridded satellite data into monthly and yearly data.

4.2. Climate Variability Trends in the Watershed

Table 4.1 indicates the general climate trends in the watershed. A positive trend with the p-value greater than the alpha value was noticed in all annual temperature variables. The calculated P-value of the temperature had statistically significant at 5% level. A positive Sen's Slope was found, and it established a rising trend in temperature year-by-year.

The increment of rainfall was indicating insignificant at the same significant level. But based on our analysis in the agroclimatic zone by a dense gridded point climate data, there is a fluctuation of results in each variable especially of rainfall in different grid points. The result variation among grid points were presented by (Wagesho et al., 2013). Besides, the trend of length of growing period/ moisture availability conditions in days/ of the watershed follows the significantly increasing trends of temperature and insignificantly increasing trends of rainfall. It implies that, the linearly upward movement of temperature in the recent time may reduce the availability of moisture that gained from the stagnant rainfall. The time effect on the climate variable had been discussed in the following class.

Table 4.1. The annual climate variables Trend in the Watershed

Variables		Trend Determinants		
No.	Climate variables	Kendall's tau	p-value	Sen's slope:
1	T min	0.5	< 0.0001	0.044
2	T max	0.4	0.0004	0.04
3	T mean	0.6	< 0.0001	0.05
4	Rainfall	0.2	0.19	5.13
4	LGP	0.02	0.91	0

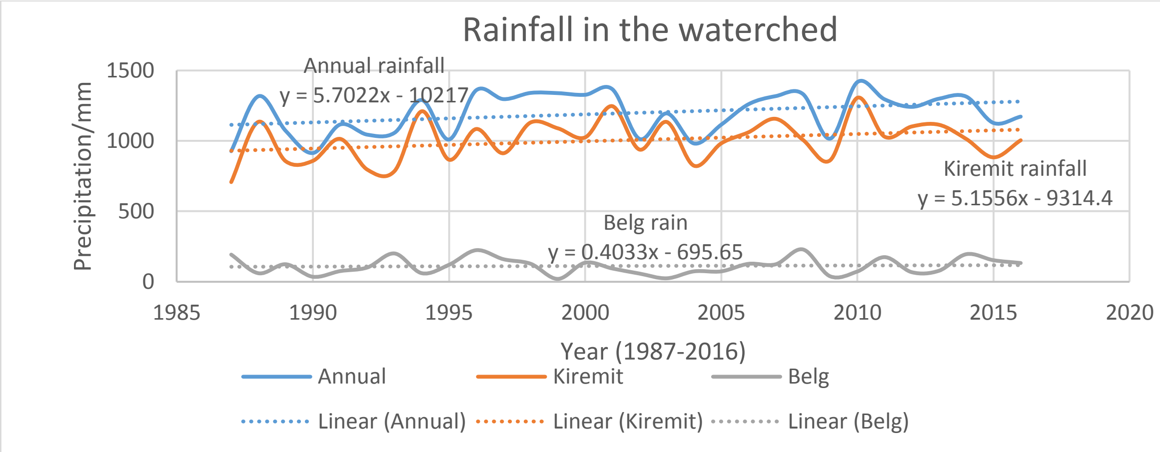

Figure 4.1. Rainfall trends and variability in the agroecological zones

4.4. The Annual and Seasonal Rainfall Trends in the Agroecological Zones

The Belg season in the Weyna Dega zone was in a decreasing trend. It is true in each gridded point at Weyna Dega zone. However, except the Belg season insignificant decreasing, all the mean seasonal value (annual, Meher and Kiremit) indicates insignificantly increasing trends.

On the other hand, both Dega and Wurch Zones are in the insignificant increasing trends at all gridded points and seasons. Even though, the cause of annual rainfall decreasing trends was described as the Belg and the Meher season shortage of rain, the kiremit (June and July months) were also contributing for the decline through their significant decreasing trends with the p-value of 0.212 and 0.592 respectively. The causes of Belg rainfall decreasing trend at all gridded point of Weyna Dega was the whole months of March, April and May play their significant decreasing trends on the Belg season rainfall.

In the Dega agroecological zone, there was no a decreasing trend at all gridded points in all season. But due to the monthly decreasing trends of March, August and October, the Belg (short rain) and Kiremit (main rain) seasons shows the non-significant increasing trend. Whereas, the Wurch agroecological zone seasonal rainfall trend indicates upward. Except the April and October, all moths were indicating an increasing trend and have no significant effects on the annual and seasonal trends to decrease.

Table 4.2 presents the mean value of rainfall trend in the agroecological zones. In the *Weyna Dega* zone there is a non-significantly increasing in annual and kiremit with decadal increment of 30.6mm and 27mm with 3.069mm and 2.781mm/year rate respectively. The two extremes that the significantly increasing and insignificantly decreasing trend were analysed in Meher and Belg season with 54mm and (-5mm) per decade and 5.123mm and (-0.408mm) per year rates respectively.

Table 4.2. The Annual and Seasonal rainfall trends and variability in the AEZs

AEZs	Month	Minimum	Maximum	Mean	contr.%	Std	CV	MK(Z)	P-value	Slope (δ)
Weyna Dega	Annual	836.7	1427.3	1199.5	100.0	140.3	0.12	0.122	0.357	3.069
	Kiremit	798.6	1309.4	1029.2	85.8	131.2	0.13	0.108	0.416	2.781
	Meher	149.3	458.6	293.4	24.5	76.3	0.26	0.393	0.002	5.123
	Bega	0.0	11.5	3.3	0.3	3.4	1.03	-0.005	0.986	-0.002
	Belg	7.8	235.6	83.4	7.0	56.2	0.67	-0.071	0.596	-0.408
Dega	Annual	918.7	1496.1	1200.1	100.0	157.4	0.13	0.122	0.357	4.206
	Kiremit	712.0	1354.0	1001.2	83.4	162.8	0.16	0.154	0.242	4.331
	Meher	97.8	371.8	198.8	16.6	61.1	0.31	0.039	0.777	0.620
	Bega	0.0	25.4	7.0	0.6	7.6	1.09	-0.046	0.734	-0.042
	Belg	18.7	257.6	126.4	10.5	62.1	0.49	0.071	0.596	0.815
Wurch	Annual	806.0	1437.0	1188.1	100.0	178.1	0.15	0.310	0.016	7.833
	Kiremit	600.0	1259.0	983.1	82.7	170.4	0.17	0.228	0.081	7.533
	Meher	62.5	339.5	201.8	17.0	60.0	0.30	0.078	0.556	0.694
	Bega	0.0	44.5	13.5	1.1	14.5	1.08	-0.164	0.221	-0.235
	Belg	7.0	276.5	124.8	10.5	72.6	0.58	0.126	0.335	1.600

Where; Kendall's tau=MK(Z)p-value= δ

**As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0 and accept the alternative hypothesis Ha.*

**As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.*

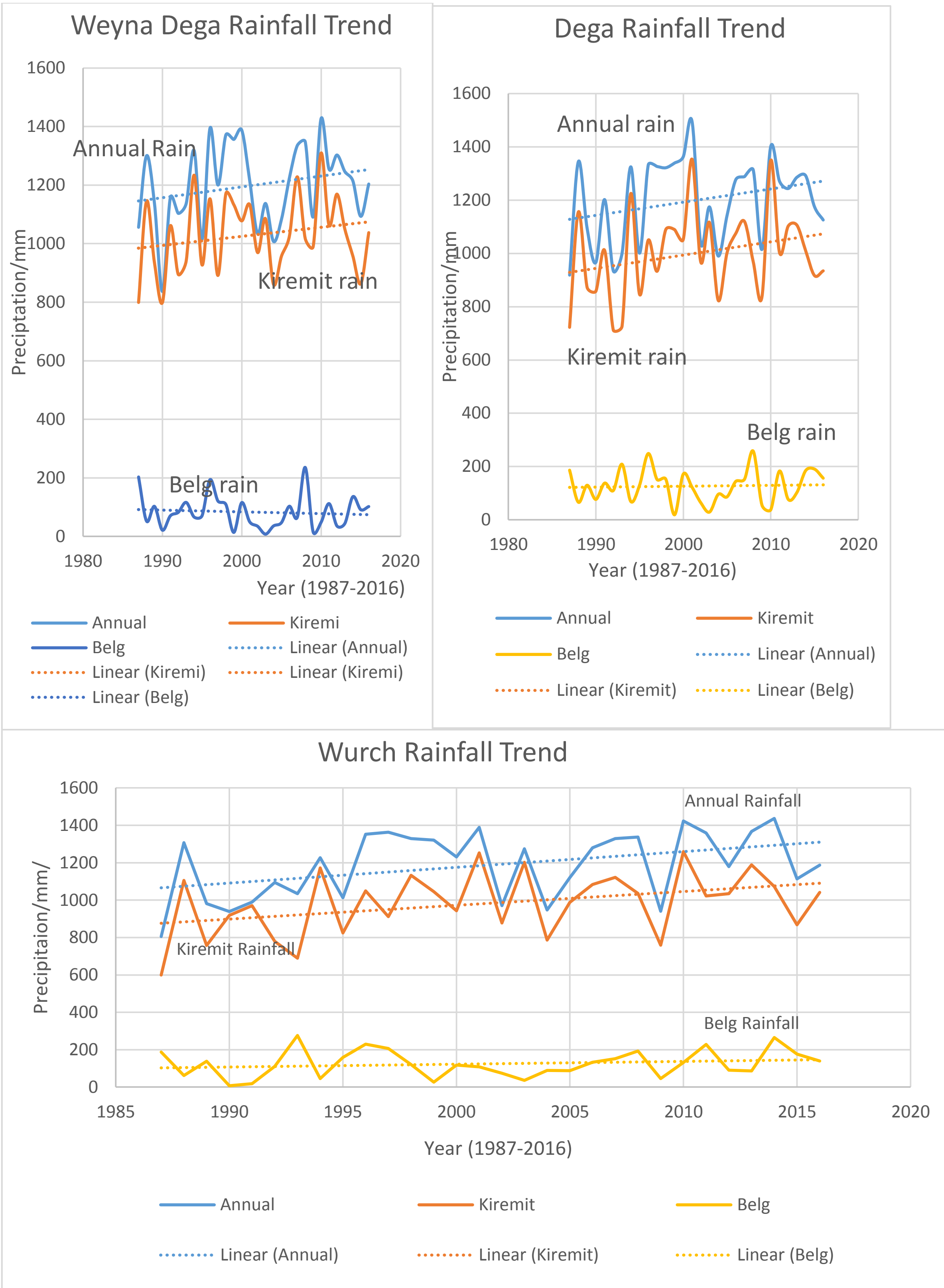

Figure 4.2. The Annual and Seasonal Rainfall Trendline in the Agroecological zones

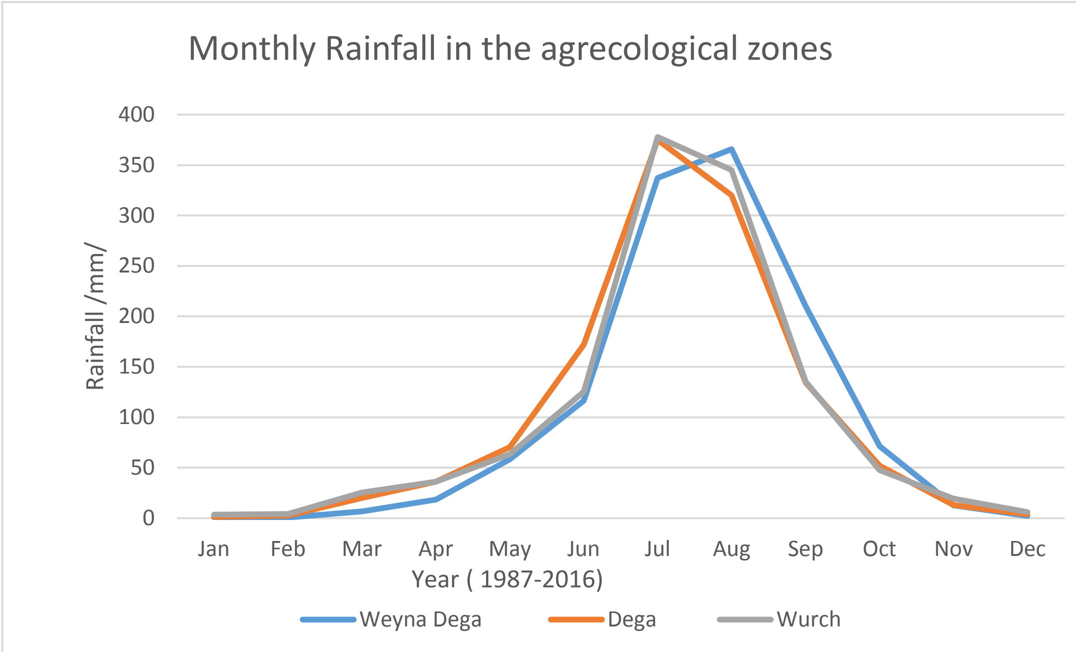

Figure 4.3. Monthly rainfall distribution in the agroecological zones

In the **Dega agroecological zone** the mean rainfall trend had the same sign of non-significantly increasing trends annually and seasonally. The annual, kiremit, Meher and Belg season decadal increment was 42mm, 43mm, 11mm and 2mm with the rate of 4.206mm, 4.331mm, 0.620mm and 0.815mm per year respectively.

Whereas, the annual rainfall in Wurch agroecological zone was significantly increasing trends, while other seasons are statistically insignificant increasing trend at the same significant level of 5%. The decadal value indicated that, the 96mm, 77mm, 16mm and 14mm increments in the annual, kiremit/main rain season/, Meher and Belg seasons with 7.833mm, 7.533mm, 0.694mm and 1.600mm rate per year respectively. However, the trend increment indicates insignificant.

Findings reported by Poudel and Shaw (2016) in a case study in Lamjung District, Nepal, the total annual precipitation at some stations were increased by 10.48 mm/year. Other studies which are lined with our analysis reported by the National Metrological Service Agency indicated that, a declining trend has been observed over the Northern half and Southwestern part of the country and an increasing trend in annual rainfall in central Ethiopia (NMSA, 2001).

Additionally, Admassu et al. (2006) reported that, there was significantly decreasing trend in kiremit rainfall in some stations across the country/ Ethiopia (for example; Gore and Jijiga). Abrha (2015) had confirmed that the change varies by the agroecology meant that the Kiremit (summer) rainfall in lowlands increased significantly by about 106mm/decade, whereas highlands experienced nonsignificant change. Additionally, Abrha and Simhadri reported an inversed to our finding on the Belg season rainfall that, the highlands lose a significant amount rainfall reaches up to 35 mm/decade. Wagesho and his friends had studied on their spatiotemporal variability of annual and seasonal rainfall over Ethiopia and the result opposingly to our findings indicated that, there were a decreasing trend of kiremit and annual rainfall in northern, northwestern (*which is our study area located*) and western parts of the country (Wagesho et al., 2013). The possible reason for this change may the local effect. On the other hand, Admassu et al. (2006) had attempted to cover relatively wider spatial coverage in Ethiopia; and the result has indicated kiremit rainfall exhibited a significant decreasing trend while the belg rainfall also indicated that no significant trend in Ethiopia.

The rainfall trend and variability analysis at Awash river basin by Bekele et al. (2016) was also the one which fit our study. The result indicated that, Kiremit season rainfall shows an insignificantly increasing trends in five stations out of 12 stations. The Belg rainfall indicated insignificantly declining in trend for seven stations. A study by Kiros et al. (2016) in Northern Ethiopia result indicated a mix of non-significant positive and negative trends of annual rainfall.

Another study in central highlands of Ethiopia by Alemayehu and Bewket (2017) reported that, the Belg (March–May) rainfall showed a significant decreasing trends as of the Weyna Dega zone in our analysis insignificantly decreasing, while annual and the Kiremit (June–September) rainfall exhibited statistically insignificant increasing trends lined with our results at all agroecological zones except the Wurch zone of annual rainfall significantly increasing trend.

Additionally, Gedefaw et al. (2018) investigated the trend of annual and seasonal rainfall variability in Amhara regional state and the result showed that, the annual rainfall was increasing in most of the stations. In the Lake Tana Basin Analysis of Rainfall Trends by Weldegerima et al. (2018) shows that, except the Adet station all other stations revealed an increasing trend of annual and kiremit rainfall, while except Dangla and Debre Tabor the belg rainfall trend indicates the decreasing trends. The trends in belg season rainfall in Debre Tabor (which is within our study area of Dega part) was very closed to our results.

Another investigation by Mengistu et al. (2014) showed that the precipitation was both in increasing and decreasing trends among stations over the upper Blue Nile river basin of Ethiopia. Woldeamlak (2007) reported that, there were intra-annual and intra-regional differences in amount and variability of rainfall in Amhara region. But there was no systematic pattern of change across the region regarding trends in annual and seasonal rainfall. It is true in our study area agroecological zones rainfall trends. Tabari et al. (2015) studied in the upper Blue Nile Basin also conclude that, there were insignificant decreasing trends in annual precipitation at most of the stations.

4.5. The Annual and Seasonal Rainfall Variability Coefficient (CV)

Table 4.3. presents the annual and seasonal rainfall variability. Thus, the coefficient of variability percentage of rainfall in Weyna Dega zone was analysed as 12%, 13%, 26% and 67% in the annual, Kiremit, Meher and Belg seasons respectively. The Dega agroecological zone was also 13%, 16%, 31% and 49% in annual, Kiremit, Meher and Belg respectively. Whereas, the Wurch zone rainfall variability coefficient indicates 15%, 17%, 30% and 58% in the annual, kiremit, meher and belg seasons respectively. On the other hand, the agroecological zone holds different values in each representative gridded point in a decal period (See Appendix 3). It fluctuates differently in time and places across the agroecology and within the agroecological zones. For example, the CV at *Weyna Dega* in the first period and gridded point was 14%, while in the same period at gridded point 6 was 19%. However, the magnitude is laid under similar variability (slightly variable) conditions. On the other hand, at the same gridded point in period 1 and 3 there is a CV differences between 17% and 10% respectively. The variability of rainfall in general hasn’t a specific determinable condition within the agroecological zones and its gridded points across the elevation like the trend results.

In the Coefficient of Variability analysis, the degree of variability of rainfall events was classified based on the (Hare, 2003) as less (CV<20%), moderate (20<CV<30%) and high (CV>30%) variability. The explanation was used by Asfaw et al. (2018) and (Behailu, 2018).

Our analysis result revealed that, the annual and kiremit rainfall was less variable in all agroecological zones, while the meher and belg season rainfall was also laid under moderately and highly variable respectively in Weyna Dega, and highly variable in Dega as well as both moderate and high variable in Wurch zone in a respective order.

Previous researches lined with our results are, except Addis Zemen and Maksegnit moderately variable , 80% of the stations annual and kiremit rainfall variability was revealed under less variable; and except Injibara other stations were also categorized under highly variable (>30%) ranges reported in the trend and variability analysis in the Tana basin of Ethiopia by (Birara *et al.*, 2018). Other studies reported by Bekele et al. (2016) stated that, 5 and 3 stations are less variable out of 12 stations in the annual and kiremit rainfall respectively. While, the Belg season was highly variable (>30%) in all stations in the Awash river basin area. Similar results lined with our studies undertaken in the Lake Tana Basin Analysis of Rainfall Trends by Weldegerima et al. (2018) the variability result indicates less variability of annual and kiremit and high variability belg seasons rainfall indicates (9% and 11%) and high variable (44%) respectively.

Table 4.3. The Annual and Seasonal Rainfall Coefficient of Variability (CV) in the AEZs

Determinants	Weyna Dega				Dega				Wurch			
	Annual	Kiremit	Meher	Belg	Annual	Kiremit	Meher	Belg	Annual	Kiremit	Meher	Belg
Mean	1200	1029	293	83	1200	1001	199	126	1188	983	202	125
Std	140	131	76	56	157	163	61	62	178	170	60	73
CV	0.12	0.13	0.26	0.67	0.13	0.16	0.31	0.49	0.15	0.17	0.30	0.58

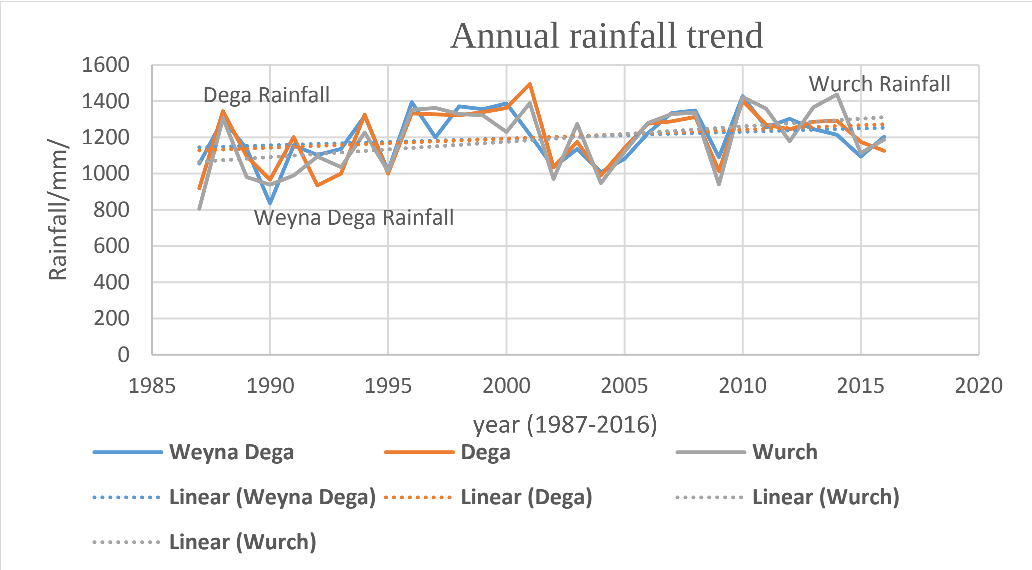

Figure 4.4. The annual rainfall trendline in the agroecological zones

4.6. The Annual Temperature Trends in the Agroecological Zones

Regardless the agroecological zones, the annual temperature trends in the watershed result in Table 4.1 indicates a statistically significant increasing of all variables. In the whole period (1987-2016) the recorded increasing value of increment was 1.2^{o}c with 0.4^{o}c rate of decadal and 0.04^{o}c yearly rate of minimum and maximum temperatures respectively. While, the mean temperature was recorded 1.5^{o}c increment in the last 30 years with 0.5^{o}c of decadal and 0.05^{o}c yearly rate of increment. However, the rate of increment was differed with in the agroecological zones.

Table 4.4 also indicates the annual temperature value in the agroecological zone results at the last line in the table indicates statistically significant increasing trends in all temperature variables at all agroecological zones in the watershed.

4.6.1 Maximum temperature

In the same period (1987-2016) of 30 years, the maximum temperature increment at the zones also revealed that, 0.3, 0.4 and 0.5^{o}c per decade with 0.03, 0.04 and 0.05 ^{o}c of yearly increasing rate respectively at Weyna Dega, Dega and Wurch zones. The maximum temperature rate of increment in the zones indicates an increasing in elevation.

4.6.2 Minimum temperature

According to the Sen Slop's estimator results, the annual minimum temperature result indicates that 0.8°c at Weyna Dega and 0.3°c at Dega and Wurch zones increment per decade in the period of 1987-2016 with 0.08, 0.03 and 0.03°c rates per year. The maximum value of annual minimum temperature was recorded at Weyna Dega. While the minimum values were recorded with similar value of 0.3°c per decade with 0.03 yearly rates at Dega and Wurch zones.

4.6.3. Mean temperature

The mean temperature rate of decadal increments indicates 0.6°c at Weyna Dega and 0.4°c at Dega and Wurch zones with 0.06 and 0.04°c rate per year respectively. As the minimum temperature increasing rate the mean temperature indicates decreasing from the Weyna Dega to Dega and Wurch with the Dega zone rates to the Wurch at the same significant level.

Table 4.4. Annual Temperature Trends in the Watershed AEZs at 5% confidence

Grid No.	Temperature variables	Weyna Dega annual			Dega annual			Wurch annual		
		MK (Z)	p-value	Sen's slope: (δ)	MK (Z)	p-value	Sen's slope: (δ)	MK (Z)	p-value	Sen's slope: (δ)
1	T-min	0.61	< 0.0001	0.12	0.30	0.022	0.03	0.375	0.003	0.03
	T-max	*0.22*	*0.094*	*0.02*	0.42	0.00	0.04	0.522	< 0.0001	0.05
	T-mean	0.54	< 0.0001	0.07	0.50	<0.0001	0.04	0.609	< 0.0001	0.04
2	T-min	0.57	< 0.0001	0.09	0.38	0.00	0.03			
	T-max	0.36	0.005	0.03	0.40	0.00	0.04			
	T-mean	0.58	< 0.0001	0.06	0.53	<0.0001	0.04			
3	T-min	0.58	< 0.0001	0.08	0.33	0.01	0.03			
	T-max	0.33	*0.009*	0.03	0.41	0.00	0.04			
	T-mean	0.59	< 0.0001	0.06	0.53	< 0.0001	0.04			
4	T-min	0.63	< 0.0001	0.08	0.28	0.03	0.02			
	T-max	0.37	*0.004*	0.04	0.38	0.00	0.05			
	T-mean	0.60	< 0.0001	0.05	0.55	<0.0001	0.03			
5	T-min	0.52	< 0.0001	0.06	0.34	0.01	0.03			
	T-max	0.34	*0.008*	0.03	0.44	0.00	0.04			
	T-mean	0.59	< 0.0001	0.05	0.56	<0.0001	0.04			

6	T-min	0.41	0.001	0.05	0.38	0.00	0.03			
	T-max	0.39	*0.002*	0.04	0.49	0.00	0.05			
	T-mean	0.54	< 0.0001	0.05	0.60	<0.0001	0.04			
Mean	T-min	0.57	< 0.0001	*0.08*	*0.37*	*0.00*	*0.03*	0.37	0.00	0.03
	T-max	0.34	0.008	0.03	0.44	0.00	0.04	0.52	< 0.0001	0.05
	T-mean	0.60	< 0.0001	0.06	0.55	< 0.0001	0.04	0.61	< 0.0001	0.04

Where; MK=(Z)=Mann Kendall test and δ=Sen slop

**As the computed p-value is lower than the significance level alpha=0.05, one should reject the null hypothesis H0 and accept the alternative hypothesis Ha.*

**As the computed p-value is greater than the significance level alpha=0.05, one cannot reject the null hypothesis H0.*

In our analysis, the increasing trend of the temperature variables is lined with other studies like; (Asfaw et al., 2018; Behailu, 2018; IPCC, 2018; Jury andFunk, 2013; Mengistu et al., 2014). The climate variability and change in Ethiopia historical data analysis result indicated that: the temperatures are increasing (Azage et al., 2017). In the decadal bases from the period of 2006–2015 the observed global mean temperature was 0.87°C in average between 0.75°C and 0.99°C fluctuations, which is higher than the average of 1850–1900 period (IPCC, 2018).

Most specifically, Regassa *et al.* (2010) reported that, the annual minimum temperature in Ethiopia increased by about 0.37°C every decade and between 1960 and 2006, the mean annual temperature increased by 1.3°C, at an average rate of 0.28°C per decade between 1951 and 2006. Another finding investigated by Mengistu et al. (2014) at Sekota area indicated that, an increased annual average minimum temperature and average maximum temperature (0.8°C and 1.4°C per decade respectively). Which are mostly closed to our finding.

On the other hand, Kassie *et al.* (2014) on their investigation on the climate variability and change in Ethiopia; the result revealed that; the mean annual temperature was significantly increased with 0.12 to 0.54 ^{o}C per decade during 1977-2007 periods. The rate of increments of the temperature lined with our findings; the Poudel and Shaw (2016) analysis on the climate variability studies in Nepal, the results showed an increase in maximum and minimum temperature of approximately 0.02 ^{o}C to 0.07^{o}C per year respectively. But the increasing rate of the minimum temperature was more than three times faster than that of the maximum temperature. The values obtained in our analysis, the rate of increment of the minimum and maximum temperature at Weyna Dega zone was lined with this study in 0.8 ^{o}C per decade

(0.08^{O}c / year rate) and 0.3 ^{o}C per decade with (0.03 ^{o}C /year rate) respectively. Opposingly, the result of Dega minimum 0.3 ^{o}C and maximum 0.4 ^{o}C temperatures and Wurch minimum 0.3 ^{o}C and maximum 0.5 ^{o}C temperatures were inversely related to the fastest rate of the two temperature variables of Poudel and his fried analysis.

Other studies conducted by Jury and Funk (2013) stated that, the upward trends in air temperature of 0.03°C per year have been observed over Ethiopia's southwestern region in the period 1948-2006. The National Metrological Agency (NMSA, 2007) in its historical data analysis also reported the increasing trend of 0.37^{0}C per decade in the annual minimum temperature from the period of 1951 to 2005 in Ethiopia lined with our Dega minimum temperature results (*0.3* ^{o}C).

Birara and his friends provided an increased result of annual maximum temperature of 1.08 ^{O}c from the period 1980-2015 with an average rate of 0.2 ^{O}c per decade and minimum temperature also increased by 0.29 ^{o}C /decade at Tana basin region (Birara et al., 2018), in which our study area was located.

The hotter maximum temperatures during kiremit (June-September) (+0.4-0.6°C/decade) were reported by D. Conway and Schipper (2011) (the United State Agency for International Development /USAID/ reporters) in the period of 1981-2014 in Ethiopia. It fits with the Weyna Dega zone of our analysis. Additionally, the USAID elaborated that; observed trend of mean average temperature increased by 1.3 °C and the most rapidly increasing months also between July and September in Amhara Region. In the Kiremit season of our analysis we have got 0.6 ^{o}C at Weyna Dega, ,0.2^{o}C at Dega and 0.5 ^{o}C in Wurch zones increments per decade, and 1.8 ^{o}C ,0.6 ^{o}C and 1.5 ^{o}C increments from 1987-2016 period.

4.8. Seasonal Temperature Trends in the Agroecological Zones

Table 4.5 indicates the average annual value of temperature trend results in Weyna Dega, Dega and Wurch zones indicated as significantly increasing trend at 5% significant level in all temperature variables during the 1987-2016 period. There was a sign of higher p-value (0.0004) of the mean annual maximum temperature than the mean minimum and mean temperatures at Weyna Dega zone in the watershed at Table 4.1. It had the maximum p-value than others across its gridded points. The Weyna Dega seasonal temperature trend inspected that, there is a statistically significant increasing trends in all gridded points of temperature variable.

Table 4.6. Seasonal Temperature Trend in the watershed AEZ gridded points

Grid points	Temp Variable	Kiremit			Meher			Bega			Belg		
		MK (Z)	p-value	δ	MK (Z)	p-value	δ	MK (Z)	p-value	δ	MK (Z)	p-value	δ
W/Dega	T min	0.55	< 0.0001	0.07	0.56	< 0.0001	0.09	0.51	< 0.0001	0.07	0.49	< 0.0001	0.09
	T max	0.35	0.01	0.03	0.29	0.03	0.03	0.30	0.02	0.03	0.23	0.08	0.04
	T mean	0.60	< 0.0001	0.06	0.47	0.00	0.04	0.39	0.00	0.04	0.51	< 0.0001	0.07
Dega Mean	T min	0.00	1.00	0.00	0.05	0.72	0.00	0.49	< 0.0001	0.08	0.45	0.00	0.06
	T max	0.44	0.00	0.04	0.33	0.01	0.04	0.30	0.02	0.05	0.29	0.02	0.05
	T mean	0.31	0.01	0.02	0.35	0.01	0.03	0.55	< 0.0001	0.06	0.42	0.00	0.06
Wurch	T min	0.42	0.00	0.04	0.31	0.01	0.04	0.03	0.83	0.01	0.40	0.00	0.06
	T max	0.47	0.00	0.05	0.34	0.01	0.04	0.36	0.00	0.06	0.38	0.00	0.07
	T mean	0.60	< 0.0001	0.05	0.43	0.00	0.04	0.34	0.01	0.03	0.44	0.00	0.06

Where; MK (Z)=Kendall's tau; (δ)=Sen's slope:

In the seasonal analysis at Table 4.6, the higher values of annual maximum temperature higher p-value causes were reflected on the Kiremit season of higher p-value of (*0.14*) at the lower part of the zone.

The mean annual and mean kiremit maximum temperature decadal increment result indicates 0.3^{o}C and 0.6^{o}C respectively at Weyna Dega zone. The mean annual maximum temperature increment was less than the kiremit mean maximum temperature. The higher increment of maximum temperature was recorded in the second (1996-2006) period of kiremit season which may affect the crop suitability conditions in this zone.

The Minimum and Mean temperature trend at Weyna Dega Zone result showed the significant increasing trend across all seasons. The minimum temperature decadal increment in annual, kiremit, Bega, Meher, and Belg results in this zone were also recorded as 0.8 ^{o}C, 0.7 ^{o}C, 0.9 ^{o}C 0.7 ^{o}C and 0.9^{o}C respectively. Whereas, the mean temperature upward movement was recorded in a 0.6 ^{o}C annual and kiremit, 0.4 ^{o}C in Meher and Bega and 0.7 ^{o}C of Belg seasons of decadal increment in the period of (1987-2016).

Annually all temperature variables at *Dega* zone shows significantly increasing trends. The annual and *kiremit* minimum (0.3 ^{o}C and 0.0 ^{o}C (no trend), maximum (0.4 ^{o}C for both seasons) and mean (0.4 ^{o}C and 0.2 ^{o}C) temperature were recorded respectively in the decadal periods (see Table 4.4). According to Chemere and his friend's finding, similar results were produced, except the midland area of their agroecological zone other lower/lowland/ and upper/highland/ parts of the zones had significantly increasing trends of minimum temperature (Chemere *et al.*, 2018).

The Wurch agroecological zone mean annual and seasonal temperature variable results also indicates significantly increasing trends. The results of annual and kiremit minimum (0.3 ^{o}c and 0.4^{o}C$^{)}$, maximum (0.5 ^{o}C and 0.5 ^{o}C) and mean (0.4^{o}C and 0.5^{o}C) temperature decadal increment were recorded respectively. Additionally, Chemere and his colleague had discussed that, in terms of the agroecological zones, the magnitude of changes in temperature extremes are high in the higher elevation/highland/, but lower in the mid land zones, implying that highlands are experiencing a higher magnitude of change occurrence of climate extremes. This trend is likely to have adverse effects on the livelihoods of people in the highland agroecological zones (Chemere et al., 2018).

The Intergovernmental Panel for Climate Change /IPCC/ reported; a warming of more than 3ºC would have negative effects on crop productivity globally. However, there is a marked difference regionally with regard to the threshold level. For instance, the local mean temperature increases up to 1-3^{0}C the potential for crop productivity is likely to increase slightly at mid to high latitudes. On the contrary, low-latitudes will experience losses in crop productivity for even small local temperature increases of 1-2^{0}C (Parry *et a*l., 2007).

4.9. Length of Growing Period /LGP/ of the agroecological Zones

The annual, kiremit and belg seasons of minimum LGP results at table 4.7 indicates 122, 92 and 31days at Weyna Dega, 122, 122 and 31 days at Dega and 92, 92 and 31days at Wurch zones respectively. The annual, kiremit and belg seasons maximum LGP at a zone is also accounts 214, 122 and 61 days at Weyna Dega, 245, 122 and 92 days at Dega and 275, 122 and 92 days at the Wurch zones respectively. The zones mean annual, kiremit and belg LGP also reveals that, (154, 121 and 14days), (178, 122 and 37) and (171, 118 and 35) at Weyna Dega, Dega and Wurch zones respectively. The kiremit season LGP at each zone ranges from minimum to maximum of (92 to 122day), (122 to 122day) and (92 to 122days) respectively at Weyna Dega, Dega and Wurch zones respectively.

The share of kiremit LGP (78.6, 68.5 and 69.0) at Weyna Dega, Dega and Wurch zones respectively was larger than the other season at all zones. The percentage of mean LGP contribution in the watershed, Weyna Dega zone was also the higher followed by the Wurch zone.

4.9.1. Spatial and temporal LGP conditions

During the three decades in the period of 1987-2016, there were 150, 156 and 156 days at Weyna Dega, 190, 165 and 180 days at Dega and 168, 165 and 180 days of recorded LGP value at Wurch zones. From this decadal data mean of 154, 178 and 171 days at Weyna Dega, Dega and Wurch zones, we examined that, there is no a significant difference in LGP between agroecological zones. Thus, based on the FAO, 1989 classification system in LGP, we couldn't define and categorize the agroecological zones differently within the watershed. However, the second period (1997-2006) were recorded the lower LGP in Dega and Wurch than other periods. While the Weyna Dega zone first period were the lower LGP recorded period.

4.9.2. Crop-moisture characteristics in the watershed

Table 4.8 also presents the mean crop-moisture suitability ranges. The result indicates that, due to the shorten day of moisture /moist season/ availability at the Wurch zone crops that are growing at the lower part of the watershed (Weyna Dega and Dega) had been got the chance to growing at the upper part of the watershed (Wurch zone). The length of growing period responds the reality of relationships between the rainfall distribution and the temperature. The state of temperature increments in the watershed agroecological zones influence the availability of moisture in the agroecological zones. The amount of rainfall in Weyna Dega and Dega zones have had the same, but there was a lower amount in Wurch zone. Similarly, the significantly increasing trends of temperature in the watershed, the Wurch zone has lost much amount moisture that was expected to have than other zones as the traditional classification ranges.

Opposingly, it shows a diminishing amount of moisture availability days. It implies that, the crops that formerly adapted at Weyna Dega and Dega zones may existed with the recent moisture availability of the Wurch zone without stress in moisture availability condition. As the significantly increasing temperature permits to grow selected crops at the zone (Wurch zone) that they couldn't existed in the earlier period, the moisture availability also gives an advance to accept those crops from the lower elevation. The statistically insignificant increasing trends of rainfall and significant increasing trends of temperature results make the "no trends" of LGP result at all zones.

We understand that, within an insignificant increasing rainfall trend, there may not be attain large amount of moisture availability days in a significantly increasing temperature during crop growing period. Thus, that is true that temperature may affect positively the crop distribution directly through making a conducive environment and indirectly in reducing the length /number days/ of growing period (moisture availability days) at the higher elevation. Implies that, crops growing at the lower elevation may survive and adapt at the higher elevation. The significantly increasing of temperature negative effects on crops also had shown by shifting the suitability ranges to unsuitable at the lower elevation/Weyna Dega zone/ of the watershed. Lane and Jarvis (2007) had reported in similar way.

4.9.3. Trends of Length of Growing Periods /LGP/

The annual trends of LGP in the following table 4.6 indicates, the no trend with the Z value of 0.09 and 0.05 at Weyna Dega and Wurch respectively at 5% of significant level. Dega Zone also shown the non-significant decreasing trends (Z= -0.07) at the same significant level. However, there was no distinct slope (magnitudes) at all zones.

The Sen Slops estimator indicates zero (means there was no either increasing or decreasing signs in the zones). Based on the MK test, the kiremit trend of LGP MK(Z) value indicates the nonsignificant positive and negative signs at Wurch (0.24) and Weyna Dega (-0.13) zones respectively. Whereas, due to the constant value of 122 days of LGP in all the years of 1987-2016 period, there was no trend sign in the kiremit LGP at Dega zone. While in the Belg season LGP trends, except the Dega zone insignificant negative trend, both the Weyna Dega and Wurch zones shown insignificantly positive trends at 5% significant level.

Bekele and his friends investigated the trends of length of growing periods at the Awash river basin, Ethiopia, they reported that, except the Koka station of significant increasing trend of the kiremit LGP, other stations were shown insignificant (Bekele et al., 2016) as the Weyna Dega zone of our study results. Additionally, they reported the declined trends of Belg season LGP for 11 out of 12 stations like our result at Dega agroecological zone. One station such as, Koka was shown statistically significant increasing trend at 5% significant level.

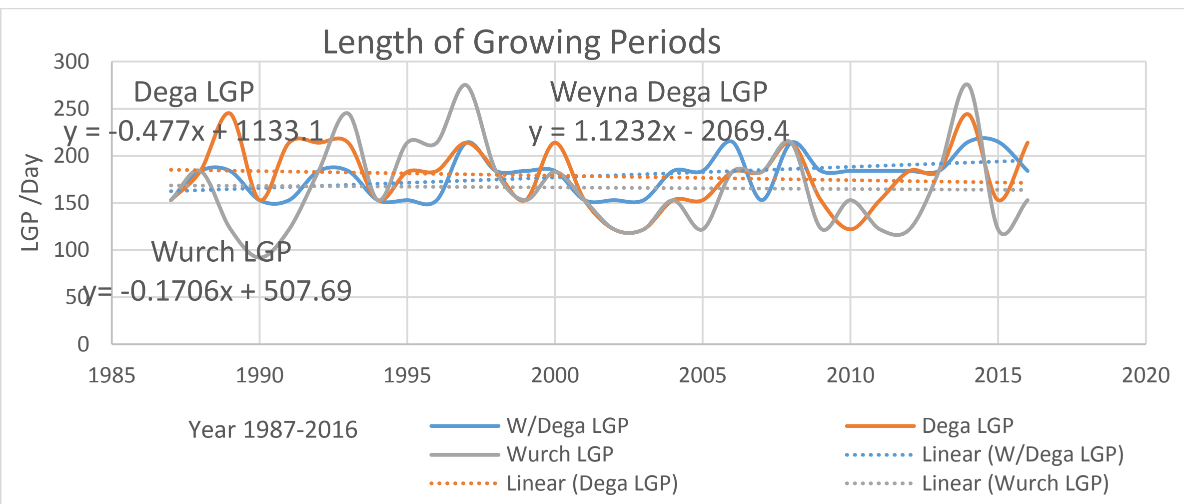

Figure 4.6. The mean annual length of growing period trendlines in the AEZs

The LGP coefficient of variability results at Mieso, Melkassa and Adami Tulu areas of Ethiopia was recorded as 44.5, 25.6, and 37.5% respectively as reported by Edao et al. (2018). Higher LGP variability results was reported in the Belg season than the main rainy season (kiremit) by Bekele et al. (2016) at Awash river basin area, Ethiopia.

Table 4.8 also depicts the mean annual and kiremit decadal moisture availability days from 1987-2016 periods. The result indicates that, there was a fluctuation in amount of moisture availability within the watershed agroecological zones. The first period (1987-1996) mean annual and kiremit LGP was (150 and 122 days), (190 and 122 days) and (168 and 113 days) at Weyna Dega, Dega and Wurch zones respectively. During the second (1997-2006) period the LGP at Weyna Dega, Dega and Wurch zones accounts (156 and 122 days), (165 and 122 days) and (165 and 122 days) in annual and kiremit seasons respectively. While in the third (2007-2016) period the mean annual and kiremit (156 and 119 days), (180 and 122 days) and (180 and 119 days) days was analysed at Weyna Dega, Dega and Wurch zones respectively.

Table 4.7. The decadal LGP in the AEZs

Periods	Weyna Dega Zone				Dega Zone				Wurch Zone			
	Annual	Kiremit	Belg	Meher	Annual	Kiremit	Belg	Meher	Annual	Kiremit	Belg	Meher
1987-1996	150	122	31	31	190	122	58	31	168	113	62	51
1997-2006	156	122	31	35	165	122	43	36	165	122	54	43
2007-2016	156	119	37	31	180	122	46	36	180	119	51	31
Mean/1987-2016/	154	121	33	33	178	122	50	35	171	118	55	42

The smallest annual (92 days) and largest (275 days) LGP was analysed during the first and last/recent/ decades respectively in the years of 1990 and 2014 at Wurch zone. The possible reason for this minimum result may the shortage of the belg rainfall. The amount of annual (939mm), kiremit (918mm) and belg (7mm) rainfall were recorded during the year (1990). The belg rainfall was the smallest in this year than all other years over the 1987-2016 period. (Refer to Appendix 2).

4.10. Crop Diversity Dynamics

4.10.1 Crop-moisture suitably growing crops in the agroecological zones

As depicted at Table 4.8, out of the seven selected indigenous crops, all the 7 at Weyna Dega, 6 (except Maize) at Dega and 2 (Niger Seed and Finger Millet) at Wurch zones were safely (without any stress either increasing or decreasing condition) growing with their moisture requirement ranges. Based on the FAO crop-moisture availability range, the length of growing period is a limiting factor at Dega and Wurch zones. In order to support the occurrence of crops in these zones, LGP must satisfied their moisture needs. Indeed, all crops suitably existed in the weyna Dega zone may grow at Dega and Wurch zones. Because these zones are satisfied the crop-moisture availability conditions that requires at the lower elevation /Weyna Dega/ zone of the watershed. However, the length of moisture availability days is not meet these elevational ranges as FAO specified.

The possible reason for this failure of LGP to satisfy crop needs in the elevational range at the Dega and Wurch zones may the statistically significant increasing temperature effect on the insignificantly increasing rainfall during the main/kiremit/ season. Except the minimum temperature insignificant increment at Dega zone, the increment of temperature variables in the kiremit season is statistically significant in the watershed agroecological zones. Besides, the rainfall distribution shows lower at the higher elevation /Wurch/ zone. Abrha reported the Kiremit rainfall (main rainy season) in lowlands increased significantly, whereas highlands experienced nonsignificant change (Abrha, 2015).

Though, since the LGP results are calculated from the interaction between temperature variables and rainfall, the higher temperature lagged the number of moisture availability days through higher evapotranspiration. The existing rainfall amount in the study area must be greater than the half of potential evapotranspiration. Thus, it shortened the expected moisture availability days at the higher elevations.

The Second Suitable/S2/ Growing Crops

Even though there was not having the significant change on the mean number of crops at the Wurch zone in the S2 minimum requirement, the decadal moisture variation has shown the dynamics of crop suitability on Barley crop by the shortage of moisture requirement in the first and second period. The recent period was meet its requirement. But at the weyna Dega and Dega zone they were grown in more moisture condition than their needs in all periods. Similarly, in the second suitability/S2/ range, Linseed crop was growing in the higher moisture availability in the Weyna Dega and Dega zones in the whole periods, but it is growing in the Wurch zone with its best fit of moisture availability conditions in all periods. (See Table 4.9, S2 part).

In the second suitability class, since the LGP is larger than each crops moisture requirement during their growing season, there will not be a visible decadal moisture variation effects on the existence of crops (crop decadal dynamics). In such a way, based on the Sen's Slope estimator, the magnitude of LGP indicates the none increasing and decreasing sign in the agroecological zones. As such, in the minimum suitability /S2/ of LGP crop rages, most crops could exist above their moisture requirements conditions at all zones and periods. But Maize is suffered in the shortage of moisture at Dega and Wurch as the mean /S1/ LGP ranges in these zones. The Barley and Wheat crops are suffered in the shortage of moisture at Wurch zone. The Tef, Linseed and Finger Millet are dominantly existed crops under S2 minimum moisture requirement conditions above their moisture requirement ranges at all zones and periods.

In the crop-maximum LGP suitability requirement only Linseed crop is growing in its best /S2/ range in the watershed zones and periods. Other crops are suffered in the shortage of moisture availability conditions in both the spatial and temporal existences.

The number of days in minimum LGP requirement of crops are reduced with the reduced suitability conditions (i.e. the suitability condition is reduced when the number of LGP days are diminishing in a minimum LGP requirements as S1 to S2, S2 to S3). While in the maximum LGP requirement of crops, there is no crops existed in the third suitability /S3/ condition. The crops that existed with their suitability ranges at a time may with the fortune of minimum length of moisture availability condition of the area. It will also an obligative factor for the cultivars to use better adaptation strategies.

From the mean crop-moisture requirement (Table 4.9) we justified the Maize crop at Dega and Wurch zones as well as other crops except the Niger Seed and Finger millet crops at Wurch zone (i.e. Tef, Barley, Wheat and Linseed) are suffered in the shortage of soil moisture availability days. Crops which are suffering the moisture stress due to the fluctuating trends of rainfall and statistically significant increasing temperature in the watershed agroecological zones, they need supplementary moisture availability actions during their growing season.

All previous literatures concerned on climate and agroecology were agreed as the recent global warming may affect positively, which makes comfortable for cultivation and for the existences of new crops at the highland areas and negatively at the lower elevation area. Interns, in the continuous effects, it resulted in species extinctions (Pearson, 2014; Rinawati et al., 2013). Alright, temperature may support crops temperature requirement as one of growing factor which affect the existence of crops in a specific area and helps to go forward to the higher elevation. But the inconsistent and erratic nature of the rainfall in the study area agroecological zones, it may not support the longtime existences of crops in the area across their shifts.

Although as the results reported by Abrha (2015), the small amount and insignificant increment of the kiremit rainfall were recorded in the highland area/Wurch zone/ of our study area /watershed. The case may exacerbate the failure of moisture availability in the zones. Thus, the existence of crop in the highland /temperate/ areas may no longer as stayed in the middle and lower elevation areas. Because, the rainfall is in an insignificantly increasing and decreasing trends with the linearly increasing of all the temperature variables, unless the rate of temperature increment must be reduced or stable as it’s and stay the area cool and cold to remain long the area LGP with the available rainfall.

Table 4.8. The decadal and mean crop-moisture suitability ranges in the AEZs

Crops and its Suitability	Mean Moisture Requirement /Days/ at the mean elevation of the zones			Decadal and Total crop richness in suitability								
				Weyna Dega			**Dega**			**Wurch**		
	Weyna Dega (2000 m.a.s.l)	Dega (2500 m.a.s.l)	Wurch /upper Dega/ (3000 m.a.s.l)	P1 (1987-1996)	P2 (1997-2006)	P3 (2007-2016)	P1 (1987-1996)	P2 (1997-2006)	P3 (2007-2016)	P1 (1987-1996)	P2 (1997-2006)	P3 (2007-2016)
S1												
Maize	140-255	245-360	>285	S↕	S↕	S↕	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓
Tef	95-230	145-280	180-315	S↕	S↕	S↕	**S**↕	**S**↕	**S**↕	NS↓	NS↓	NS↓
Barley	105-240	155-290	190-325	S↕	S↕	S↕	S↕	S↕	S↕	NS↓	NS↓	NS↓
Wheat	115-240	165-290	200-325	S↕	S↕	S↕	S↕	S↕	S↕	NS↓	NS↓	NS↓
Niger Seed	120-155	120-155	120-155	S↕	S↕	S↕	S↕	S↕	S↕	S↕	S↕	S↕
Linseed	130-240	160-270	180-290	S↕	S↕	S↕	S↕	S↕	S↕	NS↓	NS↓	NS↓
Finger Millet	90-120	160-280	NS	S↕	S↕	S↕	S↕	S↕	S↕	S↕	S↕	S↕
Total crops in AEZs				7	7	7	6	6	6	2	2	2
S2 Minimum												
Maize	120-140	255-245	-	**NS**↑	**NS**↑	**NS**↑	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓
Tef	80-95	130-145	165-180	NS↑	NS↑	NS↑	NS↑	NS↑	NS↑	NS↑	NS↑	NS↑
Barley	90-105	140-155	175-190	**NS**↑	**NS**↑	**NS**↑	**NS**↑	**NS**↑	**NS**↑	NS↓	NS↓	S↕
Wheat	100-115	150-165	185-200	**NS**↑	**NS**↑	**NS**↑	**NS**↑	**NS**↑	S↕	NS↓	NS↓	NS↓
Niger Seed	110-120	110-120	110-120	**NS**↑	**NS**↑	**NS**↑	**NS**↑	**NS**↑	**NS**↑	**NS**↑	**NS**↑	**NS**↑
Linseed	110-130	140-160	160-180	**NS**↑	**NS**↑	**NS**↑	**NS**↑	**NS**↑	**NS**↑	S↕	S↕	S↕
Finger Millet	75-90	145-160	NS	**NS**↑	**NS**↑	**NS**↑	**NS**↑	**NS**↑	**NS**↑	**NS**↑	**NS**↑	**NS**↑
Total crops in AEZ				7	7	7	6	6	**6**	**4**	**4**	**5**

S2 Maximum Maize	255-300	310-360	350-360	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓
Tef	230-255	260-285	280-305	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓
Barley	240-260	240-260	140-260	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓
Wheat	240-265	240-265	240-265	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓
Niger Seed	150-210	150-210	150-210	S↕	S↕	S↕	S↕	S↕	S↕	S↕	S↕	S↕
Linseed	240-270	240-270	240-270	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓	NS↓
Finger Millet	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
Total crops in AEZ				1	1	1	1	1	1	1	1	1

Where **NS↑**= Not-suitable due to higher moisture availability, in this case intercropping or growing more than one crops may possible. NS↓=unsuitable due to /the shortage/ lower moisture availability. S↕=In a suitable range and NS= out of the range (crop has not existed at all)

Implications of the signs; NS↑= Not-suitable due to higher moisture availability; implies, intercropping or growing more than one crops may possible. NS↓=unsuitable due to /the shortage/ lower moisture availability. But crops that are growing at Weyna Dega and Dega zones can grow in a suitable /S↕/at Wurch zone, because at the Wurch zone the availability of moisture can satisfied the crop-moisture requirements that needed at weyna Dega zone. On the other hand, crops growing under a /S↕/ suitable range means, crops existed with their optimum moisture requirements in the area. But it will be affected by the statistically significant increasing temperature in the near future. Because, the rainfall and temperature trends are not in a similar rate. As such, the trend of kiremit rainfall increment is insignificant. The availability of moisture during the cropping season may affected with this inversed relationship of these two climate variables. The sign NS is = not suitable /out of the range/ (crop has not existed at all) as specified by FAO, 1989.

4.10.2. Crop-temperature related diversity dynamics

The number of crops growing in the agroecological zones are differed in time. The difference was not only between the agroecological zones, but also within the agroecological zone parts in time. The crop diversity dynamics is the interplay changes of number of crops due to the varied temperature variables in an agroecological zone in the decadal periods. While crop migration is the movement of crops from one place to another place (AEZ to AEZ) in time (decadal period).

The first period (1987-1996) and Weyna Dega zone was the initial periods and part /AEZs/ of our analysis respectively. Based on the mean temperature increment effects on crop diversity, the number of crops and decadal dynamics at each agroecological zone had been analysed. But the effects of mean temperature had not a sole variable that change the crops suitability conditions. The maximum and minimum temperature may exert their own effects on the crop diversity situation in the agroecological zones. Thus, the mean temperature decadal effects have been analysed within and between the agroecological zones followed by the reason by which temperature variable /either maximum or minimum/ in the following sections. Because, maximum temperature (daytime temperature) accelerates crop maturity, resulting in reduced grain filling, while higher minimum nighttime temperatures increase respiration losses (Niang et al., 2017). Following the effects, farmers in different AEZs employ different farm practices on the AEZ they are situated in, they will choose a specific farm type, irrigation, crop species, and livestock species that fit that AEZs (Seo, 2011).

Crop-temperature Diversity Dynamics at Weyna Dega Zone

In the mean temperature, the Weyna Dega zone parts have suitably growing all selected indigenous crops (i.e., Maize, Tef, Barley, Wheat, Nigger Seed, Linseed and Finger Millet) in all decadal periods from 1987-2016 years. It means that, there is no visible spatial and temporal negative effects on crop diversity/number of selected crops/ to makes dynamics within the zone. (Refer to Table 4.10 and Appendix 5). Thus, fortunately we used this zone as an initial crop saturated zone. However, the minimum and maximum temperature requirements of the crop at each parts and periods are not equally met. For example, the minimum temperature in the first period was not satisfied the Maize and Niger Seed crops at the lower part of the Weyna Dega Zone.

As we discussed at the temperature trends, the lower part of Weyna Dega zone maximum temperature was indicated insignificant increments especially at gridded point one. That is why here at the lower part of Weyna Dega zone, the Tef crop decadal maximum temperature suitability condition was fluctuated from S4 to NS and S4 in the first to second and third decades respectively, that is because of the inconsistent increment of this temperature variable at this part. But as the trend result indicates, other temperature variables are in a series of increasing from period one to two, and two to three periods in a sequential increasing feature with their positive and negative effects on crops across parts. See other suitable and unsuitable conditions for different crops in partly and periodically across Table 4.9 and Appendix 5.

Table 4.10. The Spatial and Temporal Crop-Temperature Suitability Analysis in Weyna Dega

Crop type	Maximum Temperature			Mean 1987-2016	Minimum Temperature			Mean 1987-2016	Mean Temperature			Mean 1987-2016
	Decadal Period				Decadal Period				Decadal periods			
Average in Parts and periods	1987-1996	1997-2006	2007-2016		1987-1996	1997-2006	2007-2016		1987-1996	1997-2006	2007-2016	
Maize	S1	S1	S1	S1	NS	NS	S4	NS	**S**	**S**	**S**	**S**

Tef	S4	S4	S4	S4	S4	S4	S3	S4	**S**	**S**	**S**	**S**
Barley	S1	S2	S2	S2	S1	S1	S1	S1	**S**	**S**	**S**	**S**
Wheat	S1	S2	S2	S2	S3	S3	S2	S3	**S**	**S**	**S**	**S**
Nigger Seed	S2	S3	S3	S3	NS	NS	NS	NS	**S**	**S**	**S**	**S**
Linseed	S1	S2	S2	S2	S4	S4	S3	S4	**S**	**S**	**S**	**S**
Finger Millet	S1	S1	S1	S1	NS	NS	NS	NS	**S**	**S**	**S**	**S**
Periodical Richness with Suitability in the W/Dega AEZ	S1=5 S2=1 S4=1	S1=2 S2=3 S3=1 S4=1	S1=2 S2=3 S3=1 S4=1	S1=2 S2=3 S3=1 S4=1	S1=1 S3=1 S4=2 NS=3	S1=1 S3=1 S4=2 NS=3	S1=1 S2=1 S3=2 S4=1 NS=2	S1=1 S3=1 S4=2 NS=3	S=7	S=7	S=7	S=7

In the Weyna Dega Agroecological zone, the decadal periods of maximum temperature increment play a significant shift of crop diversity within the zone. In the general mean period (1987-2016) of number of crops/richness/ at the zone (Weyna Dega) indicates suitable one /S1/ for two crops (Maize and Finger Millet), suitable two/S2/ for three crops (Barley, Wheat and Linseed), suitable three/S3/ for one crop (Niger Seed) and Suitable four/S4/ for one crop such as Tef in maximum Temperature at the lower part.

The number of crops /richness/ in the case of minimum temperature results also revealed that, (S1 for Barley), (S3 for Wheat), (S4 for Tef and Linseed crops) and (not suitable /NS/ for 3 Maize, Niger Seed and Finger Millet) crops are existed in the same period at the lower part of the zone.

In all periods at all part of the zone Maize and Finger Millet crops are existed with a best suitability ranges(S1) in maximum temperature. While, in minimum temperature except the third periods suitable four/S4/ condition for maize crop, Finger Millet was suffered with the NS range in all periods. Regardless of their needs in minimum and maximum temperature, in the rough analysis (the mean temperature) may permit to exist all crops in a suitable/S1/ condition at all parts and periods in the zone.

On the other hand, Tef and Niger seed crops are mostly affected crops in Weyna Dega than other crops in both temperature /maximum and minimum/ variables. The maximum temperature increment plays important role in restricting the Tef existence under the lower elevation and shifting to higher elevation under the warming condition. From this analysis we could summarized that, the upper part of the Weyna Dega has got a special crop richness than lower parts. However, all crops may exist in some shifts of their suitability ranges either by the maximum or minimum temperatures.

Though, the mean temperature may compensate this shift of crop requirements to support their existences. The maximum temperature increment in the higher elevation permits for cops to exist in a suitable condition, whereas, the minimum temperature is oppressed crops to suffer with below their needs. Similar reports were done by Hussain and Bangash (2017) as the maximum temperature increment in the higher elevation and the state of minimum temperature at the lower elevation supports the existences of crops accordingly. Indeed, when we move towards the elevation within the Weyna Dega zone parts, we can find the number of selected crops existed within their better suitability ranges (S1) than the lower parts.

From this general result we summarized that, in the Weyna Dega zone the Tef crop is highly affected with (S4) suitability range in both cases of (minimum and maximum) temperatures. The statistically significant increasing trend of maximum temperature affects all crops that have been released their suitability ranges through time from S1 and S2 to S3 and S4 respectively except Maize and Finger Millet (Look at Table 4.10 and Appendix 5 Parts and periods).

Crop-temperature Diversity Dynamics at Dega Zone

The crop diversity richness/ number of crops/ in mean temperature at the Dega zone follows the same routs as Weyna Dega diversity situation in parts and periods. Thus, due to the significantly increasing mean kiremit temperature by 0.2^{o}c per decade, the crop-mean temperature suitability condition in the three periods indicates three (Tef, Barley and Wheat) out of seven crops are growing under suitable condition in all periods (1987-2016). Whereas, the area for other crops were not suitable. But the number of crops in a decadal bases was differed as 3 crops listed above in the first and second periods and 4 in the recent period by one crop increasing /Linseed/.

Partly, the Dega zone lower and middle parts were grown only 3 crops (Tef, Barley and Wheat) out of seven selected indigenous crops in the first (1987-1996) period. The upper part of the zone also growing only 2 crops (Barley and Wheat). In time during the 1997-2006, the crops at the lower part were increased by two additional crops (Maize and Linseed) and the number of growing crops is increasing to 5 crops. The middle part of the zone in this period holds similar number of crops growing in a suitable condition. While at the lower part of the zone, the number of crops was increasing by Tef crop to 3 crops in the time of 10 years of mean temperature increment In the recent period (2007-2016), the number of crops growing at the lower and upper parts of the zone, indicates similar as the second period (1997-2006) with similar species. But there is a change in the middle parts of the zone as 5 than 3 crops in the second period by making comfort for Maize and Linseed crops growing.

In the crop-maximum temperature suitability situation, seven crops in the first period, six crops in the second and third periods were grown in Dega zone (Table 4.10 and Appendix 10). Tef is the only negatively affected crops in the recent period from S1 in the first to S2 in the second and third periods. While in minimum temperature because of its insignificant increasing trends, there is no crops that existing in a suitable /S1/ condition from the beginning to the recent periods. Barley is growing in a second /S2/ suitability condition followed by Wheat and Linseed crops of their NS to S4 condition shifts in a recent time. With the inversely relationship, minimum temperature is the most limiting factor for the growing of crops in the Dega zone than maximum temperature unlikely happened at the Weyna Dega zone.

Table 4.11. Decadal Crop-temperature suitability analysis in parts at Dega Zone

Crop types	Maximum Temperature			Mean	Minimum Temperature			Mean	Mean Temperature			Mean
	198	199	2007	1987	198	199	200	198	198	199	200	1987-

	7-1996	7-2006	-2016	-2016	7-1996	7-2006	7-2016	7-2016	7-1996	7-2006	7-2016	2016
Maize	S1	S1	S1	S1	NS	NS	NS	NS	NS	NS	NS	NS
Tef	S1	S2	S2	S2	NS	NS	NS	NS	S	S	S	S
Barley	S1	S1	S1	S1	S2	S2	S2	S2	S	S	S	S
Wheat	S1	S1	S1	S1	NS	NS	S4	S4	S	S	S	S
Nigger Seed	S1	S1	S1	S1	NS	NS	NS	NS	NS	NS	NS	NS
Linseed	S1	S1	S1	S1	NS	NS	S4	S4	NS	NS	S	NS
Finger millet	S1	S1	S1	S2	NS	NS	NS	NS	NS	NS	NS	NS
Decadal Richness with Suitability in the Dega AEZ	S1=7	S1=6 S2=1	S1=6 S2=1	S1=5 S2=2	S2=1 NS=6	S2=1 NS=6	S2=1 S4=2 NS=4	S2=1 S4=2 NS=4	S=3 NS=4	S=3 NS=4	S=4 NS=3	S=3 NS=4

The crop-temperature suitability conditions at Dega is increased than Weyna Dega zone in maximum temperature as for 6 out of 7 crops S1 and 1 crop S2 at lower and middle respectively and 7 crops are S1 at the upper part. While in minimum temperature, crops at Dega are suffered more than Weyna Dega with unsuitable /NS/ for 3 crops at lower and middle and 6 crops in the upper parts. Except Barley (S2 condition), all crops are suffered in minimum temperature by unsuitable (NS) condition at all parts and periods. Wheat crop is existed in the second and third periods at all parts and Linseed crop is growing at lower and middle parts only in S4 suitability ranges.

Crop Diversity Dynamics at Wurch Zone

As we can see in Table 4.12, the statistically significant increasing mean kiremit temperature in 0.5^{o}c per decade, the Wurch zone afford the existence of three (Tef, Barley and Wheat) crops in a suitable condition as a Dega zone from the total mean periods of 1987-2016. But the existence was not permanent in the decadal periods as the Weyna Dega. Means that, the Weyna Dega zone period holds their own similar number of crops. While in the Wurch zone the suitably existing number of crops are increases in time from the first period of 2 crops to 3 crops in the second and third/recent periods. For example, in the mean temperature during the first period (1987-1996), two crops such as Barley and Wheat were growing. But the second and recent periods increased temperature supports to suitably growing of Tef crop and the number of crops has increased to three crops.

Although, in the whole period (1987-2016) the maximum temperature had a positive response or make a suitable condition for all crops. Most specifically, Hussain and his friend reported that, maximum temperature makes favorable condition for the existence and expansion of Maize and Wheat crops in the wet mountain area (Hussain andBangash, 2017). Additionally, they discussed the increase of maximum temperature in such areas may have some positive influences on the occurrences of major crops by limiting the extreme cold condition and making shorten their maturity days in the region. But some short-range crops like Tef affected by the increase of maximum temperature even in the higher elevation area for example, the recent period (2007-2016) temperature affect the Tef crop by shifting the area from S1 to S2 condition.

Except the Barley suitability condition shifts from suitable three/S3/ in the first period to a second suitable condition /S2/ in the second and third periods, the existence of all other crops are not supported by minimum temperature. The effect on Tef was due to the significantly increasing trend of minimum temperature at the zone by 0.4^{o}c per decade. But because of the higher elevation of the area the increment is not satisfied the crops needs. In general, minimum temperature was a limiting factor for almost all crops at Wurch and Dega zones as well as for some upper part of Weyna Dega crops. Previous research reports line with our analysis proved that, any change in recommended crop-minimum temperature requirement below the threshold level at wet mountain area may adversely affect the growing of crops (Hussain andBangash, 2017).

Table 4.12. Decadal Crop-Temperature suitability analysis at Wurch Zone

Wurch AEZ	Maximum Temperature			Mean	Minimum Temperature			Mean	Mean Temperature			Mean
	1987-1996	1997-2006	2007-2016	1987-2016	1987-1996	1997-2006	2007-2016	1987-2016	1987-1996	1997-2006	2007-2016	1987-2016
Maize	S1	S1	S1	S1	NS	NS	NS	NS	NS	NS	NS	NS
Tef	S1	S1	S2	S1	NS	NS	NS	NS	NS	S	S	S
Barley	S1	S1	S1	S1	S3	S2	S2	S2	S	S	S	S
Wheat	S1	S1	S1	S1	NS	NS	NS	NS	S	S	S	S
Nigger Seed	S1	S1	S1	S1	NS	NS	NS	NS	NS	NS	NS	NS
Linseed	S1	S1	S1	S1	NS	NS	NS	NS	NS	NS	NS	NS
Finger Millet	S1	S1	S1	S1	NS	NS	NS	NS	NS	NS	NS	NS
Periodical Richness with Suitability in Wurch	S1=7	S1=7	S1=6 S2=1	S1=7	S3=1 NS=6	S2=1 NS=6	S2=1 NS=6	S2=1 NS=6	S=2 NS=5	S=3 NS=4	S=3 NS=4	S=3 NS=4

The effects of climate variability on crop growing and distribution across agroecological zone is not uniform. The results show that the effect of average temperature is positive on all selected indigenous crops across the three agroecological zones. This is lined with Hussain and Bangash (2017) reports.

As concluded by Evangelista and his friends, the change in rainfall season and temperature in Ethiopia directly affect the distribution of Tef crop (Evangelista et al., 2013). On the other hand, in the elevational bases, Yumbya and colleagues discussed that, the Tef crop had fast shifting from the lower elevation to higher elevation (Yumbya *et al.*, 2014).

The shift indicated from the South-East to North-West towards the higher elevation of Northern Ethiopia (i.e. South Gonder, East Gojam and South Wollo areas). Following its short ranges of climate suitability condition of our analysis, Tef is highly vulnerable for climate variability, especially by the increasing state of temperature. That is why those previous researchers additionally discussed as the suitable areas at lower elevation are early affected and will be concentrated between 1200-2500 meters as they predicted. Additionally, they provided a detail information on the loose of 24% climatic suitable area of land for Tef crop in the future (2050). It will be concentratedly located in the area that temperature is between 27 °C and a low of 15 °C in 2050. That is why in our analysis, the Tef crop is shifting and moving fast to the higher elevation (Dega and Wurch zones) than other indigenous cops.

Other thoughts had attempts in the growing season of crop-temperature relationships analysis by Hussain and Bangash (2017) reported that, any changes in temperature beyond and below optimum level make disastrous for crops yield. Thus, the minimum temperature is positively related to maize and wheat yields. As minimum temperature increases yield of these two major crops also increases. In our analysis we proved that, due to the lower state of the crops need, the minimum temperature in the higher elevation is the limiting factor for the occurrences of all selected indigenous crops except Tef Barley and Wheat crops. It means that, as the minimum temperature increases, the number of crops in the higher elevation had been increase. On the other side, the significantly increasing of minimum temperature is still support the growing of all crops with stayed below their requirements and lag the maximum temperature effects on the crops at the mean suitable state at the lower elevation of the watershed.

On the other hand, they discussed that, increases in maximum temperature during the growing period is not negatively affecting these crops productivity. Although, our result indicates maximum temperature at the lower elevation is negatively affect most crops from the earlier to the recent, but also support the crops to grow at the higher elevation.

Furthermore, the average temperature increases positively related to wheat and maize crop yields. Means that, in our case, production is the function of diversity. In terns, reduction in yield is reduction of diversity due to the low of producer choices in their farm lands. As average temperature increases yield of these two crops also increases (Hussain andBangash, 2017). As proved by those guys, the mean temperature is the reason of dominantly growing of all selected crops at the lower elevation (Weyna Dega) to the higher elevation (Dega and Wurch) zones accordingly.

Tirtha and his friends discussed as the Barley crop is dominantly growing in the cool temperate regions (Katwal *et al.*, 2015), whereas the Maize crops are dominantly growing crops at dry sub-tropical regions. As the Maize crops dominantly growing at the lower part of our study area, Barley is dominant growing at all agroecological zones and considered as wide range crops.

Chapter Five: CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The paper was initiated to analyse the quantitative data at the watershed and most specifically at the agroecological zone levels. The trend of climate variables in Gumara watersheds' agroecological zones was evaluated by Mann Kendal and Sen Slope's estimator. The Coefficient of Variability/CV/ were used to analyse the climate variables. Based on the FAO crop-climate specification, the crop-climate requirement and the crop diversity dynamics due to the varied climate were analysed.

Thus, the historical annual rainfall data trend result indicates insignificantly increasing trends, whereas the length of growing period in the watershed also non-significant trend was observed with no any slops magnitude. The annual and kiremit rainfall coefficient of variability between the agroecological zones determined as increasing in variability towards the elevation (i.e., Weyna Dega to Dega to Wurch zones). But the result is in a similar category of less/slightly variable. The temperature variables trends also show statistically significant increasing trends. However, based on the gridded point data analysis, there is a result variation of these climate variables between agroecological zones and even within the agroecological zone parts itself in the watershed. The trend of rainfall in the gridded points of the agroecological zones of the watershed could not be in a concludable manner in terms of place and time. It fluctuates up and down in the study period of 1987-2016 at a single grid point without a detectable trend. The other grid points may also either in the increasing or decreasing trends. As the result obtained in the temperature, the patterns and distribution of rainfall is not governed by elevation. The calculated LGP has no significance difference as differed in elevation within the watershed, so, that is impossible to categorize the watershed to agroecological zones in terms of the availability of moisture within the watershed. The moisture availability result summarized the watershed in to one moisture availability condition called the cool and humid zone.

Even though, the LGP decadal variability doesn't make crop dynamic in the analysis period, temperature does at Weyna Dega zone lower part. The effect of temperature lags the upper part zones LGP in the watershed and, helps to accept and grow some locally new indigenous crops from the lower zones. The Weyna Dega zone mean temperature supports to grow all selected indigenous crops at all parts and periods. But due to the maximum temperature negative effect by laying above their requirements, some crops are suffered more from earlier to the recent periods and upper to lower parts. Furthermore, almost all of the selected indigenous crops at the Weyna Dega zone reaches at its maximum rate of temperature requirement. These crops may start to loss their best suitability condition/S1/ and start to growing in other suitability condition/S2, S3.../ in the near future in the mean temperature, if all temperature variables increment is continuing as the recent rate. In such away, Tef is suffered more in maximum temperature at Weyna Dega zone followed by Nigger Seed crop. On the other hand, minimum temperature in this zone is the limiting factor for the distribution and growing of some crops increasingly to the higher elevation. But inversely to the maximum temperature, the recent decade temperature makes better opportunities for crops growing at the zone.

In the Dega zone, the mean temperature makes dynamics the crops in a decadal period at all parts. The number of crops growing in the zone and its parts is increasing from the earlier decade to the second and third/recent decades. For example, the lower part of the Dega zone accept three crops/Tef, Barley, and Wheat/ from the upper part of Weyna Dega in the first decade and the area increased its number of growing crops to five by making comfort for Maize and Linseed crops. Likewise, the Weyna Dega zone; the recent maximum temperature has negatively affected some of the aforementioned crops at the lower part of the Dega zone.

5.2. Recommendations

Based on the result found in this paper which raised from the problems of our initiatives in the watershed, the following points are suggested for all field of agriculture practitioners, particularly for anyone who/which have a focus on crop production and/ diversification departments and food security facilitators anywhere. Indigenous crop conservation mechanisms shale be designed (it may be gene bank conservation facility). Following the fluctuating and erratic nature of rainfall and the statistically significant increasing temperature, improved and early matured crops must be facilitated in the watershed. Supportive irrigation mechanisms should be introduced to the watershed. On the other hand, updated metrological information/ extension services should be available to the local farming community in the study area. The traditional agroecological zone classification system of Ethiopia must be systematically updated. In order to detect the detail information on crop-climate associations/ effects of climate variability on crop diversity, the yearly analysis (the start and end date of moisture availability analysis in the soil) rather than decadal analysis; shall be suggested for future researches.

REFERENCES

Abay, F., Bjørnstad, A., & Smale, M. a. M. (2009). Measuring on farm diversity and determinants of barley diversity in Tigray, northern Ethiopia. Ethiopian Journal of Science. *1*(2).

Abrha, M., Gebrehiwot. (2015). Local climate trends and farmers' perceptions in Southern Tigray, Northern Ethiopia. International Journal of Environment Sustainability., *4*(3).

Ackerly, D. D. (2012). *Potential impacts of climate change on biodiversity and ecosystem services in the San Francisco Bay Area*: California Energy Commission.

Ademe, A., Kassa, B., Goshu, D., Mwanjalolo, M. J. I. J. o. A. M., & Development. (2017). Impact of Climate Variability on Cool Weather Crop Yield in Ethiopia. *7*(4), 415-428.

Admassu, S., Seid, I. J. E. J. o. S., & Technology. (2006). Analysis of rainfall trend in Ethiopia. *3*(2), 15-30.

Agbossou, E., Toukon, C., Akponikpè, P., & Afouda, A. J. A. C. S. J. (2012). Climate variability and implications for maize production in Benin: A stochastic rainfall analysis. *20*(2), 493-503.

Aguilar, J., Gramig, G. G., Hendrickson, J. R., Archer, D. W., Forcella, F., & Liebig, M. A. J. P. o. (2015). Crop species diversity changes in the United States: 1978–2012. *10*(8), e0136580.

Ahmed, A., Hussain, H. J. D. C. F. S. R. L., & Change, C. f. G. (2009). Climate Change and Livelihoods: An Analysis of Agro-ecological Zones of Bangladesh.

Alemayehu, A., & Bewket, W. J. G. A. S. A., Physical Geography. (2017). Local spatiotemporal variability and trends in rainfall and temperature in the central highlands of Ethiopia. *99*(2), 85-101.

Alemayehu, A. a. B., Woldeamlak (2016). Local climate variability and crop production in the central highlands of Ethiopia. *19*, 36-48.

Anwar, H. a. R., Bangash. (2017). Impact of climate change on crops' productivity across selected agro-ecological zones in Pakistan. *56*(2), 163-187.

Araya, A., Stroosnijder, L. J. A., & Meteorology, F. (2011). Assessing drought risk and irrigation need in northern Ethiopia. *151*(4), 425-436.

Asai, K. (2017). Questionnaire survey on farming adaptation for climate variability in Serang Municipality, Indonesia. *67*(2), 99-106.

Asfaw, A., Simane, B., Hassen, A., Bantider, A. J. W., & Extremes, C. (2018). Variability and time series trend analysis of rainfall and temperature in northcentral Ethiopia: A case study in Woleka sub-basin. *19*, 29-41.

Azage, M., Kumie, A., Worku, A., Bagtzoglou, A. C., & Anagnostou, E. J. P. o. (2017). Effect of climatic variability on childhood diarrhea and its high risk periods in northwestern parts of Ethiopia. *12*(10), e0186933.

Bayissa, Y., Tadesse, T., Demisse, G., & Shiferaw, A. J. R. S. (2017). Evaluation of satellite-based rainfall estimates and application to monitor meteorological drought for the Upper Blue Nile Basin, Ethiopia. *9*(7), 669.

Behailu, G. (2018). *Climate Change and Variability: Farmers' Perceptions in Sekota Woreda, Northeastern Ethiopia.* Addis Ababa University,

Bekele, D., Alamirew, T., Kebede, A., Zeleke, G., Melese, A. M. J. J. o. W., & Change, C. (2016). Analysis of rainfall trend and variability for agricultural water management in Awash River Basin, Ethiopia. *8*(1), 127-141.

Benin, S., Ehui, S., Pender, J. J. E., Development, & Sustainability. (2003). Policies for livestock development in the Ethiopian highlands. *5*(3-4), 491-510.

Berhanu, B., Melesse, A. M., & Seleshi, Y. J. C. (2013). GIS-based hydrological zones and soil geo-database of Ethiopia. *104*, 21-31.
Bewket, W. (2009). *Rainfall variability and crop production in Ethiopia: Case study in the Amhara region.* Paper presented at the Proceedings of the 16th International Conference of Ethiopian Studies.
Birara, H., Pandey, R., Mishra, S. J. J. o. W., & Change, C. (2018). Trend and variability analysis of rainfall and temperature in the Tana basin region, Ethiopia. *9*(3), 555-569.
Buishand, T. A. J. J. o. h. (1982). Some methods for testing the homogeneity of rainfall records. *58*(1-2), 11-27.
Chakilu, G., & Moges, M. J. H. C. R. (2017). Assessing the Land Use/Cover Dynamics and its Impact on the Low Flow of Gumara Watershed, Upper Blue Nile Basin, Ethiopia. *7*(268), 2.
Chemere, B., Kim, J., Lee, B., Kim, M., Kim, B., & Sung, K. J. A. (2018). Detecting long-term dry matter yield trend of sorghum-sudangrass hybrid and climatic factors using time series analysis in the Republic of Korea. *8*(12), 197.
Coll, J., Bourke, D., Gormally, M., Sheehy Skeffington, M., & Sweeney, J. (2013). Winners and Losers: Climate Change Impacts on Biodiversity in Ireland.
Conway, D., & Schipper, E. L. F. J. G. E. C. (2011). Adaptation to climate change in Africa: Challenges and opportunities identified from Ethiopia. *21*(1), 227-237.
Conway, D. S. (2000). Some aspects of climate variability in the north east Ethiopian Highlands-Wollo and Tigray. Ethiopian Journal of Science. *23*(2), 139-161.
Degefu, M. A., & Bewket, W. J. R. e. c. (2014). Variability and trends in rainfall amount and extreme event indices in the Omo-Ghibe River Basin, Ethiopia. *14*(2), 799-810.
Deressa, T. T. (2011). *Effects of climatic conditions and agro-ecological settings on the productive efficiencies of small-holder farmers in Ethiopia*. Retrieved from
Di Falco, S., Bezabih, M., & Yesuf, M. J. E. E. (2010). Seeds for livelihood: crop biodiversity and food production in Ethiopia. *69*(8), 1695-1702.
Donfouet, H. P. P., Barczak, A., Détang-Dessendre, C., & Maigné, E. J. E. E. (2017). Crop production and crop diversity in France: a spatial analysis. *134*, 29-39.
Edao, A., Kibert, K., & Mamo, G. J. A. C. S. T. (2018). Analysis of Start, End and Length of the Growing Season and Number of Rainy Days in Semi-Arid Central Refit Valley of Oromia State, Ethiopia. *6*(386), 2.
Engels, J., Diulgheroff, S., & Alvarez, J. S. (2014). Management of Crop Diversity: Key Practices for DRR Implementers.
Esayas, B., Simane, B., Teferi, E., Ongoma, V., & Tefera, N. J. A. i. M. (2018). Trends in extreme climate events over three agroecological zones of southern Ethiopia. *2018*.
Evangelista, P., Young, N., & Burnett, J. J. C. c. (2013). How will climate change spatially affect agriculture production in Ethiopia? Case studies of important cereal crops. *119*(3-4), 855-873.
FAO. (1989). *Reconnaissance physical land evaluation in Ethiopia. The Peoples of Democratic Republic of Ethiopia Ministry of Agriculture, Land use Planning and Regulatory Department, Addis Ababa Ethiopia.* (Vol. 37): Food & Agriculture Organization of the UN (FAO).
FAO. (1996). *Agro-ecological zoning: Guidelines. Agriculture Organization of the United Nations. Soil Resources Conservation Service,* Food & Agriculture Org.

FAO. (1998). *Crop evapotranspiration: Guidelines for computing crop water requirements. FAO irrigation and drainage paper 56. Rome, Italy.* . Retrieved from
FAO. (2017). The Food and Agricultural of United State: Strategy on Climate Change. *181*, 18-22.
FAO. (2012). *State of Food and Agriculture 2012: Investing in Agriculture for a Better Future*: FAO.
Fischer, G., Van Velthuizen, H., Shah, M., & Nachtergaele, F. O. (2002). Global agro-ecological assessment for agriculture in the 21st century: methodology and results.
Ganaie, S. A., Bhat, M. S., Kuchay, N. A., & Parry, J. (2014). Delineation of micro agro-climatic zones of jammu and kashmir. *10*(1), 219-225.

Gebrechorkos, S., Hülsmann, S., & Bernhofer, C. (2018). Evaluation of multiple climate data sources for managing environmental resources in East AfricaHydrology.Earth System Sciences. *22*(8), 4547-4564.

Gebreegziabher, Z., Stage, J., Mekonnen, A., & Alemu, A. (2011). *Climate change and the Ethiopian economy: A computable general equilibrium analysis*: Resources for the Future.

Gebremicael, T. G., Mohamed, Y. A., van der Zaag, P., Berhe, A., Haile, G. G., Hagos, E. Y., & Hagos, M. K. J. H. E. S. S. D. (2017). Comparison and validation of eight satellite rainfall products over the rugged topography of Tekeze-Atbara Basin at different spatial and temporal scales. 1-31.

Gedefaw, M., Yan, D., Wang, H., Qin, T., Girma, A., Abiyu, A., & Batsuren, D. J. A. (2018). Innovative trend analysis of annual and seasonal rainfall variability in Amhara regional state, Ethiopia. *9*(9), 326.

Getachew, M. (2014). *The Effects of Urban Development Activity on the Relocated Residents: The Case of Arada Sub-City*. Addis Ababa University,

Gore, T., Hillier, D. J. O. P., Practice: Agriculture, F., & Land. (2011). Climate Change and Future Impacts on Food Security. *11*(7), 57-62.

Gorfu, D. a. A., Eshetu (2012). Crops and agro-ecological zones of Ethiopia.

Gutu, T., Bezabih, E., Mengistu, K. J. I. R. J. o. A. S., & Science, S. (2012). Econometric analysis of local level perception, adaptation and coping strategies to climate change induced shocks in North Shewa, Ethiopia. *2*(8), 347-363.

Hansen, G., & Cramer, W. J. N. C. C. (2015). Global distribution of observed climate change impacts. *5*(3), 182.

Hare, W. (2003). Assessment of knowledge on impacts of climate change-contribution to the specification of art. 2 of the UNFCCC: Impacts on ecosystems, food production, water and socio-economic systems.

Helmiö, T., Varis, O., & Kokkonen, T. J. W. W. M. O., Working Group on Hydrology, Regional Association VI . Draft Report: WGH/RA VI/Doc. (2005). Climate and water: operational hydrology and climate change in Europe. *6*, 26.

Howden, M., Hughes, L., Dunlop, M., Zethoven, I., Hiblert, D., & Chilcott, C. (2003). Climate change impacts on biodiversity in Australia: Outcomes of a workshop sponsored by the Biological Diversity Advisory Committee, 1-2 October 2002.

Hui, D. (2013). Global climate change and biodiversity: Issues and future research. Journal of Biodiversity Endangered Species. *1*(1), 1-2.

Hurni, H. (1998). Agroecological belts of Ethiopia. Explanatory notes on three maps., *1*(1,000,000).

Hussain, A., & Bangash, R. a. J. P. (2017). Impact of climate change on crops' productivity across selected agro-ecological zones in Pakistan *56*(2), 163-187.

IIASA, F. a. I., & FAO, R., Italy. (2012). Global Agro-ecological Zones (GAEZ v3. 0). Laxenburg, Austria.

IPCC. (1990). *Scientific Assessment of Climate Change: The Policymakers' Summary of the Report of Working Group I to the Intergovernmental Panel on Climate Change*: World Meteorological Organization/United Nations Environment Programme ….

IPCC. (2001). The scientific basis. Contribution of Working Group 1 to the Third Assessment Report of the Intergovernmental Panel on Climate Change, edited by JT Houghton, Y. Ding, DJ Griggs, M. Noguer, PJ van der Linden, X. Dai, K. Maskell and CA Johnson (eds). Cambridge University Press, Cambridge, UK, and New York, USA, 2001. No. of pages: 881. Price£ 34.95, US 49.95,ISBN0- 521- 01495- 6(paperback).£90.00,US 130.00, ISBN 0- 521- 80767- 0 (hardback). *22*(9), 1144-1144.

IPCC. (2013). Climate Change 2013: The physical science basis. contribution of working group I to the fifth assessment report of IPCC the intergovernmental panel on climate change. In: Cambridge University Press.

IPCC. (2014). *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change*: Ipcc.

IPCC. (2018). *Global Warming of 1.5° C: An IPCC Special Report on the Impacts of Global Warming of 1.5° C Above Pre-industrial Levels and Related Global Greenhouse Gas Emission Pathways, in the Context of Strengthening the Global Response to the Threat of Climate Change, Sustainable Development, and Efforts to Eradicate Poverty*: Intergovernmental Panel on Climate Change.

Jones, P. D., & Moberg, A. J. J. o. c. (2003). Hemispheric and large-scale surface air temperature variations: An extensive revision and an update to 2001. *16*(2), 206-223.

Jury, M. R., & Funk, C. J. I. J. o. C. (2013). Climatic trends over Ethiopia: regional signals and drivers. *33*(8), 1924-1935.

Kassie, B., Rötter, R., Hengsdijk, H., Asseng, S., Van Ittersum, M., Kahiluoto, H., & Van Keulen, H. J. T. J. o. A. S. (2014). Climate variability and change in the Central Rift Valley of Ethiopia: challenges for rainfed crop production. *152*(1), 58-74.

Katwal, T., Dorji, S., Dorji, R., Tshering, L., Ghimiray, M., Chhetri, G., . . . Tamang, A. J. A. (2015). Community perspectives on the on-farm diversity of six major cereals and climate change in Bhutan. *5*(1), 2-16.

Kiros, G., Shetty, A., & Nandagiri, L. J. A. J. o. G. (2016). Analysis of variability and trends in rainfall over northern Ethiopia. *9*(6), 451.

Koudahe, K., Koffi, D., Kayode, J., Awokola, S., & Adebola, A. J. E. P. C. C. (2018). Impact of Climate Variability on Crop Yields in Southern Togo. *2*(148), 10.4172.

Lane, A., & Jarvis, A. (2007). Changes in climate will modify the geography of crop suitability: agricultural biodiversity can help with adaptation.

Le Treut, H., Somerville, R., Cubasch, U., Ding, Y., Mauritzen, C., Mokssit, A., . . . Prather, M. J. C. C. T. P. S. B. C. o. W. G. I. t. t. F. A. R. o. t. I. P. o. C. C. (2007). Chapter 1: Historical Overview of Climate Change.

Longobardi, A., & Villani, P. J. I. j. o. C. (2010). Trend analysis of annual and seasonal rainfall time series in the Mediterranean area. *30*(10), 1538-1546.

Mach, K. J., Mastrandrea, M. D., Bilir, T. E., & Field, C. B. J. C. C. (2016). Understanding and responding to danger from climate change: the role of key risks in the IPCC AR5. *136*(3-4), 427-444.

Melke, A. (2015). *Impact of climate change on hydrological responses of Gumara catchment, in the Lake Tana Basin-Upper Blue Nile Basin of Ethiopia.* Addis Ababa University,

Mengistu, D., Bewket, W., & Lal, R. J. I. J. o. C. (2014). Recent spatiotemporal temperature and rainfall variability and trends over the Upper Blue Nile River Basin, Ethiopia. *34*(7), 2278-2292.

Mesike, C., Esekhade, T. J. A. J. o. E. S., & Technology. (2014). Rainfall variability and rubber production in Nigeria. *8*(1), 54-57.

Meze-Hausken, E. J. C. r. (2004). Contrasting climate variability and meteorological drought with perceived drought and climate change in northern Ethiopia. *27*(1), 19-31.

Mupangwa, W., Walker, S., & Twomlow, S. J. J. o. A. E. (2011). Start, end and dry spells of the growing season in semi-arid southern Zimbabwe. *75*(11), 1097-1104.

Ngongondo, C., Xu, C.-Y., Gottschalk, L., Alemaw, B. J. T., & climatology, a. (2011). Evaluation of spatial and temporal characteristics of rainfall in Malawi: a case of data scarce region. *106*(1-2), 79-93.

Niang, I., Ruppel, O., Abdrabo, M., Essel, A., Lennard, C., Padgham, J., & Urquhart, P. (2017). Climate change 2014: impacts, adaptation, and vulnerability. Part B: regional aspects.

NMSA. (2007). Climate change national adaptation programme of action (Napa) of Ethiopia. , National Meteorological Services Agency, Federal Democratic Republic of Ethiopia, Addis Ababa.

Onyeneke, R., & Madukwe, D. J. S. W. J. (2010). Adaptation measures by crop farmers in the southeast rainforest zone of Nigeria to climate change. *5*(1).

Oseni, T., & Masarirambi, M. J. c. (2011). Effect of climate change on maize (Zea mays) production and food security in Swaziland. *2*, 3.

Osman, M., Sauerborn, P. J. C. t. o. f., tropics, s. l. u. i. t., & subtropics, D. T. (2002). A preliminary assessment of characteristics and long term variability of rainfall in Ethiopia–Basis for sustainable land use and resource management.

Oumer, M., Abebe, M., Kabeto, B., Wolde Giorgis, A., Asefa, K., & Tarekegn, D. (2007). CLIMATE CHANGE NATIONAL ADAPTATION PROGRAMME OF ACTION (NAPA) OF ETHIOPIA JUNE 2007 ADDIS ABABA ETHIOPIA.

Overton, I., Colloff, M., Doody, T., Henderson, B., & Cuddy, S. J. R. p. f. t. N. W. C. b. C. W. f. a. H. C. F. (2009). Ecological outcomes of flow regimes in the Murray-Darling Basin.

OXFAM. (2011). Briefing on the Horn of Africa Drought: Climate change and future impacts on food security. *5*, 45-48.

Pachauri, R. K., Allen, M. R., Barros, V. R., Broome, J., Cramer, W., Christ, R., . . . Dasgupta, P. (2014). *Climate change 2014: synthesis report. Contribution of Working Groups I, II and III to the fifth assessment report of the Intergovernmental Panel on Climate Change*: Ipcc.

Padgham, J. (2009). *Agricultural development under a changing climate: opportunities and challenges for adaptation*: World Bank.

Parmesan, C., Duarte, C., Poloczanska, E., Richardson, A. J., & Singer, M. C. J. N. C. C. (2011). Overstretching attribution. *1*(1), 2.

Parry, M., Parry, M. L., Canziani, O., Palutikof, J., Van der Linden, P., & Hanson, C. (2007). *Climate change 2007-impacts, adaptation and vulnerability: Working group II contribution to the fourth assessment report of the IPCC* (Vol. 4): Cambridge University Press.

Partal, T., & Kahya, E. J. H. P. A. I. J. (2006). Trend analysis in Turkish precipitation data. *20*(9), 2011-2026.

Pearson, R. (2014). Climate change, biodiversity and extinction risk. In: Academy of Science of South Africa.

Pecl, G. T., Araújo, M. B., Bell, J. D., Blanchard, J., Bonebrake, T. C., Chen, I.-C., . . . Evengård, B. J. S. (2017). Biodiversity redistribution under climate change: Impacts on ecosystems and human well-being. *355*(6332), eaai9214.

Pérez, J. (2008). *Potential impacts of climate change on biodiversityin Central America, Mexico, Dominican Republic* (9962894115). Retrieved from

Poudel, S., & Shaw, R. J. C. (2016). The relationships between climate variability and crop yield in a mountainous environment: a case study in Lamjung District, Nepal. *4*(1), 13.

Regassa, S., Givey, C., Castillo, G. J. O. P., Change, P. C., & Resilience. (2010). The Rain Doesn't Come on time anymore: Poverty, vulnerability, and climate variability in Ethiopia. *6*(1), 90-134.

Rinawati, F., Stein, K., & Lindner, A. J. D. (2013). Climate change impacts on biodiversity—the setting of a lingering global crisis. *5*(1), 114-123.

Sadoff, C. (2019). Managing water resources to maximize sustainable growth: a World Bank water resources assistance strategy for Ethiopia.

Sahin, S., & Cigizoglu, H. K. J. H. P. A. I. J. (2010). Homogeneity analysis of Turkish meteorological data set. *24*(8), 981-992.

Salmi, T., Määttä, A., Anttila, P., Ruoho-Airola, T., & Amnell, T. J. F. M. I., Helsinki. (2002). Detecting trends of annual values of atmospheric pollutants by the Mann-Kendall test and Sen’s slope estimates MAKESENS–The excel template application.

Segele, Z. T., Lamb, P. J. J. M., & Physics, A. (2005). Characterization and variability of Kiremt rainy season over Ethiopia. *89*(1-4), 153-180.
Seleshi, Y., & Zanke, U. J. I. J. o. C. A. J. o. t. R. M. S. (2004). Recent changes in rainfall and rainy days in Ethiopia. *24*(8), 973-983.
Seo, S. J. T. J. o. A. S. (2011). A geographically scaled analysis of adaptation to climate change with spatial models using agricultural systems in Africa. *149*(4), 437-449.
Siebenhüner, B., & Policy. (2002). How do scientific assessments learn?: Part 1. Conceptual framework and case study of the IPCC. Environmental Science. *5*(5), 411-420.
Skambraks, A. (2014). Smallholder Farmers' Adaptation to Climate Change in Zenzelima, Ethiopia.
Surendran, U., Sushanth, C., Mammen, G., & Joseph, E. J. A. P. (2015). Modelling the crop water requirement using FAO-CROPWAT and assessment of water resources for sustainable water resource management: A case study in Palakkad district of humid tropical Kerala, India. *4*, 1211-1219.
Swiderska, H. R. a. K. (2008). Biodiversity, climate change and poverty: exploring the links. An International Institute for Environment and Development (IIED) Briefing.
Tabari, H., Taye, M. T., Willems, P. J. S. e. r., & assessment, r. (2015). Statistical assessment of precipitation trends in the upper Blue Nile River basin. *29*(7), 1751-1761.
Taye, M., Zewdu, F., & Ayalew, D. J. A. J. o. R. C. (2013). Characterizing the climate system of Western Amhara, Ethiopia: a GIS approach. *1*(10), 319-355.
Traore, B., Corbeels, M., Van Wijk, M. T., Rufino, M. C., & Giller, K. E. J. E. J. o. A. (2013). Effects of climate variability and climate change on crop production in southern Mali. *49*, 115-125.
UNDP. (2011). Framework for UNDP Ethiopia's Climate Change, Environment and Disaster Risk Management Portfolio. In: Ethiopia.
UNFCCC, F. (2007). *Climate change: impacts, vulnerabilities and adaptation in developing countries*.
Van der Laan, M., Bristow, K., Stirzaker, R. J., Annandale, J. J. A., Ecosystems, & Environment. (2017). Towards ecologically sustainable crop production: A South African perspective. *236*, 108-119.
Wagesho, N., Goel, N., & Jain, M. J. H. S. J. (2013). Temporal and spatial variability of annual and seasonal rainfall over Ethiopia. *58*(2), 354-373.
Weldegerima, T. M., Zeleke, T. T., Birhanu, B. S., Zaitchik, B. F., & Fetene, Z. A. J. A. i. M. (2018). Analysis of rainfall trends and its relationship with SST signals in the Lake Tana Basin, Ethiopia. *2018*.
Winters, P., Cavatassi, R., & Lipper, L. (2006). Sowing the seeds of social relations: The role of social capital in crop diversity.
WMO. (2016). WMO Statement on the State of the Global Climate in 2016. In: WMO.
Woldeamlak, B. (2007). Rainfall variability and agricultural vulnerability in the Amhara region, Ethiopia. Ethiopian Journal of Development Research. *29*(1), 1-34.
Woldeamlak, B. (2009). *Rainfall variability and crop production in Ethiopia: Case study in the Amhara region.* Paper presented at the Proceedings of the 16th International Conference of Ethiopian Studies.
Wubie, M. A., Assen, M., & Nicolau, M. D. J. E. S. R. (2016). Patterns, causes and consequences of land use/cover dynamics in the Gumara watershed of lake Tana basin, Northwestern Ethiopia. *5*(1), 8.
Yamane, T. (1967). *Problems to accompany" Statistics, an introductory analysis"*: Harper & Row.
Yue, S., Pilon, P., & Cavadias, G. J. J. o. h. (2002). Power of the Mann–Kendall and Spearman's rho tests for detecting monotonic trends in hydrological series. *259*(1-4), 254-271.
Yumbya, J., De Vaate, M. B., Kiambi, D., Kebebew, F., & Rao, K. J. A. C. S. J. (2014). Geographic information systems for assessment of climate change effects on teff in Ethiopia. *22*, 847-858.

LIST OF APPENDIX S

Appendix 1. The Watershed Gridded Climate Data Values and Their Homogeneity (Pettit's test) Results.

FID	Lat	Long	Altitude	Climate variables and Homogeneity (Pettit's) tests value at 5% significant level					
				T-max		T-min		Rf	
				^{O}C	P-value	^{O}C	P-value	mm	P-value
1	11.80092	37.59305	1878	28.4	0.56	12.5	0.02	1276	0.68
2	11.76492	37.59305	1954	28.3	0.42	12.5	0.58	1326	0.17
3	11.80092	37.62905	1792	28.4	0.01	12.5	0.82	1257	0.24
4	11.76492	37.62905	1869	28.3	0.23	12.4	0.23	1305	0.46
5	11.80092	37.66505	1811	28.3	0.16	12.4	0.18	1249	0.16
6	11.76492	37.66505	1982	28.1	0.42	12.3	0.11	1286	0.98
7	11.80092	37.70105	1865	28.0	0.00	12.1	0.23	1261	0.16
8	11.76492	37.70105	1898	27.9	0.00	12.1	0.00	1311	0.01
9	11.72892	37.70105	2061	27.7	0.00	12.0	0.52	1296	0.00
10	11.69292	37.70105	2169	27.4	0.12	11.9	0.25	1250	0.16
11	11.80092	37.73705	1877	27.8	0.31	11.9	0.21	1236	0.34
12	11.76492	37.73705	1930	27.7	0.28	11.9	0.36	1267	0.91
13	11.72892	37.73705	2145	27.4	0.02	11.7	0.58	1262	0.00
14	11.69292	37.73705	2167	27.2	0.65	11.4	0.40	1218	0.64
15	11.80092	37.73705	1877	27.8	0.12	11.6	0.26	1210	0.03
16	11.76492	37.77305	1896	27.2	0.48	11.5	0.00	1214	0.78
17	11.72892	37.77305	2004	27.1	0.03	11.3	0.42	1209	0.39
18	11.69292	37.77305	2126	26.9	0.26	11.2	0.16	1183	0.34
19	11.80092	37.80905	1904	26.9	0.24	11.2	0.02	1184	0.42
20	11.76492	37.80905	1904	26.7	0.04	11.1	0.36	1179	0.18
21	11.72892	37.80905	1950	26.6	0.31	10.9	0.37	1167	0.49
22	11.69292	37.80905	2181	26.5	0.14	10.8	0.84	1098	0.18
23	11.80092	37.84505	1928	26.3	0.58	10.8	0.03	1169	0.00
24	11.76492	37.84505	1922	26.2	0.02	10.7	0.45	1153	0.28
25	11.72892	37.84505	2021	26.1	0.14	10.6	0.26	1130	0.89
26	11.69292	37.84505	2081	26.1	0.03	10.4	0.72	1052	0.25
27	11.80092	37.88105	1962	25.5	0.12	10.4	0.01	1176	0.02
28	11.76492	37.88105	1985	25.5	0.15	10.3	0.25	1155	0.01
29	11.72892	37.88105	2098	25.6	0.12	10.2	0.47	1119	0.47
30	11.69292	37.88105	2196	25.8	0.01	10.0	0.60	1064	0.23
31	11.80092	37.91705	2106	24.6	036	10.0	0.21	1220	0.36
32	11.76492	37.91705	2018	24.8	0.46	10.0	0.29	1174	0.03

33	11.72892	37.91705	2172	25.2	0.11	9.8	0.69	1141	0.12
34	11.69292	37.91705	2120	25.5	0.81	9.7	0.47	1070	0.48
35	11.80092	37.95305	2210	23.8	0.68	9.7	0.64	1258	0.61
36	11.76492	37.95305	2042	24.3	0.02	9.7	041	1198	0.51
38	11.69292	37.95305	2285	25.3	0.37	9.4	0.64	1101	0.85
40	11.76492	37.98905	2122	23.6	0.28	9.3	0.22	1209	0.14
41	11.72892	37.98905	2268	24.4	0.13	9.1	0.17	1179	0.26
	W/ Dega Mean			**26.5**		**11.0**		**1200**	
37	11.72892	37.95305	2389	24.8	0.11	9.5	0.00	1162	0.12
39	11.80092	37.98905	2348	23.0	0.02	9.3	0.12	1275	0.68
42	11.69292	37.98905	2604	25.0	0.26	8.9	0.30	1158	0.34
43	11.80092	38.02505	2564	22.7	0.01	9.1	0.02	1243	0.25
44	11.76492	38.02505	2300	23.5	0.26	9.0	0.48	1211	0.00
45	11.72892	38.02505	2561	24.3	0.28	8.9	0.00	1214	0.42
46	11.69292	38.02505	2702	25.0	0.04	8.8	0.60	1171	0.14
47	11.80092	38.06105	2637	22.8	0.45	9.0	0.01	1220	0.02
48	11.76492	38.06105	2363	23.5	0.53	8.9	0.45	1235	0.78
49	11.72892	38.06105	2713	24.2	0.00	8.7	0.03	1249	0.68
50	11.69292	38.06105	2641	24.9	0.25	8.6	0.26	1182	0.91
51	11.80092	38.09705	2767	22.6	0.36	8.6	0.02	1218	0.11
52	11.76492	38.09705	2814	23.1	0.00	8.5	0.19	1223	0.01
53	11.72892	38.09705	2622	23.7	0.54	8.4	0.14	1221	0.28
54	11.69292	38.09705	2821	24.4	0.62	8.4	0.00	1163	0.57
55	11.76492	38.13305	2903	22.9	0.26	8.3	0.03	1179	0.16
56	11.72892	38.13305	2939	23.4	0.03	8.2	0.01	1159	0.79
57	11.69292	38.13305	2881	23.9	0.11	8.2	0.28	1118	0.64
	Wurch Mean			**23.8**		**8.8**		**1200**	
58	11.727	38.168	3372	22.9	0.23	8.0	0.29	1186	0.11
	Wurch Mean			**22.9**		**8.0**		**1188**	

Key: If the P-value is greater than the predetermined alpha value (significant level at 1%/0.01/, 5% /0.05/, or 10%/0.10/), the homogenity result were considered as homogenous.