THE IMPACT OF CLIMATE CHANGE ON THE OCCURRENCE OF DROUGHT AT LOGIA CATCHMENT, LOWER AWASHI RIVER BASIN, ETHIOPIA

MSc THESIS

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Haramaya University, Haramaya

THE IMPACT OF CLIMATE CHANGE ON THE OCCURRENCE OF DROUGHT AT LOGIA CATCHMENT AWASHI RIVER BASIN, ETHIOPIA

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APPROVAL SHEET

DIRECTORATE FOR POSTGRADUATE PROGRAM

We hereby certify that we have read and evaluated this Thesis titled **"The Impact of Climate Change on the Occurrence of Drought at Logia Catchment, Lower Awash River Basin Ethiopia"** prepared under our guidance by Henok Mengistie. We recommended that it be submitted as fulfilling the Thesis requirement.

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As members of the board of Examiners of the Mc Thesis Open Defense Examinations, we certify that we have read and we have evaluated the Thesis prepared by Henok Mengistie and examined the candidate. We recommended that the Thesis be accepted as fulfilling the Thesis requirement for the degree of Master of Science in Irrigation Engineering.

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Final approval and acceptance of the Thesis is contingent up on the submission of the final copy of the Thesis to the Council of Graduate Studies (CGS) through the candidate's department or Haramaya Institute of Technology Graduate Committee (HIGC).

DEDACTION

I dedicate this thesis manuscript to the memory of my mother, Yeshi. She always wishes to see the fruit of her child and my elder brother Prof. Habtamu Mengiste for his contribution throughout my life, and all my sisters and brothers.

STATEMENT OF THE AUTHOR

By my signature below, I declare and affirm that this Thesis is my own work. I have followed all ethical and technical principles of scholarship in the preparation, data collection, data analysis and completion of this Thesis. Any scholarly matter that is included in the Thesis has been given recognition through citation.

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BIOGRAPHICAL SKETCH

The author was born at Amahara region (MertuLe mariam town), in July 5, 1995. He began his education at MertuLe mariam elementary school and attended his secondary school at Abraha we atsbeha secondary school. Later he joined Degeazmach Weldhear Yzengaw preparatory School to complete his preparatory education in June 2012. After completing preparatory education, he joined Haramaya University in 2013 and graduated with Bachelor of Science Degree in Water resource and Irrigation Engineering in 2017.

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ABBREVIATION AND ACRONYMS

DRINC	Drought Index Calculator
EEA	European Environmental Agency
FAO	Food and Agricultural Organization
FEWNET	Famine Early Warning System Network
GCM	General Circulation Model
GHG	Greenhouse Gas
IPCC	Inter-Governmental Panel on Climate Change
MAI	Moisture Adequacy Index
MarkSim	Markov Weather Simulator
MoME	Ministry of Mine and Energy
MoFED	Ministry of Finance and Economic Development
MoWIE	Ministry of Water, Irrigation and Electricity
NMA	National Meteorological Agency
NCDC	National Climate data center
PD	Precipitation Deciles
PHDI	Palmer Hydrological Drought Index
PPM	Parts Per Million
RCP	Representative Concentration Pathway
SPI	Standardize Precipitation Index
SRES	Spatial Report on Emission Scenarios
TGCIA	Task Group on Scenarios for Climate and Impact Assessment

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ABSRACT

Drought is a significant phenomenon affecting several economic, agricultural, social and environmental sectors. Therefore, assessing the impact of climate change on the occurrence of drought in different areas is too important especially those with arid and semi-*arid climates. The aim of this paper is to investigate climate change impacts on meteorological and agricultural drought in logia river basin which is located in Awash River basin, Ethiopia, between the years (1988-2017) under present and future (2018–2077) climates. The analysis was based on the records of observed meteorological data and the future projected from the output of ensemble of 17 GCMs with aid of a MarkSim-GCM model under RCP 4.5and RCP8.5 scenarios. For this study; the RDI result shows that the precipitation was an increment of (+24.96 %,) from the base period to RCP 4.5(2020), +25.72 % to RCP 4.5 (2050), +28.06 % to RCP 8.5 (2020) and +30.19% to RCP 8.5 (2050) periods. Slight increase in maximum temperature ranges between + 0.31from the base period to RCP 4.5 2020 and +1.16 from RCP4.5 2050 and +0.56 from RCP 8.5 2020 and +1.27 from RCP 8.5 2050 and there is an increment of +0.85 from RCP 4.5 2020 to RCP 4.5 2050 and +0.69 from RCP 8.5 2020 to RCP 8.5 2050 scenarios. Also, the minimum temperature would be increased by +0.36 from the base period to RCP 4.5(2020), +1.17 to RCP 4.5 (2050), +0.56 to RCP 8.5 (2020), and +2.2 to RCP 8.5, (2050).The RDI annual results showed that the change in PET was an increment of + 0.42% from the base period to RCP 4.5 (2020), +1.02%, to RCP (2050), +1.65% to RCP 8.5 (2020) and +3.36 to RCP 8.5 (2050). The drought condition was observed in the base period (56.12%) was meteorological and (63.27%) agricultural drought and in the RCP 4.5 (2020) (54.17%) will be meteorological and (49.99%) will be agricultural drought and in RCP 4.5 (2050) (49.45%) will be meteorological and (53.34%)will be agricultural drought and for near future scenarios of RCP 8.5 the meteorological drought will be (53.33%) and the agricultural drought will be (50%)and in midcentury scenarios of RCP 8.5 the meteorological and agricultural drought will be (46.95%) and (60%) respectively. The return period of severe drought conditions in base period was 13 and 20 meteorological and agricultural respectively. In RCP 4.5 (2020) the return period of severe drought conditions will be 50 meteorological and no return period in agricultural drought. Likely for RCP 4.5 (2050) the return period in severe drought conditions will be 33 meteorological and no return period for agricultural. For the near future of RCP 8.5 periods the return period of severe metrological and agricultural drought will be* 33 metrological 16 agricultural droughts. *Likely, for midcentury of RCP8.5, 50 sever meteorological drought and 20 severe agricultural droughts. As drought depends on both precipitation and temperature, it is expected that both the magnitude and frequency of drought will change as climate changes.*

KEY WORDS: *RDI; drought; frequency analysis; MarkSim-GCM, DrinC, logia sub basin, Ethiopia*

1. INTRODUCTION

Water is life, sustaining ecosystems and regulates our climate. While water is plenty in our blue planet, less than 1% of the total usable freshwater is available for supporting ecosystems and humans. The very nature of this limitation is often overlooked in appropriation of water to human use. Water use is growing at twice the rate of population increase in the last century. With rapid exploitation of this resource that constantly alter quality and availability of freshwater, humankind can be exposing itself to catastrophic risk. If climate change keeps raising average temperature across the country, water is expected to become even scarcer in many areas so it's vital to find solution to protect this resource. In many places, water scarcity increases as water systems are subject to rises in pollution and exploitation (Postel, 2000; Postel *et al*., 1996).

As documented in the reports of IPCC (2007), substantial advances have been made in scientific understanding of human caused climate change the risk it poses to people and ecological systems and response options to mitigate the adapt. Climate change is recognized as one of the most serious global challenges of the 21 century; this is because of its multiple effects on basic human support systems such as agricultural production, forests, water resources and the ecosystem (Aklilu andAlebachew, 2009).

Drought is a well-known climate-related natural hazard and is reported as the most costly (Keyantash and Dracup, 2002; Svoboda *et al*., 2002). According to the National Drought Mitigation Center (NDMC), drought can generally be defined as a deficiency of precipitation over an extended period of time that results in a water shortage. A universal definition of drought has not been agreed upon, making it difficult for policymakers to develop drought plans and allocate funds to drought-stricken areas (Wilhite and Glantz, 1985; Redmond, 2002).

Drought is the natural hazard that affects a large number of people with the most negative consequences in Africa being responsible for famine (Scrimshaw, 1987).Among the most important natural disasters affecting the world, the two with highest number killed between

1974 and 2007, were the droughts that killed 450,000 and 325,000 persons in 1984 and 1974 in Ethiopia/Sudan and the Sahel region, respectively (UN, 2008).

Drought in Ethiopia has shown a spatial and temporal distribution over the last fifty years and there are certain regions in the country that are affected by drought more frequently; the eastern and south eastern and rift valley regions. The recurrence frequency was one in ten years during earlier periods. Three decades ago, Haile (1988) reported drought in Ethiopia to occur with 3–5 and 6–8 years in northern parts of the country and every 8–10 years for the whole country. Recently it was observed that drought frequency shortens and devastating drought occurred in three successive years. The drought that occurred in 2015–2017 (OHCA, 2017; USGS, 2017) is a case in point. It is believed that global warming has played a pivotal role in shortening the recurrence frequency of the droughts in Ethiopia, and it is believed to have increased the severity of the impact as well (Wilhite, and Smith, 2005).

Generally, in most areas the rural population living in drier areas are the worst affected. Thus, of the region in Ethiopia, Afar is one of the most drought affected region. Drought has been affecting the regions environmental and socio economic condition causing children malnutrition, starvation, migration and livestock demise and land degradation (Edossa et al.,2009).

Awash Basin is the most developed basin in Ethiopia due to availability of suitable land and water resources for the development of irrigated agriculture (infrastructure and market accessibility). This study region is heavily dependent on rain-fed agriculture, which is driven by intra-seasonal and inter-annual variability in climate, resulting in the occurrence of frequent droughts and floods that negatively affect agricultural production. The precipitation and discharge of the Awash River basin has changed to varying degrees in recent years. Highly variable rainfall, frequent floods and droughts, and limited storage capacity continue to constrain the ability of the basin to produce reliable food supplies in spite of be relatively rich in water and land resources.

Drought is one of the recurring natural hazards in the Awash River Basin, Ethiopia. According to a survey conducted in the Upper Awash Basin, reported that drought occurs every two years in the area (Desalegn *et al*., 2006). Again, drought analysis in Awash River Basin by Desalegn *et al*., (2010) indicate that considering extreme drought category on 12-month time scale, areas where droughts occur most frequently are found to be around two sites in the Middle Awash Basin (Hurso and Miesso areas), followed by Metehara, Nazareth and Holeta areas in the Upper Awash and Dubti, Mille and Cheffa areas in the Lower Basin. However, on 3- and 6-month time scales, areas most frequently hit by droughts of mild and above mild categories are those located in the Middle and Lower Awash Basin. The same research shows that hydrologic drought events of all severity level are observed in lower part of the basin, at Adaitu and Dubti stations.

As we know logia river catchment is one part of Awash River basin which is under stress of climate change. We most often think about drought in relation to precipitation assessing the degree of dryness (in compression to a local or original average) and the duration of the dry period. The hydrological work in logia river catchment was carried out and other researcher tried to know the extent of flood zone corresponding to the less frequent floods of different return period and some scientists investigate different studies on the catchment. But in logia river catchment there was no any study to determine the climate change impact on the occurrence of drought and impact of climate change historically and in the future period.

Therefore, this study helps to put the direction to prevent the impact of drought, the way how to manage the water resource, to put in place a drought early warning system and to aware the community in order to reduce the things that are encourage the drought condition and this management system creates the integrated environmental and social safeguards begin to avoid negative impacts and generate good environment.

So, here to fill this gap, this study analyzed and recommended the drought conditions for Logia river catchment from one drought condition analysis techniques. Reconnaissance Drought Index (RDI) this is one technique applied to solve problems that have been identified in the study area. The drought condition analysis techniques had the input parameters and they have their own calculation procedure and DrinC software was incorporated for the implementation of this Reconnaissance Drought Index (RDI) techniques and for future scenario analysis the ensemble of 17 GCMs output through MarkSim-GCM which are recommended by IPCC AR5 had been used for the medium (RCP4.5) and high (RCP8.5) emission scenarios.

Generally, the study answer the following research questions

- How the drought condition was seem like with previous climate condition?
- What will be the impact of climate on drought using the future and previous climate condition?
- What will be the effect of climate change on the occurrence of drought?

Considering the above research question, the general objective of this study was to analyze the impact of climate change on the occurrence of drought at Logia river catchment. And this study has the following specific objectives:

- To analyze meteorological drought and agricultural drought condition, using the previous and the future climate change on Logia river catchment and
- To predict the impact of future climate change on the frequency of drought occurrence in the study area

2. LITERATURE REVIEWS

2.1. Climate and Drought

2.1.1. Climate

According to the Intergovernmental Panel on Climate Change (IPCC)'s Fifth Assessment Report, climate change is already negatively affecting global crop production and is expected to continue doing so unless adaptive measures are taken after reviewing many

Studies covering a large number of crops and regions, the IPCC concluded that the negative effects of climate change on yields have been more common than the positive ones, the latter occurring mainly in high-latitude regions. The IPCC also concluded that, without adaptation, local temperature increases of 2°C or more will likely cause decreases in the yields of major crops in tropical and temperate regions (IPCC, 2014a).

2.1.2. Drought

Drought is a phenomenon that can affect society and the environment. As Palmer (1965) states various people have different concerns which depend on the effects of a drought. According to a report from EEA (1999), European Environment Agency, it is shown that in recent years it has become clear how vulnerable even industrialized and economically well-off regions like Europe can be to drought, when several severe and prolonged water deficit periods cause major environmental, social and economic problems. This seems to continue: for example, in Europe there was an exceptional drought in 2003 which was estimated to have cost 8.7 billion euro's (EEA, 2010). A potentially significant impact of climate change over many regions will be changes in the frequency and characteristics of droughts (Blenkinsopp and Fowler, 2007).

The key factors to drought occurrence and drought severity are precipitation and evapotranspiration (Blenkinsopp and Fowler, 2007). Therefore, if climate change results in changes in one or both of these factors it can be expected that drought occurrence and its severity will change as well. Precipitation and evapotranspiration are part of the hydrological cycle and one of the key features of global climate change will be perturbations to the hydrological regime across Europe (Blenkinsopp and Fowler, 2007). It is also expected that climate change can affect mean precipitation and its variability (Trenberth *et al*., 2003). A change in the precipitation mean and variability obviously influence the occurrence and severity of drought. According to a study by IPCC (2007) changes in temperature, radiation, atmospheric humidity, and wind speed will affect the amount of evaporation which can exaggerate effects of decreased precipitation on surface water and run-off. Evaporation is closely related to temperature (Thornthwaite, 1948). A study by Lenderink*et al*. (2007) suggests temperature and evaporation increase when imposing future climate boundary conditions on Europe. A study by Vicente-Serrano *et al*. (2010) suggests that temperature will play a major role in determining future drought severity.

A similar conclusion by Wang *et al*. (2011) is drawn stressing the importance of temperature for drought. Furthermore, according to a study by Schär *et al*. (2004) an increase in variability of temperature implies an increase in extremes climatic conditions. Drought indices have been developed to objectively assess drought conditions and different kinds of drought. Looking only at meteorological drought, the departure from normal of meteorological variables that induces drying of the surface (Liu *et al*., 2012), it can be stated that duration, intensity and total deficit should be assessed. Liu *et al*. (2012) concluded that more drought indices from ecological and socioeconomic perspectives should be investigated and inter-compared to provide a more complete 2 picture of drought risks and its potential impacts on the nature-human coupled system. A drought can also be characterized by its frequency and spatial extent (Blenkinsopp and Fowler, 2007).

2.2. Greenhouse Gas Effect on Temperature

Greenhouse gas effect is the capacity of greenhouse gases in the atmosphere to trap heat emitted from the surface of the earth. The greenhouse effect act as thermal blankets regulating the temperature of the earth’s surface without which, the average earth’s temperature would be 33ºC cooler. The anthropogenic modification of this natural process resulting in increased levels of heat-trapping gases (greenhouse gases) in the atmosphere have presented the current rapid warming of the earth, altering the global weather patterns, particularly rise in temperature of the earth’s atmosphere, sea levels and stormy activities, called climate change.

The greenhouse effect causes the atmosphere to trap more heat energy at the earth's surface and within the atmosphere by absorbing and re-emitting long wave energy or radiation. Of the long wave energy emitted back to space, 90% is intercepted and absorbed by greenhouse gases (GHG). Without the greenhouse effect the earth's average global temperature would be -18˚C, rather than the present 15˚C (Pidwimy, 2006).

Conversion of natural ecosystems into agricultural land continues briskly today, with cropland and pasture still expanding globally (FAO, 1993). Land clearing, being the second largest source of CO_2 emissions after fossil fuel combustion, currently accounts for approximately 10 to 30% of total net CO_2 emissions (IPCC, 1996). Much land clearing Earth's surface occurs in areas of tropical forests. Approximately 11 million hectares of tropical forest are now being converted each year, while only about 1 million hectares are reforested (Burke and Lashof, 1990).

2.3. Global Climate Change

Climate change is a global concern with significant current and future impacts to society and ecological systems. Anthropogenic GHG emissions, which have been steadily increasing since the 1970s, are identified as the primary driver of climate change. The largest increase in emissions has occurred since 2000, despite world-wide mitigation efforts, with 78% of those emissions caused by fossil fuel combustion and industrial processes. Although impoverished countries, especially those in warm climates, have borne the brunt of climate change effects thus far, no areas of the globe have been immune to climate change effects (IPCC, 2014).

2.4. Climate Change in Africa

Climate is a narrow sense usually defined as the average weather or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time from months to thousands or millions of years. Climate change refers any change in climate over time through natural variability or as a result of human activities (IPCC, 2007).

Climate change refers a change of climate which is attributed directly or indirectly to human activities that alter the composition of the global atmosphere and which are in addition to natural climate variability observed over comparable time period. Africa is highly stressed, low adaptive capacity and easy vulnerable to climate change. The main consequences of this negative impact of climate change or current climatic hazards are poverty, unequal access to resources, food Insecurity, globalization trends, social and political conflicts and incidences of diseases such as malaria, tuberculosis and HIV/AIDS. This impact of climate change presents a substantial challenge to regional agricultural development. The sub Saharan Africa country are low adaptation mechanism and vulnerable to the widespread effect of climate change. With this bid serious problem, the coming 2100 year in most part of the continent GDP will predict to loss. For instance, 2-7 percent in part of sub Saharan Africa, 2-4 percent in west and central Africa and 0.4-1.3 percent in north and southern Africa (FAO 2009).

According to IPCC (2007) increase in global average temperature above the range of 1.5°C-2.5°C which is negatively influences species distribution and survival. In most of developing country where the majority of the population has the dependence on natural resources based livelihoods, this can an impact on socio economic and difficulty to the overall threats to sustainable development. This project report predicts that during 21thcentury greenhouse gas emission will increase by 25-90 percent. This will be continuing for future period/year.

2.5. Climate Change in Ethiopia

According to IPCC (2014) Fifth Assessment Report of Famine Early Warning Systems Network (FEWS NET), there has been an increase in seasonal mean temperature in many areas of Ethiopia. According to the UNDP climate change country profiles, the average annual temperature of Ethiopia increased by 1.3°C between 1960 and 2006 (McSweeney *et al.*, 2010). The average number of ‘hot’ days and ‘hot’ nights per year are also increased from time to time. Based on, McSweeney *et al,* (2010) expression, there is no statistically significant trend in observed average rainfall in any season and also daily rainfall records are insufficient to identify current trends in daily rainfall. In addition that NMA (2007) report shows, Ethiopia experienced 10 wet years and 11 dry years over the last 55 years, indicating the strong inter annual variability.

2.6. Causes of Climate Change in Ethiopia

Change in the intensity of sunlight reaching the earth cause cycles of warming and cooling that have been a regular feature of the Earth's climatic history. But, the main and direct cause of greenhouse gas (GHG) emissions is carbon dioxide (70%), primarily from burning of fossil fuel (petroleum) imported other countries, while the other sources of GHG are methane and nitrous oxide caused by deforestation and agricultural activities, particularly the use of pesticides. Ethiopia’s share to global GHG emission is very minimal. However, emissions from agriculture and energy sectors doubled since 1994.

MoFED (2010) reports indicate that, these two sectors are the major emitters in Ethiopia which accounting for 85% and 15% of the total gas emission respectively. This reflects the fact that livestock farming goes together with high methane emissions. The dominant position of livestock farming in Ethiopia’s economy also influences the relative contribution of GHG to the total emissions. These are dominated by methane emissions, which account for 80% of the warming potential. Climate scientists now reach an agreement that the human caused pollution mainly from fossil fuels, has added considerably to global warming in the past 50 years (Stern, 2006). Generally, there were increasing trends of greenhouse gas emissions in Ethiopia in a period of 1990-1995. The relative comparisons of increase indicated that CO_2 has increased by 24% while emission of CH_4 and N_2O increased by 1% and 19% respectively. Aggregate greenhouse gases emissions in terms of CO_2- equivalents have increased by 12% (NMA, 2001). Ethiopia’s GHG emissions are closely linked to basic needs of the population; food production (through livestock farming) and heating. Therefore, the future GHG emissions will likely increase with the projected increase in population. The greenhouse gas emission from energy sector is also important contributor to the total national emission. According to the 2004 inventory, it was accounted for more than 50% of the total GHGs emission and was twice of the 1994 values. Among these sub sectors, the transport and the domestic take the largest contribution which accounts for about 68% and 16.1% respectively in 2004. The combustion of fossil fuels mainly in the transportation sector was responsible for 88 % of the total CO_2 in 1994 (BM Hashim 2016).

2.7. Impact of Climate Change in Ethiopia

Currently climate change and variability is already impose significant challenge to Ethiopia by affecting food security, water and energy supply, health, poverty reduction and sustainable development efforts (Abebe, 2007). Furthermore, extreme weather events, such as droughts, floods, or landslides, may cause death to domestic animals. Livestock suffering and death often means that farmer's wealth is decreased and they lost much of their resources (Pettengell, 2010). The adverse impact of climate change are not only these particularly climate change/variability also has significant impact on rain fed agriculture (IPCC, 2007). According to IFPRI (2009), agriculture is the most vulnerable sector to climate change. Higher temperatures eventually reduce yields of desirable crops while encouraging weed and pest proliferation. According to reports of the IPCC (2007), the projected yield reduction because of climate change in some poor countries could be as much as 50% by 2020. Under climate change, much agricultural land will be lost, with shorter growing seasons and lower yields. National communications report that climate change will cause a general decline in most of the subsistence crops, example sorghum in Sudan, Ethiopia, Eritrea and Zambia; maize in Ghana; Millet in Sudan; and groundnuts in Gambia (UNFCCC, 2007).

2.8. Climate Models Tools and Downscaling Techniques

2.8.1 Climate models

As described by (Reto Knutti 2008), Climate models consist of a set of equations that are discredited on a grid and solved numerically on a large computer. Some equations are derived from first principles (e.g. equations of motion, and conservation of energy, mass and angular momentum), but many processes have to be parameterized in a simplified form. The equations derived from these laws are so complex that they must be solved numerically. For the parts of the model governed by fundamental equations (e.g. the equations of motion), increased computational capacity and thus finer resolution will improve the simulation.

Models quantitatively simulate the interactions of the atmosphere, oceans, land surface, and ice. They are used for a variety of purposes from study of the dynamics of the climate system to projections of future climate. All climate models take into account the energy balance by taking into account of incoming energy from the sun as short wave electromagnetic radiation, chiefly visible and shortwave (near) infrared, as well as outgoing long wave far) infrared electromagnetic radiation.

There are various scientific studies trying to ascertain the actuality of climate change which includes some experiments. These experiments including the use of variety of models have been developed to study different aspects of the climate system both the past and future. Currently, more than a dozen centers around the world develop climate models to enhance our understanding of climate and climate change and to support the activities of the Intergovernmental Panel on Climate Change (IPCC). However, climate models may not be perfect. This critic was stated by Reichlers and Kim (2008) in the fact that our theoretical understanding of climate is still incomplete, and certain simplifying assumptions are unavoidable when building these models. As a consequence, climate 2 models provide a solution which is discrete in space and time, meaning that the results obtained represent averages over regions, whose size depends on model resolution, and for specific times. For instance, some models provide only globally or zonally averaged values while others have a numerical grid whose spatial resolution could be less than 100 km. The time step could be between minutes and several years, depending on the process studied.

2.9. Types of Climate Models

According to Orth and Seneviratne (2015) Models vary in complexity ranging from simple radiant heat transfer model to (coupled) atmosphere–ocean models. This means the models like Energy Balance Models (EBMs), Radioactive-Convective Models, Statistical Dynamical Models (SDs) and General Circulation Models (GCMs) are named in the respective increase, in complexity, from first to last, in the degree to which they simulate particular processes, and in their temporal and spatial resolution. The simplest models permit little interaction between the primary processes, radiation, dynamics and surface processes, whereas the most complex models are fully interactive.

2.9.1. Atmosphere model

An atmospheric model is a mathematical model constructed around the full set of primitive dynamical equations which govern atmospheric motions. It can supplement these equations with parameterizations for turbulent diffusion, radiation, moist processes (clouds and precipitation), heat exchange, soil, vegetation, surface water, the kinematic effects of terrain, and convection. They can predict micro scale phenomena such as tornadoes and boundary layer eddies, sub-micron scale turbulent flow over buildings, as well as synoptic and global flows. The horizontal domain of a model is either global, covering the entire Earth, or regional, covering only part of the Earth (Lynch, 2008).

In general the atmospheric models employ Radiation and energy balance (Earth and Sun) such as interactions between different levels in the atmosphere, Surface effects (albedo), Clouds, water vapor, CO_2 and other gases, aerosols etc; Atmospheric dynamics like winds, pressure distribution, boundary-layer processes; and Hydrologic cycle such as Precipitation formation, evaporation and precipitation.

2.9.2. Land surface model

The land surface forms an essential part of the climate system. It interacts with the atmosphere through the exchange of water and energy and hence influences weather and climate (Seneviratne *et al.,* 2010). The land surface models are also employed by scientists in climate change studies. The Land surface models (LSMs) use quantitative methods to simulate the exchange of surface water and energy fluxes at the soil–atmosphere interface. They are key component of climate models. They have been evolved from oversimplified schemes, which described the surface boundary conditions for general circulation models (GCMs), to complex models that can be used alone or as part of GCMs to investigate the biogeochemical, hydrological, and energy cycles at the earth's surface.

2.9.3. Global climate model

According to Gary (1995) this is a special kind of model that includes both the seas and the air. These combined models are called "coupled models". A coupled atmosphere-ocean model has been developed for climate predictions at decade to century scales. General Circulation Models (GCMs)5 are a class of computer-driven models for weather forecasting, understanding climate and projecting climate change, where they are commonly called Global Climate Models. Due to the dominating influence of the ocean atmosphere link in the climate system, realistic climate change experiments require OGCM s and AGCM s to be coupled together by exchanging information about the sea surface temperature, the ice cover, the total (latent, sensible and net long wave radioactive) heat flux, the solar radiation and the wind stress.

A global climate model or general circulation model aims to describe climate behavior by integrating a variety of fluid-dynamical, chemical, or even biological equations that are either derived directly from physical laws. There are both atmospheric GCMs (AGCMs) and ocean GCMs (OGCMs).

Winkler et al., (1997) advised that enough data should be available for both model calibrations and validation. As the choice of the calibration period, as well as the mathematical form of the model relationship(s) and season definitions determines the statistical characteristics of the downscaled scenarios.

2.10. Downscaling Techniques

Wilby and Wigley (1997) studied the present generation of downscaling tools under four main groups: stochastic weather generators; regression methods; weather pattern-based approaches; and limited-area climate models. In these different approaches regression methods are preferred because of its ease of implementation and low computation requirements. A number of methodologies have been developed for the derivation of detailed regional scenarios of climate change for impacts studies. There are two types of downscaling: Dynamic Downscaling and Statistical Downscaling (Lenart, 2008).

2.10.1. Dynamic downscaling method

Dynamic downscaling method is nesting a regional climate model (RCM) into a global climate model (GCM) (Wilby and Wigley, 1997). Kim *et al.,* 1984 defines dynamic downscaling as a technique to obtain high resolution data from low resolution data using output from another higher solution data driving a regional model. This kind of a technique uses grid-nesting and are relatively complex and requires high computational costs (Salathe *et al.,* 2007).

2.10.2. Statistical downscaling method (SDSM)

Statistical downscaling method has gained a lot of interest from climate modelers and researchers since its results are sufficiently accurate in the estimation of relationship between the GCM and station level information (Fowler *et al.,* 2007). The assumption made in statistical downscaling is that stable statistical relationships occur at different temporal and spatial scales (Wilby *et al.,* 1998). Statistical downscaling are based and conceptualized on three assumptions (Tripathi *et al.,* 2006). First, that the predictors have been modeled realistically by the GCMs. Second, the empirical relationship between predict and the predictor will remain the same under future conditions. It is for this reason that unlike in dynamic downscaling, change in land use-land cover and climatic factors is not a matter of consideration for this method. Third, it is assumed that the predictors accurately represent climate changes and their indications.

2.11. Climate Change Scenarios

Climate change scenarios are possible sequences and /or combination of plausible change in future climate. They are used to assess the future consequence of climate change and assist the relevant authorities to formulate appropriate mitigation and prepare adaptive measurements to accommodate the change. So, development of climate change scenarios is an important step in the hydrological impact of climate change study.

A climate change scenarios is a plausible representation of future climate is constructed from consistent assumptions about future emission greenhouse gas (GHGs) and other pollutant, for explicit use in investigating the potential impact of anthropogenic climate change. Scenarios are not forecasts of future climate but rather are intended to provide adequate quantitative measurement of uncertainty that is represented with range of plausible future path (IPCC 2007a). future greenhouse gas concentration are an unknown because we cannot predict what activities human will engage in that will or reduce or increase them. The future scenarios of forecasting agents (e.g. greenhouse gas and aerosols) are fed in to the climate models as input, and the output of these climate models is further used in climate change analysis and hence, the assessment of impacts, adaptation and mitigation. Several sets of scenarios including the IS92 scenarios (Legegett *et al.,* 1992).the scenarios from the special report on emission scenarios (SRES) (Nakicenovic *et al.,* 1992) and, more recently , the representative concentration pathway (RCP) (van vuuren *et al.,* 20011) are used in climate research. In addition to this, according to IPCC-TGICA (2007) there are three types of climate change scenarios.

2.11.1. The special report on emission scenarios (SRES)

In 1996 the IPCC began the development of a new set of emission scenarios, effectively to update and replace the well –known IS92 scenarios. The approved new set of scenarios is described in the IUPCC special report on emission scenarios (SRES). Climate models have parameterized using four main emission scenarios anthropogenic forcing published by the IPCC special scenarios on emission scenarios (Nakicenovic *et al.,* 2000) for using the climate change studies. These scenarios, defined according to four storylines namely A1, A2, B1 and B2, were constructed to explore future socio-economic development in terms of economics, population growth and technological advancement.

2.11.2. Representative concentration pathway (RCPs)

In climate research, different types of emission scenarios are used to assess the long-term impact of atmospheric greenhouse gases and pollutants based on assumption of population growth, economic development level, etc. scenarios by the IPCC include SA90 (IPCC, 1990),IS92 (Legegett *et al.,*1992)and SRES (Nakicenovic *et al.,* 2000).

The latest scenarios developed by the research community are denoted by representative concentration pathway (RCPs); (van vuuren *et al.,* 2011). There are four RCPs defined by their level of the total radioactive forcing pathway in the year 2100 and are representative for the existing literature about emission scenarios.RCP 8.5-Intermediate emission: this RCP is consistent with a future with no policy change to reduce emission. It corresponding to the rising radioactive forcing pathway leading to 8.5 w/m^2 (~1370 ppm CO_2) by 2100 (Riahi *et al.,* 2007) scenarios with no climate policy baseline comparatively high greenhouse gas emission. It was developed by the international institute for applied system analysis in Austria and is characterized increasing greenhouse gas emissions that lead to high greenhouse gas concentration over time.

This scenario is highly energy intensive with total consumption continuing to grow thought the century reaching well over three times current levels. Oil use grow rapidly until 2070 after which drops even quickly. Land use continuous current trends with crop and grass areas increasing with forest areas decreasing. RCPs 6.5 intermediate emission: this RCP is developed by national institute for environmental studies in Japan. Radioactive forcing is stabilized shortly after the year 2100, which is consists with the application of range technologies and strategies for reducing greenhouse emission. This scenario is also similar to RCP4.5, with stabilization without overshooting pathway to 6w/m_2 (~850 ppm CO_2) at stabilization after 2100 P (Fujino *et al.,* 2006).

RCP 4.5 –intermediate emission: this RCP is developed by the Pacific Northwest National Laboratory in the US. Here radioactive forcing is stabilized shortly after the year 2100, consists with a future with relatively ambitious emission reduction. The RCP4.5 stabilization scenario is a coast –minimizing pathway. It assume that all nation of the world undertake emission mitigation simultaneously and effectively, and share a common global price that all emission to the atmosphere must pay with emission of different gas priced according to their hundred year global warming potentials (foster et al., 2007). RCP 2.6 –low emission: this scenarios has been referred to as RCP3 PD representing the radioactive forcing trajectory which goes to a peak level of 3 W/m^2 (~490 ppm CO_2) before 2100, followed by a decline (PD=Peak-Decline). The selective pathway declines to 2.6 W/m^2 by 2100 (van vuuren *et al.,* 2007).

2.12. Definition of Drought

Drought is complex event which may impair social, economic, agricultural and other activities of society. It is a prolonged, abnormally dry period when there is shortage of water for normal needs. It is temporary, recurring natural disaster, which originates from the lack of precipitation and brings significant economic losses. It is a slow poison, no one knows when it creeps in, it can last any number of days and its severity cannot be predicted. The non-structural characteristic of drought impacts has certainly hindered the development of accurate, reliable, and timely estimates of severity and ultimately, the formulation of drought preparedness plans by most governments. The impacts of drought, like those of other hazards, can be reduced through mitigation and preparedness.

Drought is an extended period where water availability falls below the statistical requirements for a region. It is not a purely physical phenomenon, but rather interplays between natural water availability and human demands for water supply. There are two main kinds of drought definitions: conceptual and operational. Conceptually, it can be defined as "a protracted period of deficient precipitation resulting in extensive damage to crops, resulting in loss of yield"(National Drought Mitigation Center, 2006)."

Conceptual definitions may also be important in establishing drought policy. Operational definitions identify the beginning, end, spatial extent and severity of a drought. They are often region-specific and are based on scientific reasoning, which follows the analysis of certain amounts of hydro meteorological information. They are beneficial in developing drought policies, monitoring systems, mitigation strategies and preparedness plans. Operational definitions are formulated in terms of drought indices. It is not possible to avoid droughts. The success of drought preparedness and its impact, amongst the others, on how well the droughts are defined and drought characteristics quantified (Smakhtin and Hughes, 2004).

Defining drought is difficult; it depends on differences in regions, needs, and disciplinary perspectives. Drought always starts with the lack of precipitation, but may (or may not, depending on how long and severe it is) affect soil moisture, streams, groundwater, ecosystems and human beings. This leads to the identification of different types of drought (meteorological, agricultural, hydrological, socio-economic, ecological), which reflect the perspectives of different sectors on water shortages.

2.13. Types of Drought

Droughts can be classified in four major categories these are; metrological, agricultural, hydrological and socio- economic. The first three are said to be environmental drought (NDMC, 2006).

2.13.1. Meteorological drought

It simply implies rainfall deficiency where the precipitation is reduced by more than 25% from normal in any given area. These are region specific, since deficiency of precipitation is highly variable from region to region (NDMC, 2006).

2.13.2. Hydrological drought

These are associated with the deficiency of water on surface or subsurface due to shortfall in precipitation (NDMC, 2006). Although all droughts have their origination from deficiency in precipitation, hydrological drought is mainly concerned about how this deficiency affects components of the hydrological system such as soil moisture, stream flow, groundwater and reservoir levels etc.

2.13.3. Agricultural drought

This links various characteristics of meteorological or hydrological drought to agricultural impacts, focusing on precipitation shortages, differences between actual potential evapo-transpiration, soil, soil water deficits, and reduced ground water or reservoir levels. Plant water demand depends on prevailing weather conditions, biological characteristics of the specific plant, and its stage of growth and the physical and biological properties of the soil (NDMC, 2006).

2.13.4. Socio-economic drought

It is associated with the demand and supply aspect of economic goods together with elements of meteorological, hydrological and agricultural drought. This type of drought mainly occurs when there the demand for an economic good exceeds its supply due to weather related shortfall in water supply.

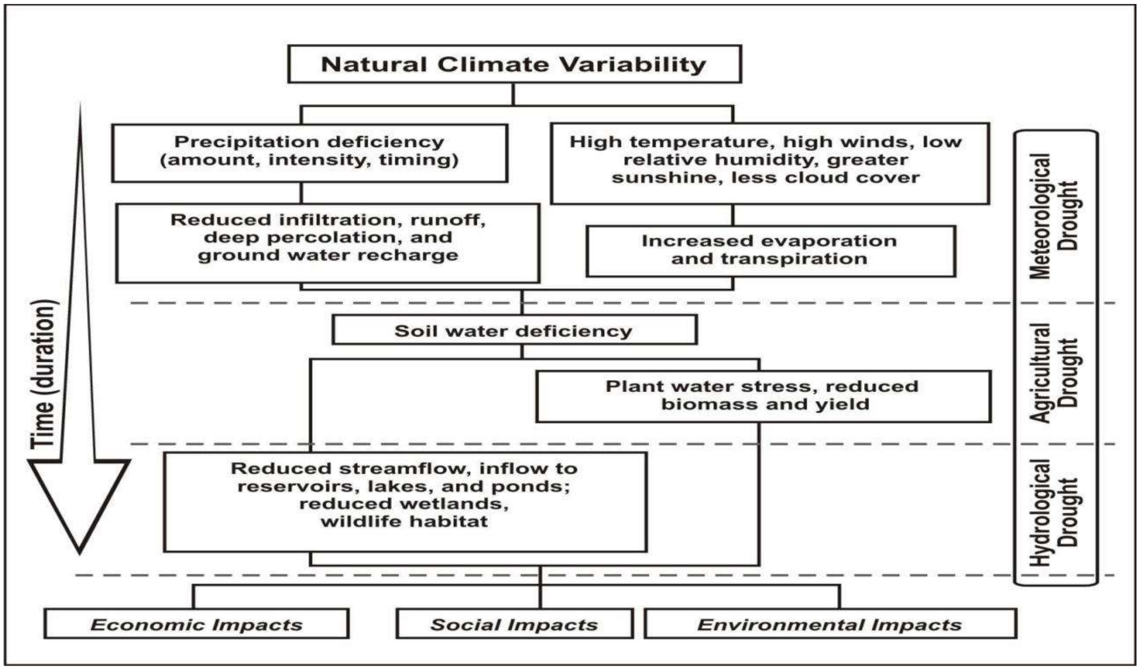

Figure 1. Sequence of drought occurrence

Source: National Drought Mitigation Center, University of Nebraska-Lincoln USA (2013).

2.14. Drought in Ethiopia

According to Webb *et al*. (1992) since 250 BC droughts have occurred in different parts of Ethiopia at different times. Its frequency has increased over the past few decades particularly in the lowlands (NMS, 2007). Similarly, Gebrehiwot and his colleagues said that throughout the human history, the country is frequently exposed to drought and famine (Gebrehiwot*et al*., 2011).

Drought is a major problem affecting social, economic and environmental aspects of the country. This disaster mainly affects the agricultural production and livelihoods of the 15 farming and pastoral communities. This is due to the fact that the sector is highly depends on the availability of rainfall. In line with this World Bank (2003) reported that drought occurrence in Ethiopia can reduce farming output by up to 90% of normal year output. It can also lead to the death of human beings and livestock. According to available literatures drought occurred in Ethiopia in the year of, 1964 – 1966, 1972 – 1973, 1978 – 1979, 1983 – 1984, 1987– 1988, 1992, 1993 – 1994, 2000, 2002/2003, 2008/2009 (Degefu, 1987; Webb and

Braun, 1994; Government of Ethiopia, 2009; Temesgen*et al*., 2010) and the currently occurring drought. These droughts were took place with different magnitude and spatial coverage.

Table 1. Major drought years and their effects in different regions of Ethiopia for the last 50 years

Year	Region	Impacts
1964-1966	Tigray and wollo	About 1.5 million people were affected and 300,000 livestock died
1972-1973	Tigray and wollo	Death of about 200,000 people and 30% of livestock population in the area
1987-1979	Southern Ethiopia	1.4 million people were affected
1983-1984	All regions	8 million people were affected and 1 million people died
1982	Northern Ethiopia	2 million people were affected
1987-1988	All regions	7 million people were affected
1991-1992	North, east and south Ethiopia	4 million people were affected
1993-1994	Tigray and Wollo	7.6 million people were affected
2000	All regions	About 10.5 million people were affected
2002-2003	All regions	About 13 million people were affected; 1.4 million livestock died
2006	South Ethiopia (Borena)	About 7.4 million people affected and 247,000 livestock died
2008	South Ethiopia (Borena)	About 26,000 livestock died
2008-2009	All regions	About 5 million people were affected
2011	South central, and eastern parts of Ethiopia	About 4.5 million people were affected
2015-2016	Northern and Eastern Ethiopia	About 10.2 million people were affected

Sources: Compiled from Degefu (1987), Meze-Hausken (2000), FAO (2003), Segele and Lamb (2005), Amsalu and Adem (2009), Deressa*et al*. (2010), Famine Early Warning Systems Network (FEWS NET) (2011), Viste*et al*. (2012) and FDRE (2016).

2.15. Frequency of Drought Occurrence

The frequency of occurrence of drought is very strongly influenced by the regularity and pattern of natural climate variability, and may be influenced by changing in land cover thus, the effect of an increasing concentration of greenhouse gas on “drought” and its “impact” are like to be extremity complex (Henny *et al*., 2007). Change in climate (change in frequency and intensity of extreme weather events) is likely to have major impact on natural and human system (Arets, 2004). The analysis and extreme climate event has become increasingly relevant to making planning effect. Although drought is becoming the most common and damaging natural hazard in Ethiopia, there were no as such detail studies conducted about its magnitude, frequency and spatial extent in different region of Ethiopia (Degefu and Bewket, 2003).

2.16. Drought Indices

In the process of monitoring and assessing droughts, drought indices play an essential role because their use assists the simplification of the perplexing relationships between climate and climate-related parameters. A drought index is acceptable when it presents a clear, simple and qualitative analysis of the main drought characteristics namely the intensity, the duration and the special extent (Hayes, 2000). Drought indices incorporate several variables related to drought, (e.g. precipitation, temperature, potential evapotranspiration, soil moisture, snowpack) into a single number, the use of which is more efficient in the decision making process than raw data (Hayes *et al*., 2007).

2.16.1. Meteorological drought indices

2.16.1.1. Standardize precipitation indices (SPI)

The Standardized Precipitation Index was developed by McKee *et al*. (1993) and is supposed to overcome the shortcomings of PDSI (e.g., cannot be used for multiple time scales, original PDSI could not be compared spatially). SPI uses only precipitation data for its calculation and fits a mathematical function to the historical precipitation data. The SPI is designed to be spatially and temporally comparable because the values are standardized by the fitting function. Different probability distributions give slightly different values and for the sake of spatial comparison the same function is used at all the locations. The SPI values are standardized such that the mean is zero and negative and positive values indicate drier than normal and wetter than normal conditions, respectively.

After fitting the historical precipitation record with a probability density function, the record is transformed using an inverse normal function (Guttman 1999). McKee (1993) used the classification system shown in the SPI value table below (Table 2) to define drought intensities resulting from the SPI. They also defined the criteria for a drought event for any of the timescales. A drought event occurs any time the SPI is continuously negative and reaches an intensity of -1.0 or less. The event ends when the SPI becomes positive. Each drought event, therefore, has a duration defined by its beginning and end, and intensity for each month that the event continues. The positive sum of the SPI for all the months within a drought event can be termed the drought's "magnitude".

Table2. Drought classification based on SPI (McKee *et al.*, 1993)

SPI value	Drought condition
2.0+	Extremely wet
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately wet
-.99 to .99	Near normal
-1.0 to -1.49	Moderately dry
-1.5 to -1.99	Severely dry
-2 and less	Extremely dry

2.16.1.2. Palmer drought severity index (PDSI)

First presented in 1965, and often said to have revolutionized the drought research, the Palmer Drought Severity Index (PDSI (Palmer, 1965)) is one of the longest used indices for drought monitoring (Vicente-Serrano *et al.*, 2012), (Dai, 2011), (Mishra and Singh, 2010). According to Andreadis *et al*. (2005) the PDSI is also one of the most widely used drought index, at least for long-term drought characterization. In similarity with the before mentioned SPI, the PDSI expresses drought, with the value of zero corresponding to normal conditions while negative values indicate droughts and positive values indicate abnormally wet periods (Heim, 2002). The main differences between the two indices are the incorporation of evapotranspiration (as temperature) and soil properties in the PDSI while SPI solely uses precipitation data. In using the additional parameters the PDSI can link meteorological drought with hydrological and agricultural drought (Andreadis*et al.*, 2005).

2.16.1.3. Reconnaissance drought index (RDI)

The Reconnaissance Drought Index (RDI) was developed to approach the water deficit in a more accurate way, as a sort of balance between input and output in a water system (Tsakiris and Vangelis, 2005; Tsakiris *et al.*, 2007c). It is based both on cumulative precipitation (P) and potential Eva-transpiration (PET), which are one measured (P) and one calculated (PET) determinant.

RDI is based on cumulative precipitation (p) and PET. Both RDI and PET will be computed by DrinC software, where, in Hargreaves equation will be used for PET. The initial value (αk) of RDI is calculated for the i-th year in a time basis of k (months) as follows:

$$ak^{(\mathrm{i})} = \frac{\sum_{j=1}^{k} Pij}{\sum_{j=1}^{k} PETij}, i = 1(1)N and j = 1(1)k \qquad 1$$

In which $P_{ij}$and$PE_{ij}$are the precipitation and potential Evapotranspiration of the j-th month of thei-th year and N is the total number of years of the available data. The values of αk follow satisfactorily both the lognormal and the gamma distributions in a wide range of locations and different time scales, in which they will be tested (Tigkas 2008; Tsakiris *et al.*,2008).

When applying the lognormal distribution, the following equation was usedfor the calculation of RDIst:

$$RDIst^{(i)} = \frac{y^{(i)} - \mathrm{y}^{-}}{\sigma\hat{}\mathrm{y}} \qquad 2$$

In which $y^{(i)}$ is the ln ($ak^{(i)}$), y^{-} is its arithmetic mean and $\sigma\hat{}y$ is its standard deviation. In case of applying the gamma distribution, the RDIst can be calculated by fitting the gamma Probability density function (pdf) to the given frequency distribution of αk (Tigkas,2008; Tsakiris *et al*.,2008). For this study Hargreaves method was preferred to determine the PET from the other methods of determination PET like Thornthwaite equation, The (FAO56) Penman-Monteith equation and Hamon equation. The reason why it was preferred to this study: (a) shown to over predict PET in humid climate, since this is also property of the study area, (b) good estimation of results (Jensn*etal*., 1990) and (c) it requires climate data means Tmin and Tmax simple data required and the equation Hargreaves *et al*. (1985)

$$\text{PET} = 0.0023\ (Tm+17.8)\ (\sqrt{Tmax - Tmin})\ \text{Ra} \qquad 3$$

where,Tm is daily mean air temperature [°C], Tmax is daily maximum air temperature [°C], Tmin is daily minimum air temperature [°C], and Ra is extraterrestrial radiation [MJ m-2 day-1]. The mean air temperature in the Hargreaves equation is calculated as an average of Tmax and Tmin and Ra is computed from information on location of the site and time of the year.

Table 3. Reconnaissance drought index classification criteria (Tsakiris*et al*. 2007)

RDI values	Drought Class
>2	Extremely wet
1.5-1.99	Very wet
1.0-1.49	Moderately wet
-0.99-0.99	Near normal
-1.0 to-1.49	Moderately dry
-1.5 to-1.99	Very dry
<-2	Extremely dry

2.16.2. Hydrological drought indices

The Hydrological drought indices have been developed for the applications in the hydrological domain. They are generally the indices pointing towards low flow in streams. It is important to analyze the data from stream flow from various gauging stations to estimate the Hydrological drought indices values. This category of drought indices serves their usefulness in the irrigation water estimation (Tallaksen and Lanen, 2004).

The Palmer Hydrological drought index and Surface Water Supply Index are the best known drought indices in this category. Another popular Hydrological index is Reclamation Drought Index. The “Palmer Hydrological drought Index” (PHDI) (Palmer, 1965) is derived from PDSI. The difference between PDSI and PHDI is that the criteria for discarding or accepting of drought spells and wet spells are stringently defined in case of PHDI. The end of drought is decided by PDSI when moisture begins to rise but PHDI considers the complete disappearance of moisture deficit. As the meteorological phenomenon is faster than the hydrological phenomenon, the retarding criterion in PHDI discussed above is reasonable for a Hydrological drought index.

2.16.3. Agricultural drought indices

The agriculture is a very crucial sector for the well existence of the socio-economic situations. Drought is a potential threat with a destructive damage to agricultural production. The necessity of a drought index specialized for agriculture led to development of various indices with explicit characteristics for Agricultural drought assessment. They included indices based on the theories of rainfall, soil moisture, actual and potential evapotranspiration and many other factors. Some of the Agricultural drought indices are Moisture Adequacy Index, Crop Moisture Index, Crop Specific Drought Index, soil moisture and Evapotranspiration Deficit Indices. The “Moisture Adequacy Index” (MAI) (McGuire and Palmer, 1957) is the basic Agricultural drought index to implement the concept of potential evapotranspiration.

2.17. Drought Indices Calculator (DrinC) Software

DrinC (Drought Indices Calculator) aims at providing a user-friendly tool for the calculation of several drought indices. Key objective in its design was the widest possible applicability for several types of drought (meteorological, hydrological, agricultural) and different locations. It was also taken into Account that drought studies are particularly essential in arid and semi-arid regions, where data availability is usually limited. Therefore, the main criteria for the selection of indices were: a) to have relatively low data requirements, allowing the application of the software in many regions and b) their results to be clearly interpreted for direct and efficient operational use. Based on these criteria, two recently developed and two more widely known indices were included in DrinC

The Reconnaissance Drought Index (RDI), the Stream flow Drought Index (SDI), the Standardized Precipitation Index (SPI) and the Precipitation Deciles (PD). As can be easily understood, RDI, SPI and PD refer to the meteorological drought and use as main determinant the precipitation (and additionally the potential evapotranspiration for RDI only). Further, RDI can also be used for the agricultural drought analysis, as it can adequately describe the water balance, and it is particularly useful when reference periods related to development stages of the crop are selected (Tsakiris*et al*., 2010). On the other hand, SDI applies to hydrological drought and uses the stream flow as the key determinant. Apart from the originally proposed methods of calculation for each index, DrinC incorporates alternative methods that allow the comparison of the results among the indices. Further, this gives a key advantage to the user, since it provides the flexibility to select among various options for adjusting the outputs to his particular needs.

2.18. Drought prediction Models

2.18.1. Markov chain model for drought prediction

Liu *et al*. (2009) said Markov chain has been widely applied in the disciplines of natural science, engineering, economics and management. This approach has also been widely used in drought forecasting, Lohani and Loganathan, (1997); Lohani *et al*. (1998). Paulo and Pereira (2007) stated that the Markov chain modeling approach is useful in understanding the stochastic characteristics of droughts and rainfall through the analysis of probabilities for each severity class, times for reaching the no drought class from any drought severity state, and residence times in each drought class. They found that the approach can be satisfactorily used as a predictive tool for forecasting transitions among drought severity classes up to 3 months ahead Lohani and Loganathan (1997) and Lohani *et al*. (1998) developed an early warning system for drought management using the Markov chain, in two climatic areas of Virginia (U.S.A.).The same approach was also adopted for developing a meteorological drought/rainfall forecasting model by Liu *et al*. (2009) in Laohahe catchment in northern China.

2.18.2. Bayesian network-based drought forecasting (BNDF) model

Probabilistic model for forecasting drought based on Bayesian networks, which can be applied to complex systems to explicitly represent the uncertainties of variables. Bayesian networks have been applied in various academic fields, such as medical sciences, economics, industrial engineering, sociology, and environmental engineering, in order to make decisions and predictions. In hydrology and water resources, few studies have attempted to utilize Bayesian network models for risk assessment; to the best of our knowledge, only one study employed Bayesian networks to calculate the conditional probability of copula-based forecasting. In this study, the Bayesian network and its inference algorithm were applied as a main tool to forecast drought considering the persistence of a drought index. Since Bayesian networks express uncertainties through probability distribution, the present study suggested a drought outlook framework based on meteorological drought forecasting results, B. T. Gutierrez, N. G. Plant, and E. R. Thieler, (2011).

2.19. Land Use Land Cover Change in Ethiopia in Ethiopia

As per Ministry of Mines and Energy (MoME, 2003) the total area of Ethiopia covers above 1.12 million km^2. About 55% of this area is below 1500m a.m.s.l. which is lowland, whereas the remaining 45% of the area, with an altitude of greater than 1500m is highland (Tefera, 2011). In Ethiopia the land is dominantly used for mixed farming system, by smallholders who farm for subsistence (Tefera, 2011; Geremew, 2013). The country also kwon by several environmental, climatic, and socio-economic problems such as: environmental degradation, erratic rainfall, recurrent droughts and drought-related distressing famines, prevalence of malaria and HIV/AIDS, widespread poverty and poor governance (Tefera, 2011). The aforementioned problems are directly or indirectly linked with Climate change and LU/LCC. LU/LCC including forest cover change is one of the major environmental problems in Ethiopia (Alemu *et al.,* 2015).

Most of the researches were conducted in the northern highland; there are numbers of LU/LCC studies carried out in Ethiopia, at catchment, zone, watershed and village levels.In Ethiopia expansion of agricultural land and loss of natural vegetation are associated with population growth, poor economic condition, unclear land tenure right and several other biophysical and socio-political factors (Melaku, 2003). According to Sege (1994) and Turner and Meyer (1994) in most developing countries including Africa, Asia and L/America countries population growth and LU/LCC have a strong statistical correlation. In agreement to these different studies undertaken in different parts of Ethiopia also reported population growth as a major cause for LU/LCC. Population growth was the major cause for the expansion of agriculture and reduction of vegetation covers in Ethiopian highlands (Muluneh, 2010).

3. MATERIALS AND METHODS

3.1. Description of the Study Area

3.1.1. Location

Awash River basin is one of the major river basins' in Ethiopia. It is located between latitudes 7°53' and 12°00'N and longitudes of 37°57' and 43°25'E. Awash River originates over the highlands of Central Ethiopia, about 150 km west of Addis Ababa and flows north-eastwards, where it eventually drains into the Lake Abe. The total length of the river is about 1,200 km and its catchment area is more than 110,000 km^2. The Awash River Basin has been divided into distinct zones Upper Basin, Middle Basin, and Lower Basin (MoWIE, 2013). Logia watershed is situated on the western side Awash River basin of Ethiopia and it is one among the sub-basins of the Lower Awash River basin.Having its source in the Ethiopian highlands,thisstreamflowseastwardstobecomeatributaryof theAwash River.Geographically, it is located between 11°40' and 12°07'N latitude and 39°42 and 41°01'E longitude(Figure 2). The total area of the Logia river catchment is 4,094.40 km^2 (MoWIE, 2013).

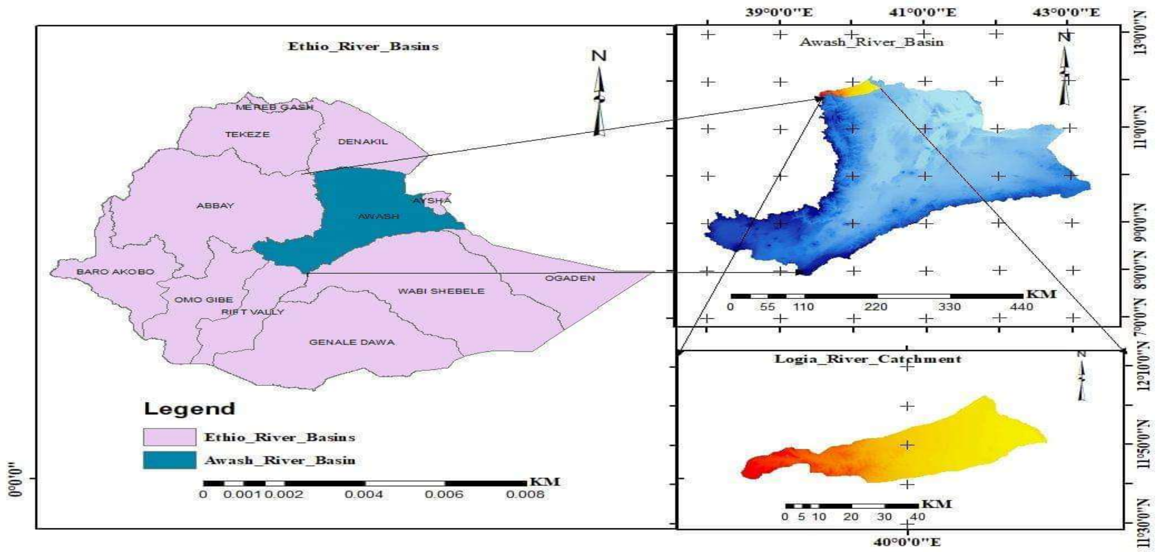

Figure 2.Locations map of study area map

3.1.2. Climate

The Ethiopian climate system is traditionally classified based on existing altitudinal range and temperature. Thus, there are five climate zones in the country. The arid zone is very hot and the hyper-arid region having an altitude of below 500m.a.s.l and semiarid zone is a hot and arid region ranged between 500-1500 m.a.s. latitudes. Similarly, sub humid is an optimum temperature from 1500-2500 m.a.s.l altitude humid zones is found in the highland regions with 2500-3000 m.a.s.l and greater than 3000 m.a.s.l altitude respectively (NAM, 2012). In the study area, the mean annual precipitation ranges from 204 mm (Dubti) to 1059 mm (Sirinka), and with a mean monthly maximum temperature varies between 37.55°C to 26.13°C and the range of minimum temperature is 23.37°C to 13.3°C at Dubti and Sirinka stations respectively. The monthly precipitation distribution of the study area indicates, July and August (main rainy season) are the wettest months of the year and followed by March and April (small rainy season) (NMA, 2012).From Logia river catchment the meteorological stations, mean monthly rainfall, monthly mean average Tmin and Tmax for Dubti, merssa, mille and Sirinka were represented were shown in the (Figure 3).

3.1.3. Topography

There is a very high elevation change between the upstream (western part) and downstream (eastern part) of the watershed, which is 3492 and 386 m.a.s.l. at the upstream and edge of the watershed, respectively.

3.2. Materials, Software and Models Used

3.2.1. Materials

The materials that are used for this study are GPS for taking geographic-coordinate values (altitude, latitude and longitude) and Digital camera for field photographs

3.2.2. Models and software

To achieve the objective of this study in addition to the precipitation and climate data, MarkSim –GCM) output of ensemble of seventeen GCM is used for future period. The model was downloaded from the website (http://gismap.ciat.cgiar.org/MarkSimGCM/). The drought indexes RDI were computed by the help of DrinC Software. The software was downloaded from the website (http://drinc.ewra.net/).And ArcGIS was used for map the study area and to create a theissen polygon which used to identify the stations for the catchment under study.

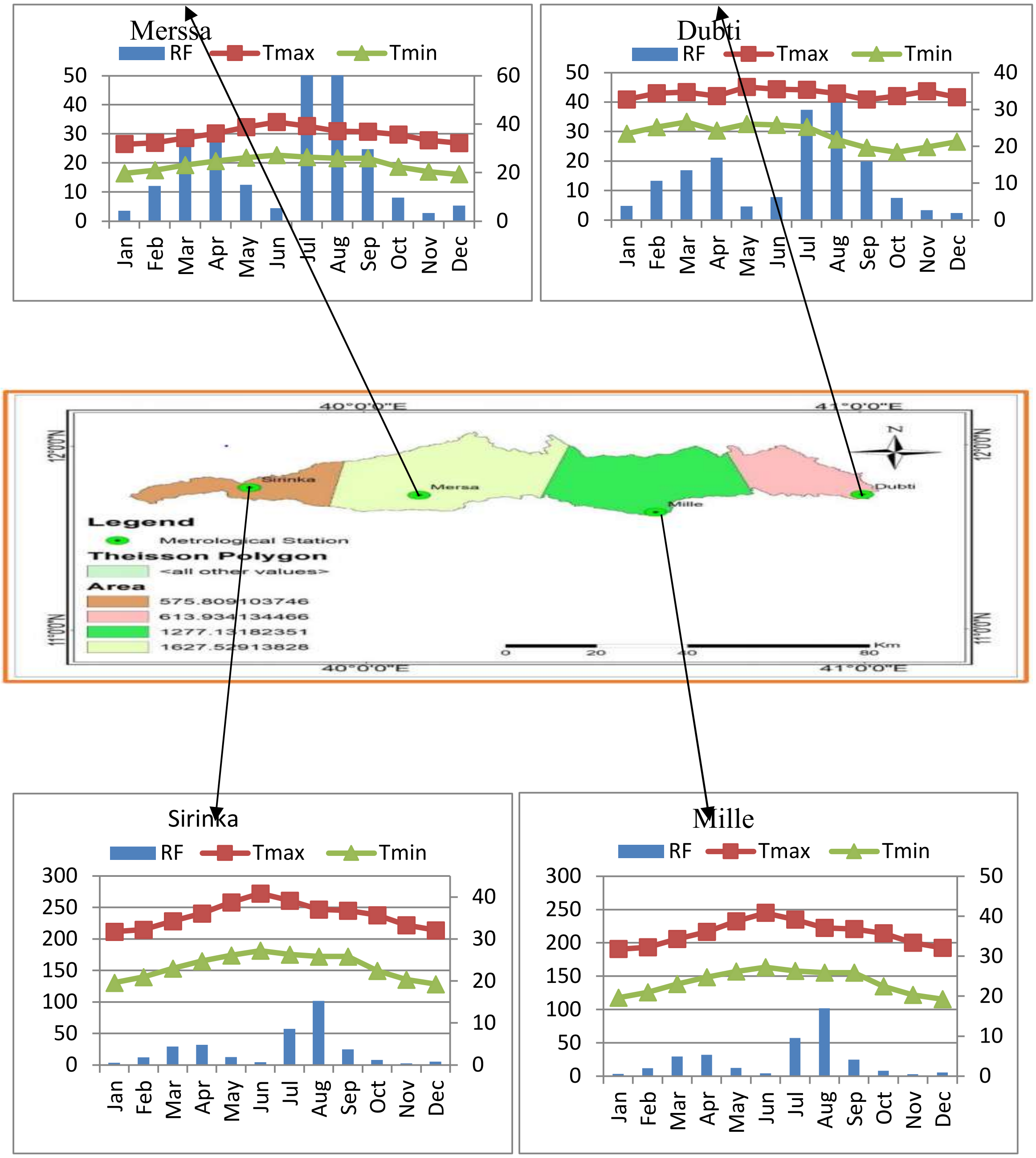

Figure 3. Four meteorological stations, observed monthly mean rainfall, Tmax and Tmin

3.2.2. Models and softwares

To achieve the objective of this study in addition to the precipitation and climate data, MarkSim –GCM) output of ensemble of seventeen GCM is used for future period. The model was downloaded from the website (http://gismap.ciat.cgiar.org/MarkSimGCM/). The drought indexes RDI were computed by the help of DrinC Software. The software was downloaded from the website (http://drinc.ewra.net/).And ArcGIS was used for map the study area and to create a theissen polygon which used to identify the stations for the catchment under study.

3.3. Data Collection

To achieve the objective of the study different data were collected such as historical daily minimum and maximum temperature and precipitation. These data were collected from Ethiopia National Meteorological Agency (NMA). For the projection of future period (Tmin, Tmax and precipitation), projected daily weather data based on the climate models (ensemble average) that resulted from MarcSim- IPCC' fifth Assessment report (CMIP5) and derived from emission scenario of RCP4.5 and RCP8.5.

3.3.1. Meteorological data

Historical daily minimum and maximum temperature and precipitation data for Logia river catchment were collected from Ethiopian National Meteorological Agency (NMA). Some descriptions about the selected meteorological stations were given in Table 4.

Table 4. Description of four selected stations

No.	Station name	Latitude (°)	Longitude (°)	m.a.s.l (m)	Record time	Area coverage from total area (Km^2)
1	Dubti	11.72	41.01	376	1988-2017	613.934
2	Mille	11.42	40.77	487	1988-2017	1277.132
3	Merrsa	11.66	39.66	1578	1988-2017	1627.53
4	Sirinka	11.75	39.61	1861	1988-2017	575.810

3.4. Areal Rainfall and PET from Point Rainfall and Point PET

Areal precipitation distribution and PET distribution is the way to determine the precise content values within the areal coverage for the selecting stations in the specific study area. To determine such accurate information Thiessen polygons were applied for capturing individual stations weight and mean rainfall and PET over the entire of the study area. For the study area there were four selected meteorological stations within each area in Logia river catchment for collecting rainfall. The collected daily rainfall data is taken as coverage of the rainfall. However; the rainfall might vary from one station to another station. Therefore, the average based annual rainfall value might be less accurate. To avoid or to reduce the less accurate result Thiessen polygon used to calculate the station weights based on the relative area of measurement station in the Thiessen polygon.

So, to change the precipitation and PET to areal distribution the collected pointed data were multiplied by their own areal coverage weight percentage or with their polygon within the study area and the sum of these products were divided by the total area of the Logia river catchment. For the PET was also calculated in similar way with that of precipitation areal weighted calculation. The general formula to calculate area weighted averages is (Forestry, 2001).

$$\mathrm{Pave} = \frac{\mathrm{P1A1+P2A2} \ \cdots \mathrm{PnAn}}{\mathrm{A1+A2} \ \cdots \mathrm{An}} \qquad 4$$

Where: P*ave* =areal mean precipitation

=P_1, P_2…$P_n$are the rainfall magnitude recorded by the stations 1, 2…n respectively belongs to areas of the polygon

=A_1, A_2…$A_n$are areas of each polygon

3.5. Data Preparation

Errors in data may arise from instrumentation, station condition, observation and recording, transmission, coding and transcription. Therefore, the data that were collected from the source to use as input for the Model and Software may not be reliable due to the above reasons, so input data were filled and checked for missing values, consistency and homogeneity.

3.5.1 Estimating missing data

The meteorological missing data were filled using arithmetic mean method for this study. The reason why Arithmetic mean method was applicable is that the existing percentages of missed data for normal annual precipitation and temperature at various stations were difference less than 10% with its Normal rainfall and mathematically estimated as follows:

$$px = \frac{1}{m}[p1 + p2 + \cdots + pm] \qquad 5$$

Where, P_{X}=missing annual precipitation at station X not included in the M stations,

p_1, p_2, p_3...p_m =annual precipitation at neighboring m stations 1, 2, 3…m and

m =number of stations

3.5.2. Consistency test

To check the consistency of the record rainfall data in the station, the missing data were first estimated and the consistency analysis was applied. Double mass curve techniques were used to check the consistency of rainfall data on the catchment.

3.5.3. Homogeneity test

The non-dimensional observed precipitation data said to be homogeneous if the periodic data are proportional to an appropriate simultaneous period, method, materials, place, and environment. Homogeneity is an important issue to detect the variability of the given data. Homogeneity change mostly caused by change in measurement techniques, observational procedures, environment characteristics and location of the stations. In order to detect the change it is better to test the homogeneity of meteorological data using SNHT method and most country used it for test (Wijngaard *et al.*, 2003). Due to this reason, for this study, the data were tested using XLSTAT software with SNHT method.

3.5.4. General structural setup of the study approaches

To implement the study effectively, this flowchart was followed. This shows the schematic representation of the step to be followed in this research. It helps to follow up the steps to accomplish the work orderly.

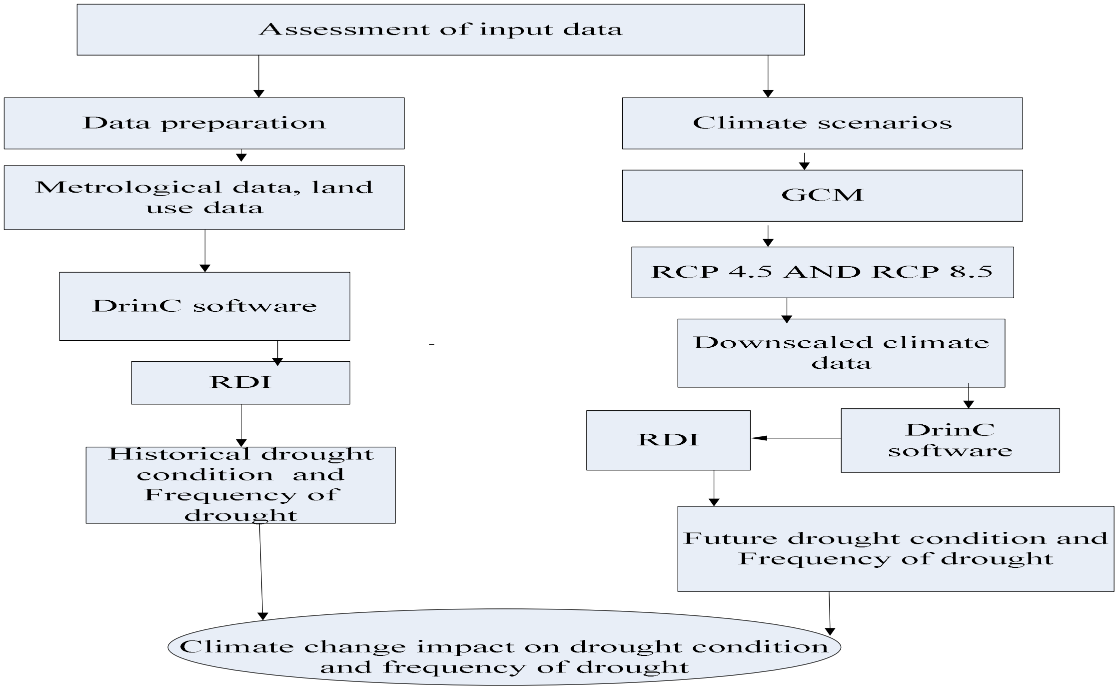

Figure 4. Structural setup of the study approaches

3.6. Data Analysis

3.6.1. Reconnaissance drought index (RDI)

RDI is based on cumulative precipitation (p) and PET. Both RDI and PET were computed by DrinC software, where, in Hargreaves equation used for PET. The initial value (αk) of RDI is calculated for the i-th year in a time basis of k (months) as follows:

$$ak^{(\mathrm{i})} = \frac{\sum_{j=1}^{k} Pij}{\sum_{j=1}^{k} PETij}, i = 1(1)Nandj = 1(1)k \qquad 6$$

In which $P_{ij}$and $PE_{ij}$are the precipitation and potential Evapotranspiration of the *j*-th month of thei-th year and N is the total number of years of the available data. The values of αk follow satisfactorily both the lognormal and the gamma distributions in a wide range of locations and different time scales, in which they will be tested (Tigkas 2008; Tsakiris *et al.*,2008).

When applying the lognormal distribution, the following equation was usedfor the calculation of RDIst:

$$RDIst^{(i)} = \frac{y^{(i)} - \bar{y}}{\hat{\sigma}y} \qquad 7$$

In which $y^{(i)}$ is the ln $(ak^{(i)})$, $\bar{y}$ is its arithmetic mean and $\hat{\sigma}y$ is its standard deviation. In case of applying the gamma distribution, the RDIst can be calculated by fitting the gamma Probability density function (pdf) to the given frequency distribution of (Tigkas,2008; Tsakiris *et al.*,2008). For this study Hargreaves method was preferred to determine the PET from the other methods of determination PET like Thornthwaite equation, The (FAO56) Penman-Monteith equation and Hamon equation. The reason why it was preferred to this study: (a) shown to over predict PET in humid climate, since this is also property of the study area, (b) good estimation of results (Jensn *et al.*, 1990) and (c) it requires climate data means Tmin and Tmax simple data required and the equation Hargreaves *et al.* (1985).

$$PET=0.0023\ (Tm+17.8)\ (\sqrt{Tmax - Tmin})\ Ra \qquad 8$$

Where, T*m* is daily mean air temperature [°C], Tmax is daily maximum air temperature [°C], Tmin is daily minimum air temperature [°C], and R*a* is extraterrestrial radiation [MJ m-2 day-1]. The mean air temperature in the Hargreaves equation is calculated as an average of Tmax and Tmin and *Ra* is computed from information on location of the site and time of the year.

Table 5.Reconnaissance drought index classification criteria (Tsakiris *et al.* 2007)

RDI values	Drought Class
>2	Extremely wet
1.5-1.99	Very wet
1.0-1.49	Moderately wet
-0.99-0.99	Near normal
-1.0 to-1.49	Moderately dry
-1.5 to-1.99	Very dry
<-2	Extremely dry

3.7. Estimate the Drought Occurrence Probability

In terms of water management, design events of given return periods are often the basis for operational guidelines, policy and insurance standards, and risk acceptance. Estimates of the probability of occurrence of extreme events can be derived from analyses of time series, either historical records or simulated series, by the method of frequency analysis.

Frequency analysis's one of the most common and earliest applications of statistics within hydrology. It involves (a) definition of the hydrological event and extreme characteristics to be studied, (b) selection of the extreme events and probability distribution to describe the data,(c) estimation of the parameters of the distribution, and (d) estimation of extreme events or design values for a given problem. The procedure is straightforward, but the uncertainty of the estimated extreme values depends strongly on the sample size and the basic assumptions of the models adopted. Knowing such information lead for great preparedness before the occurrence the effects or to overcome a problem before affecting the recommended area. One of the main purposes of frequency analysis is to find the most suitable probability distribution to describe the data in question. Considering such benefits, for this study to determine the probability of occurrence and return period of the drought condition the California formula was adopted.

$$\mathrm{P} = \frac{\mathrm{m}}{\mathrm{n}} * 100 \qquad 9$$

$$\mathrm{T} = \frac{1}{\mathrm{P}} * 100 \qquad 10$$

Where: P=the probability of drought occurrence
m=frequency of the events
n=total number of events
T=return period

4. RESULTS AND DISCUSION

4.1. Data Quality Control and Set for Analysis

4.1.1. Consistency analysis

As indicated in Figure 5 the consistency of rainfall data for this study were checked by the double mass curve method which is plot of the annual cumulative total rainfall data of base stations with the annual cumulative total rainfall of neighbor stations of the considered stations.

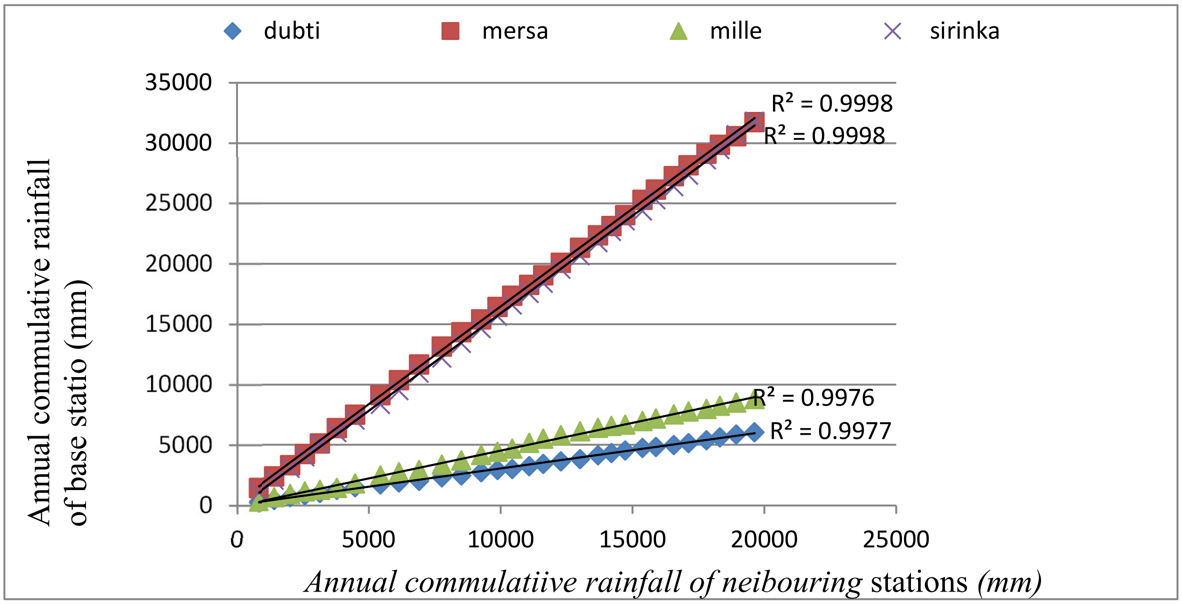

Figure 5. Double mass curves for consistency test of stations

4.1.2. Homogeneity test of time series

Homogeneity of the annual rainfall for the stations was tested using XLSTAT statistics software by the means of SNHT (Standard Normal Homogeneity Test). As shown in Table 6 the results of the meteorological stations show that the data were homogenous and the greater p-value from significance level alpha and the red horizontal broken line had shown in Figure 6 implies homogeneity of the rainfall station for Logia watershed.

Table 6. Standard normal homogeneity test (SNHT) for rainfall

S.NO.	Station name	variable	Obs	Mean	SD	To	P-value	Alpha
1	dubti	Prec	30	202.71	55.30	2.13	0.8036	0.05
2	Mersa	Prec	30	1045.62	155.73	5.45	0.15	0.05
3	Mille	Prec	30	294.29	114.24	3.61	0.42	0.05
4	sirinka	Prec	30	1061.35	155.76	3.97	0.38	0.05

To = statistic derives, SD= standard deviation, prec= precipitation, Obs= observation

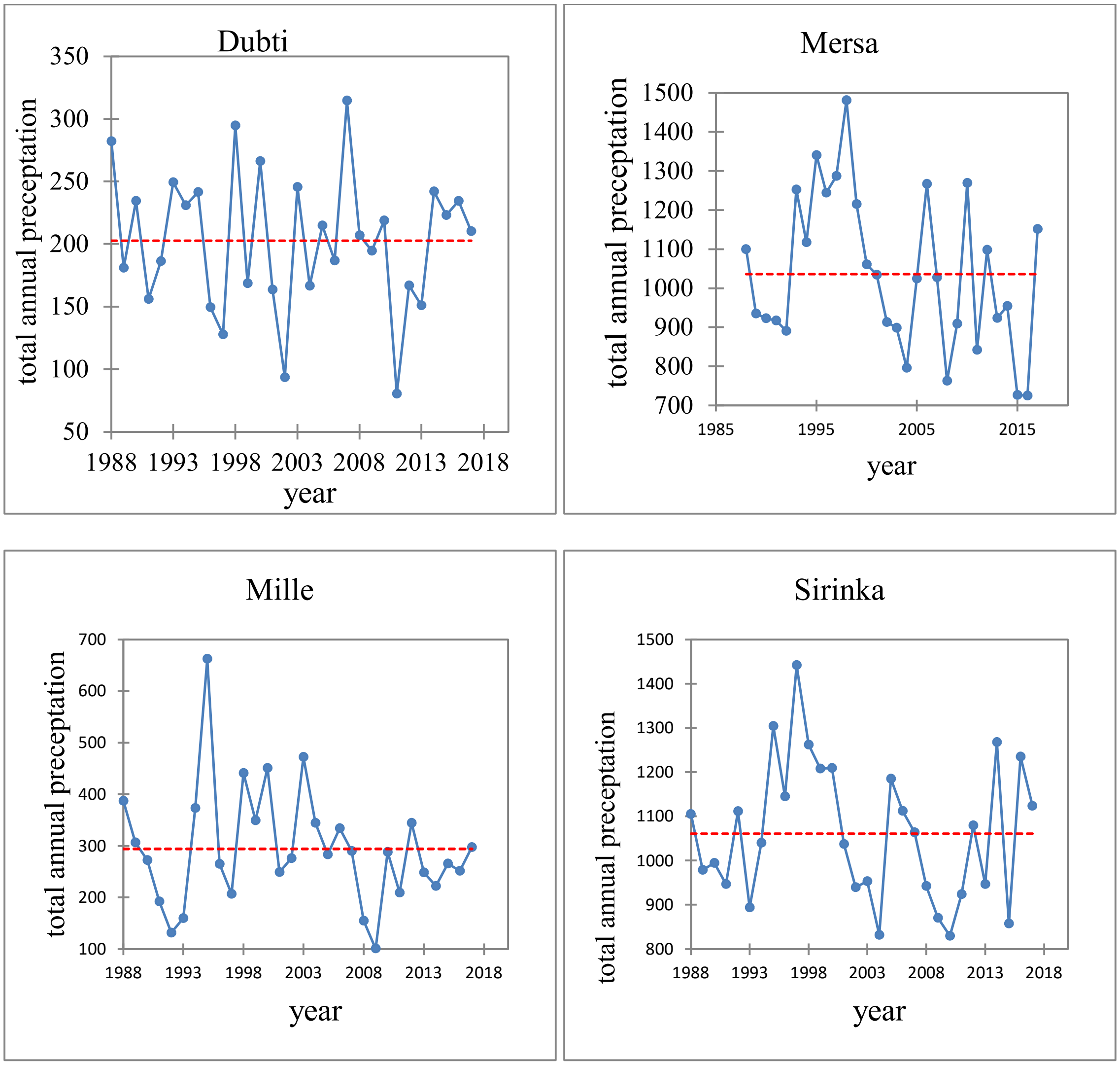

Figure 6. Homogeneity test for annual rainfall of four stations

4.2. Application of Theissen Polygon to Transform Rainfall and PET

In this study the metrological rain fall and PET data was determined by areal form. To change the point data to areal Theissen polygon method was applied for calculating the area contribution of each station for the total area of sub basin. Theissen polygon method was determined by Arc GIS 10.4 software by taking the sub basin location of stations was shown in Figure 7.TheTheissengauge weights and the area of the sub-basin with four rainfall gauging stations are presented in Table 7

Table7. Theissen gauge weights for logia river basin

Station name	Area (km^2)	Gauge weight (%)
Dubti	613.93	0.14
Mersa	1627.53	0.39
Mille	1277.13	0.31
Sirinka	575.81	0.14
Total	4094.40	1.00

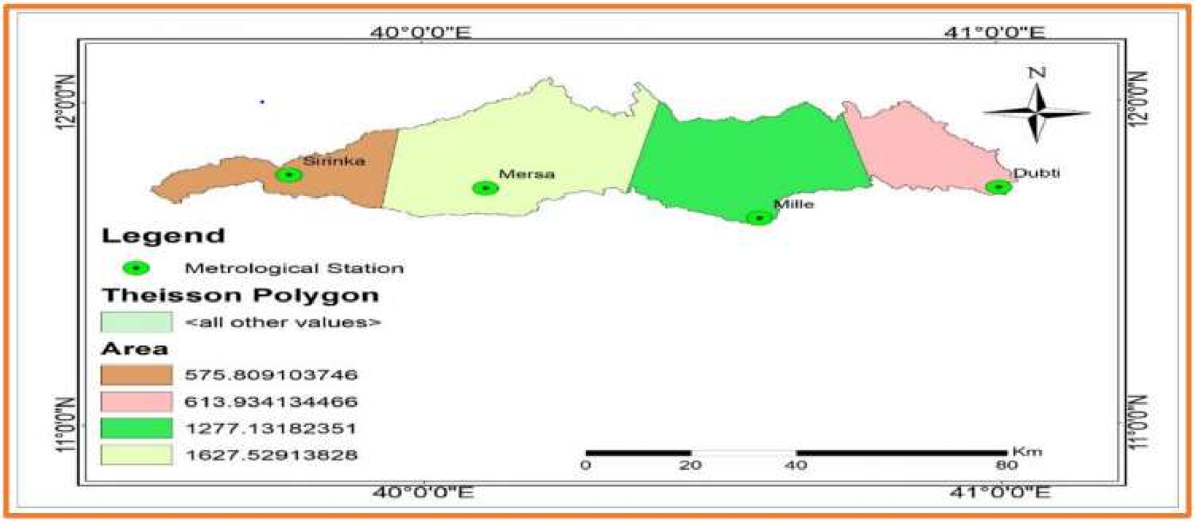

Figure 7. Thessen polygon developed for logia river basin

4.3. Climate Change

In this study, the analysis was performed by areal precipitation and areal PET, and this potential evapotraspiration was computed based on temperature (T max and T min) data. To change the point data to areal data, the theissen polygon method was applied for rainfall and PET data to see the climate change of the river basin.

4.3.1. Maximum temperature

The mean monthly and annual maximum temperate and change in maximum temperature for the base period and future climate scenarios, (RCP 4.5,2020, RCP 4.5, 2050, RCP 8.5, 2020 and RCP 8.5, 2050) are shown in Figure 8. The annual mean Tmax (RCP 4.5,2020, RCP 4.5, 2050, RCP 8.5, 2020 and RCP 8.5, 2050) is 31.81ºC, 32.12ºC, 32.97ºC, 32.37ºC and 33.06ºC respectively. The result showed an increasing trend for all scenarios. The mean annual increment of maximum temperature ranges between + 0.31ºC from the base period to RCP 4.5, 2020 and +1.16ºC from RCP4.5, 2050 and +0.56 ºC from RCP 8.5 2020 and +1.27ºC from RCP 8.5, 2050 and there is an increment of +0.85ºC from RCP 4.5, 2020 to RCP 4.5, 2050 and +0.69ºC from RCP 8.5, 2020 to RCP 8.5, 2050.

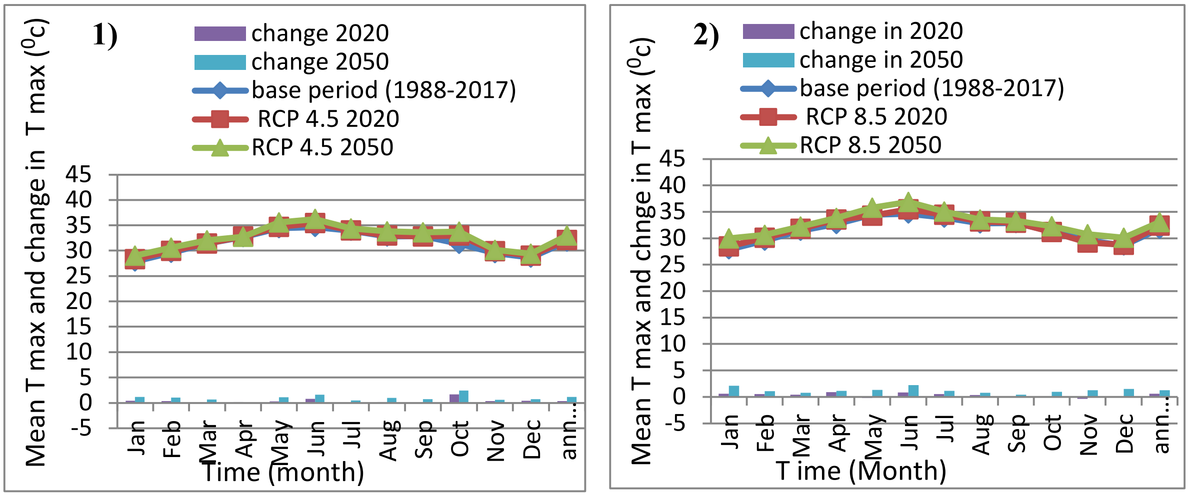

Figure 8. Mean monthly and annual Tmax and change of Tmax Base period and all scenarios

4.3.2. Minimum temperature

It can be seen in Figure 9 that the minimum monthly and annual temperature, and change in minimum temperature from the base period to future climate scenarios, (RCP 4.5,2020, RCP 4.5, 2050, RCP 8.5, 2020 and RCP 8.5, 2050) are 16.89ºC, 17.25ºC, 18.06ºC, 17.46ºC, and 19.099ºC, respectively. The average annual minimum temperature would be increased by +0.36ºC, +1.17ºC, +0.56ºC, and +2.2ºC for (RCP 4.5,2020, RCP 4.5, 2050, RCP 8.5, 2020 and RCP 8.5, 2050) from the base period in each scenario respectively. Generally, for both (T max and T min) the increment was not worth for all scenarios based on IPCC-TGICA, (2007) in which the globally average surface air temperature was projected to warm 1.4ºC to 5.8ºC by 2001. These results (change of Tmin and Tmax) are harmonious with (Conway, 2011, Tekleab *et al.,* 2013, Kassie *et al.,* 2013, and IPCC, 2013). Kassie *et al.* (2013) found mean temperatures increasing to 0.8°C in 2020s and 1.2°C in 2050s in Ethiopia. Fikru *et al.* (2018), also indicates that, with respect to the future climate in the Guder Catchment, Upper Blue Nile, there is high confidence that the temperature will increase.

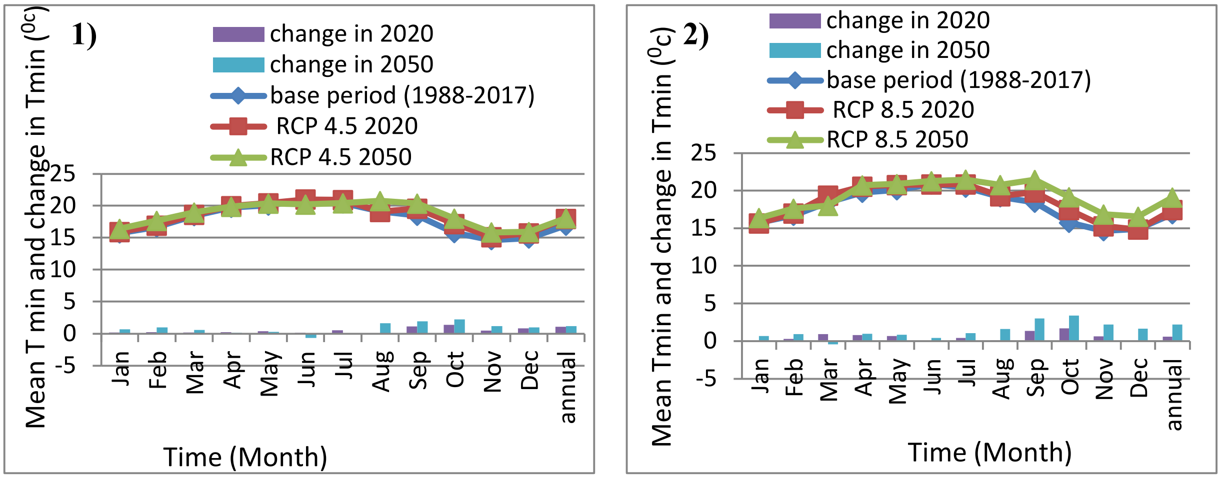

Figure 9. Mean monthly and annual Tmin and change of Tmin) Base period and all scenarios

4.3.3. Areal Precipitation

It is clear from Figure 10 that the mean monthly and annual precipitation and change in precipitation of logia river basin for the base period and future climate scenario (RCP4.5, 2020, RCP4.5, 2050, RCP8.5, 2020 and RCP8.5, 2050) are 694.52mm, 870.28mm, 886.47mm, and 901.21mm, respectively. The Mean annual precipitation has been increased in each scenario for all selected time slice. The mean annual precipitation would be increased compared from the base period by +24.96%, +25.72%, +28.06%, and +30.19% respectively. Generally, our result agrees with IPCC-TGICA (2007) and Fikru *et al.* (2018) that rainfall increases in future. IPCC (2011) also point out that there would be a likely increase of rainfall over areas of central and eastern Africa. The National Meteorological Agency was specified about the variability of precipitation in Ethiopia. IPPC (2013) also indicated that in rain season heavy precipitation events has increased over the World.

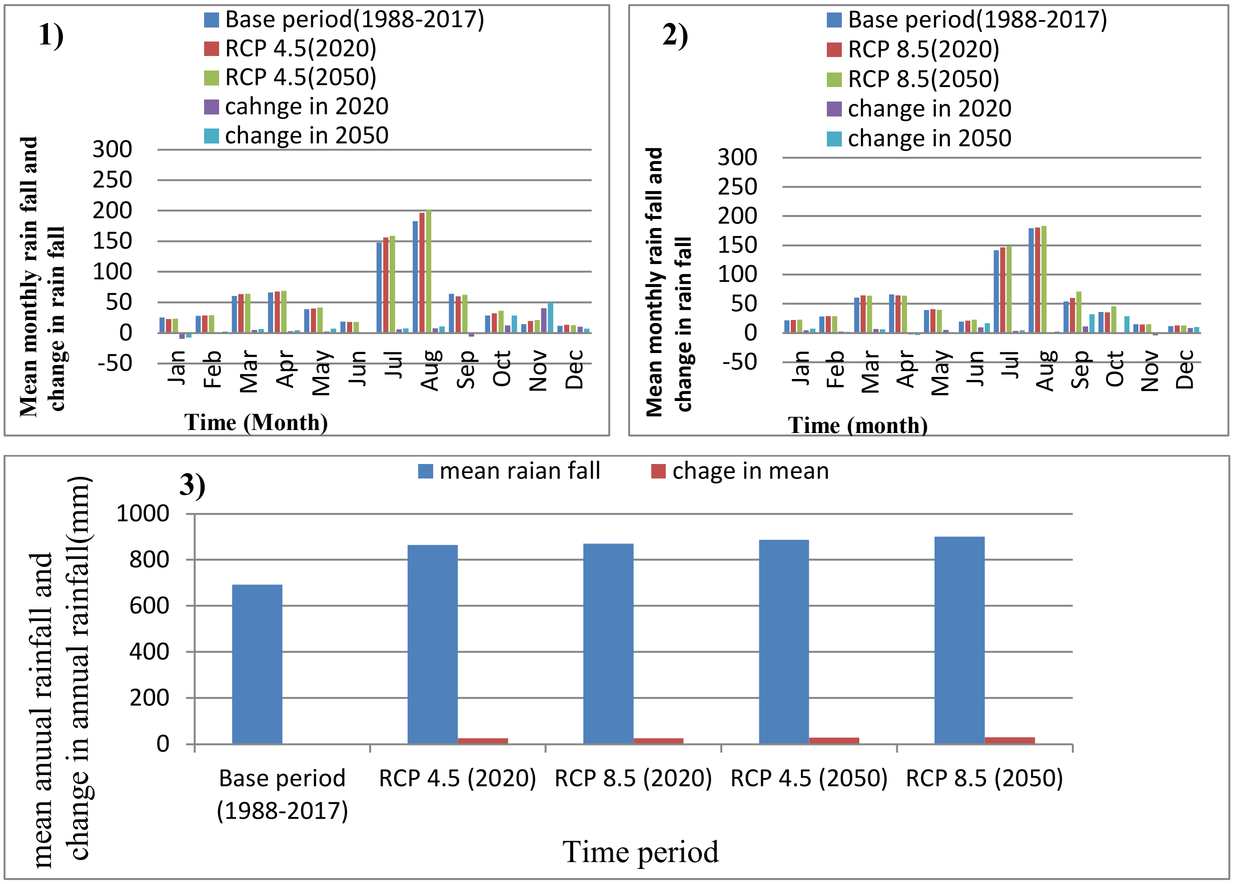

Figure 10. Areal mean monthly, change in rainfall and annual rainfall of all scenarios

4.4. Areal Potential Evapotranspiration (PET)

From Figure 11 it is clear that the annual and monthly potential evapotranspiration and change in PET from the base period to the future scenarios (RCP 4.5, 2020, RCP 4.5, 2050, RCP 8.5, 2020 and RCP 8.5, 2050) values are 1900.54mm, 1908.57mm,1920.00mm,1931.98mm, and 1964.53mm respectively. The result shows that an increment of PET for both scenarios and the changes in PET are +0.42% from the base period +1.02%, +1.65% and +3.36% respectively. This result is in line with (Engida, 1999), reported the highly increasing PET over the northeastern and northwestern lowlands of Ethiopia and Warner (2015) reported, increasing of average temperature with rise of 0.2-0.28ºC per decade, implying the corresponding increase of PET over the country.

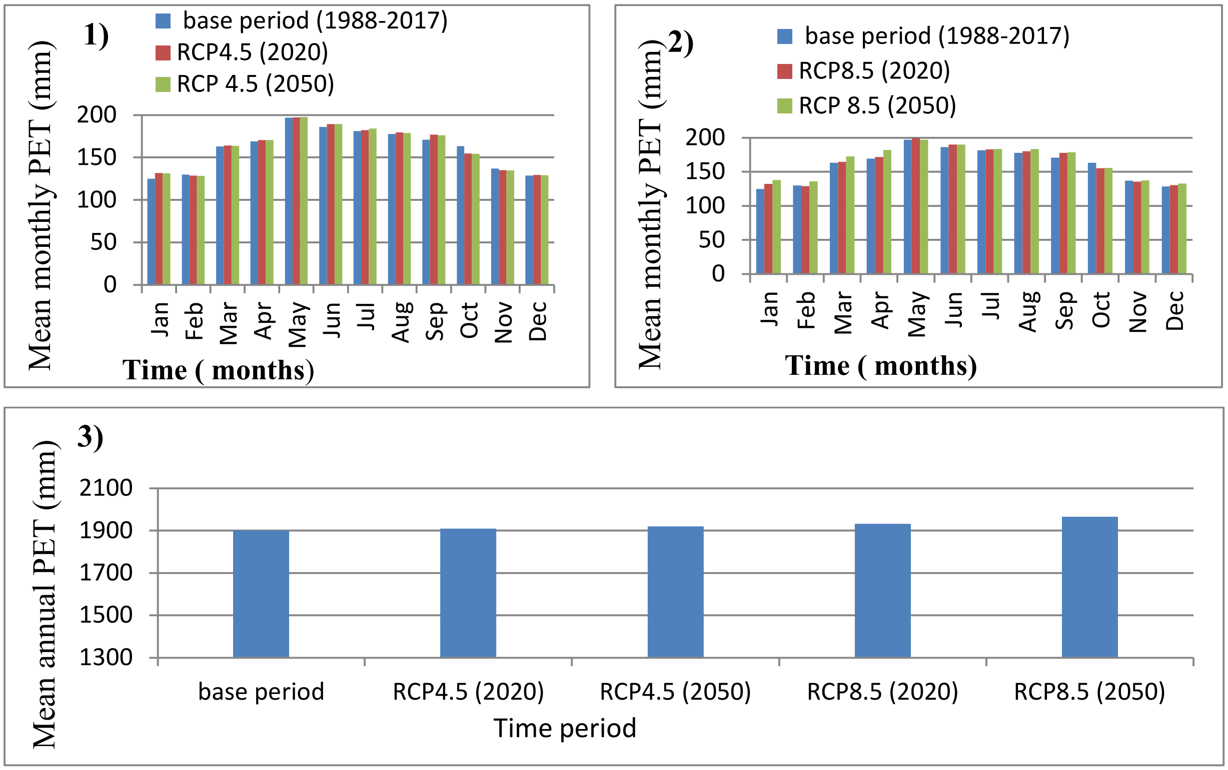

Figure 11. Areal mean monthly PET of base period and Annual PET (mm) of all time periods.

4.5. Drought Conditions

4.5.1. Metrological drought condition

Table 8. Observed meteorological drought (1988-2017)

No	Months	Drought severity year (1988-2017)		
		Extreme	Sever	Moderate
1	Jan	1994 and 1999	1988,1994,2000,2002,and 2017	1995,2000 and 2010
2	Feb	*	1993 and 2000	1994,2015,2016,and 2017
3	Mar	1988 and 2017	2016	2000
4	Apr	2017	1997 and 2016	2015
5	May	2016	2015	2009 and 2017
6	Jun	*	*	*
7	Jul	2002	2003 and 2008	2017
8	Aug	*	2002 and 2009	1999,2004 and 2008
9	Sep	1988 and 1989	*	1990,1991,1999and 2004
10	Oct	1988 and 1995	1990,1992 and 1993	1989,1991,2002 and 2004
11	Nov	1988 and 1998	1999 and 2007	1989,1990,1995,1996,1999 and 2002
12	Dec	1988,1990 and 99	2001	*

*= no drought severity year

As it can be seen from Figure 12, the overall result of base period from the total month of 360, 17 (4.72%), 21 (5.83%), 31 (8.61%), and 133 (36.94%) months were affected by extreme, sever or very dry, moderately dry and near normal metrological drought respectively. Only 158months (43.88%) are normal and wet condition

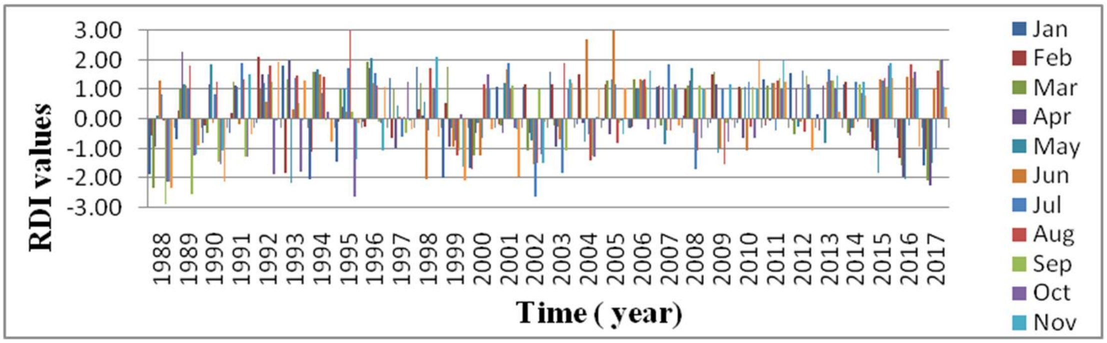

Figure 12. Observed meteorological drought (1988-2017)

Table 9. Near future meteorological drought of RCP 4.5 (2020)

No	Months	Drought severity year (2018-2047)		
		Extreme	Sever	Moderate
1	Jan	2039	2018	2012,30,34 and 2040
2	Feb	*	2038 and 2040	2019,32 and 2039
3	Mar	*	2030	2019,23,25 and 2029
4	Apr	*	2023,2025 and 2034	2018,19,20,28,31,40,41 and 2042
5	May	*	2037,45,46 and 2047	2031,33,34,38 and 2041
6	Jun	*	2026,40 and 2043	2022,23,33,39,40,41,42,46 and 2047
7	Jul	*	2020,35 and 2042	*
8	Aug	*	2039	2032
9	Sep	2031	2032,33,37,38and 2039	2018,19,29 and 2034
10	Oct	*	2018,19 and 2041	2020,34 and 2035
11	Nov	2036	2018,19,20 and 2036	2021,25,30,31,32,36 and 2045
12	Dec	2030 and 2031	2021,27,32 and2035	2022

*= no drought severity year

As shown in (Figure13) in the near future scenarios the overall result of RCP 4.5 (2020), out of 360 months 5 (1.39%), 34 (9.44%), 49 (13.61%) and 107 (29. 72%) months were affected by extreme, sever or very dry, moderately dry and near normal metrological drought respectively. Only 165 months (45.83%) are normal and wet condition. The change between base period and the near future scenario RCP 4.5 (2020) are decreases (4.72%) to (1.39%) respectively in extreme meteorological drought; increases (5.83%) to (9.44%) sever meteorological drought; increases (8.61%) to (13.61%) in Moderate meteorological drought; decreases (36.94%) to (29. 72%) in Near normal meteorological drought; and increases (43.88%) to (45.83%) in normal and wet condition.

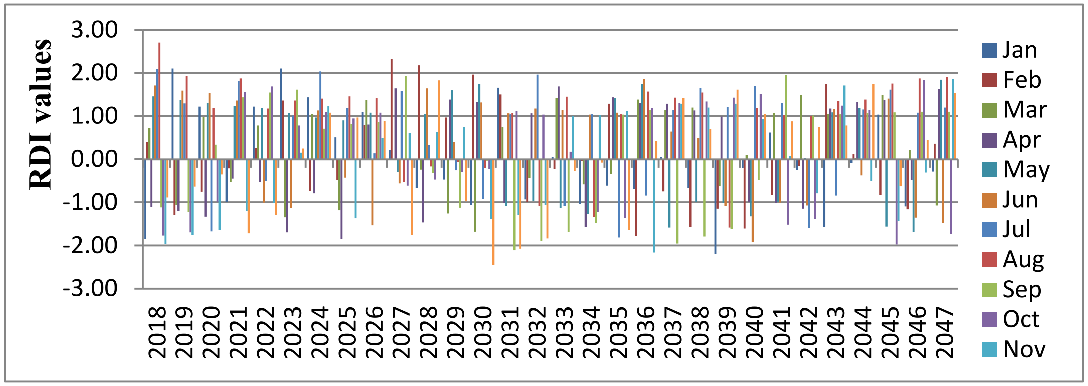

Figure 13. Near future meteorological drought of RCP 4.5 (2020)

Table 10. The mid century meteorological drought of RCP 4.5 (2050)

No	Months	Drought severity year (1988-2017)		
		Extreme	Sever	Moderate
1	Jan	2061	2057	2055 and 2068
2	Feb	*	2058,75 and 2077	2070 and 2077
3	Mar	2076	2071,72,74,75 and 2077	2073
4	Apr	*	*	2061,62,63,64,76 and 2077
5	May	*	*	2055,56,57,58 and 2059
6	Jun	*	*	2057,58,59 and 2061
7	Jul	*	2070	2048,49,56,57,61 and 2062
8	Aug	2049	2053	2050,51 and 2056
9	Sep	*	2070	2056,57,58,59,60,61 and 2062
10	Oct	2048 and 2049	2061	2063,64 and 2065
11	Nov	2077	2070,74,75 and 2076	2071,72 and 2073
12	Dec	*	2070,73,74,75,76 and 2077	2071,72 and 2075

*= no drought severity year

It can be seen in Figure14 in the mid century scenario of RCP 4.5 (2050), out of 360 months 6 months (1.66%), 23 months (6.39%), 44 months (12.22%) 105 months (29.17%) will be affected by extreme, severe, moderate and near normal metrological drought respectively. and only 182 months (50.55%) shows normal and wet conditions. comparing the two future scenarios RCP 4.5 (2020) and RCP (2050) there is a increases of (1.39%) to (1.66%) in extreme metrological drought and decreases of (9.44%), to (6.39%) in sever metrological drought and decreases of (13.61%) to (12.22%) in Moderate meteorological drought and decreases of (29. 72%) to(29.17%) in Near normal meteorological drought and increases of (45.83%) to (50.55%) in normal and wet drought conditions.

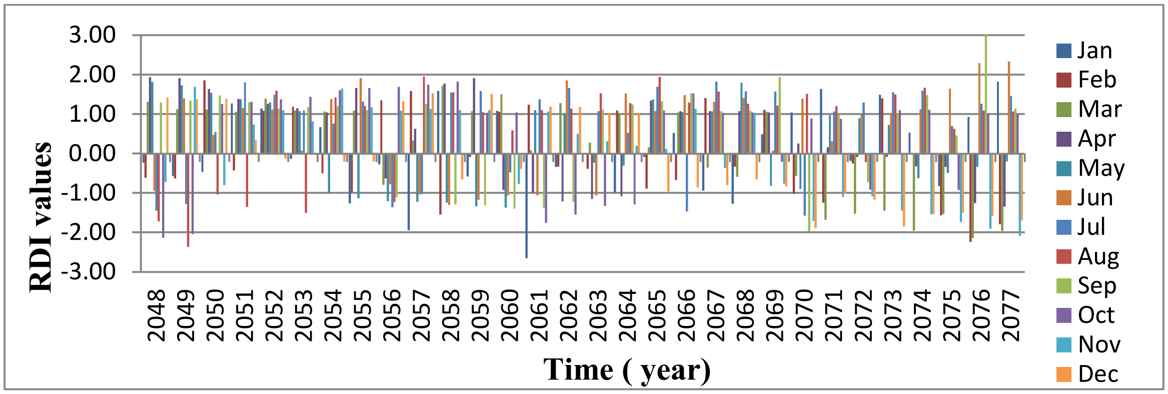

Figure 14. The mid century meteorological drought of RCP 4.5 (2050)

Table 11. Near future meteorological drought of RCP 8.5 (2020)

No	Months	Drought severity year (1988-2017)		
		Extreme	Sever	Moderate
1	Jan	2021 and 2030	2032 and 2037	2023 and 2033
2	Feb	*	*	2023,24,25,26,45,46 and 2047
3	Mar	*	2047	2027,30,44,45,46 and 2047
4	Apr	2047	2027 and 2046	2022, 25,26 and 2042
5	May	2028	2027,45,46 and 2047	2042,43 and 44
6	Jun	*	2018	2019,36,37,45,46 and 2047
7	Jul	*	*	2024 and 2046
8	Aug	*	2040	2023, 24,35,36 and 2038
9	Sep	*	2018 and 2029	2022,23,30,31 and 2038
10	Oct	*	2018 and 2019	2027,28,29,42,43 and 2045
11	Nov	2036	2029, 31 and 2045	2021,22.23.24.44 and 2046
12	Dec	2023 and 2030	2031,32 and 2040	2022, 35,36 and 2043

*= no drought severity year

As shown in (Figure15) in the RCP 8.5 (2020), from the total of 360 months 7 months (1.94%), 21 (5.83%), 56 (15.55%) and 108 (30%) are affected by extreme, severe, moderate and near normal metrological drought respectively. and only 168 (46.67%) shows normal and wet conditions. comparing the result of base period and RCP 8.5 (2020) the extreme metrological drought was decreases (4.72%) to (1.94%) and sever metrological drought was not changed and moderate metrological drought was increases (8.61%) to (15.55%) and near normal metrological drought was decreases (36.94%) to (30%) and normal and wet condition was increases (43.88%) to (46.67%).

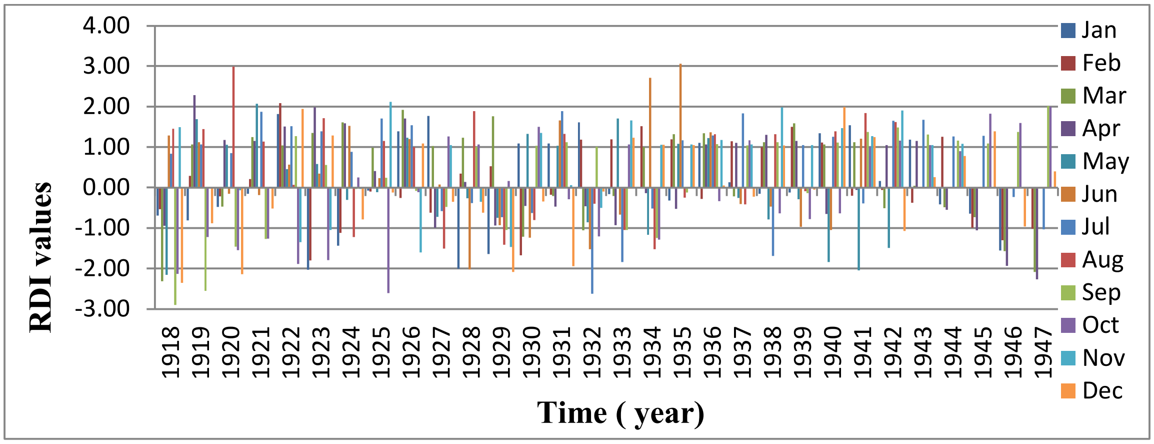

Figure 15. Near future meteorological drought of RCP 8.5 (2020)

Table 12. The mid century meteorological drought of RCP 8.5 (2050)

No	Months	Drought severity year (1988-2017)		
		Extreme	Sever	Moderate
1	Jan	*		2072, 73 and 2074,
2	Feb	*	2076	2058 and 2059
3	Mar	2048	*	*
4	Apr	*	2076 and 2077	2062, 63 and 2064
5	May	*		2057, 58, 59, 63 and 2077
6	Jun	2058 and 2077	2049 and 2046	2063
7	Jul	*	2061 and 2077	2063, Jul of 2053, 54, 60 and 2076
8	Aug	*	2064	2088 and 2076
9	Sep	*	*	2049, 50, 70, 71, 72 and 2073
10	Oct	*	*	2048, 51, 59, 60, 61, 66 and 2067
11	Nov	*	*	2051, 52,53, 55 and 2073
12	Dec	2066	2071 and 2073	2048, 65, 69 and 2070

*= no drought severity year

From Figure 16 it can be observed that the RDI result of RCP8.5 (2050) from the total of 360 months affected by extreme, severe, moderate and near normal metrological drought are 4 months (1.1%), 10 months (2.77%), 42 months (11.66%) and 113 months (31.38%) respectively. Only 191 months (53.05%) will shows normal and wet conditions. Comparing the result with RCP 8.5 (2020) the extreme metrological drought was decreases (1.94%), to (1.1%) and sever metrological drought was decreases(5.83%), to (2.77%) and moderate meteorological drought was decreases(15.55%) to (11.66%) and near normal metrological drought was increases (30%) to(31.38%) and normal and wet conditions will be increases (46.67%) to (53.05%). And also comparing the result of the two future RCP4.5 and RCP 8.5 scenarios in the time slice 2020 the total metrological drought will be (54.17%) and (45.83%) will be normal and wet condition and (53.33%) will be metrological and (46.67%) will be normal and wet condition respectively. And in both scenarios the time slice of 2050 the total metrological drought will be (49.45%) and (50.55%) will be normal and wet condition and (46.95%) will be metrological drought and (53.05%) will be normal and wet condition respectively.

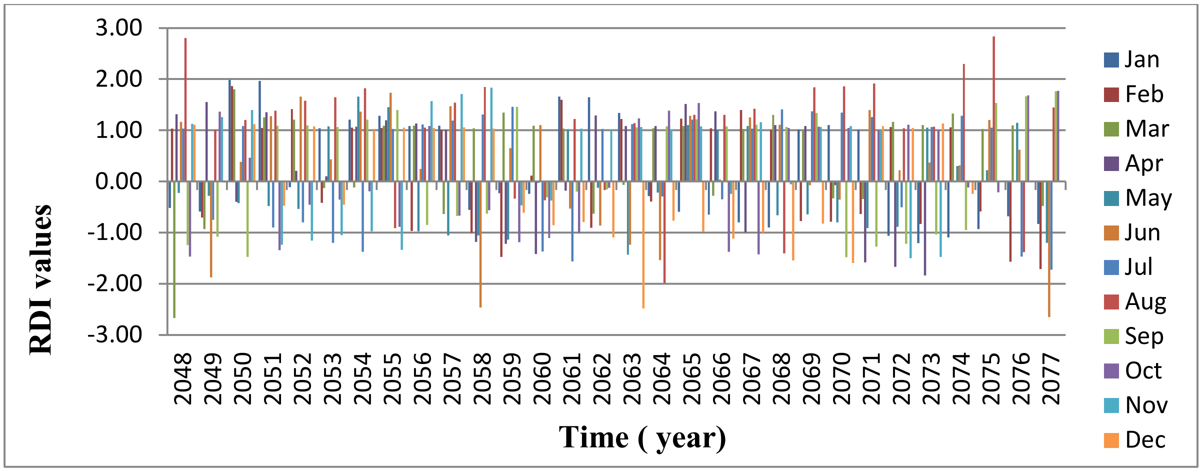

Figure 16. The mid century meteorological drought of RCP 8.5 (2050)

4.5.2. Agricultural drought condition

As it can be seen from figure 17, the *Kiremt* season over the base period (1988-2017) the extreme agricultural drought was observed in 2002 and Very dry or severe agricultural drought was observed in 1999 and Moderate agricultural drought was observed in 1989, 2008 and 2009 and near normal agricultural drought was observed in 1990, 91, 93, 94, 96, 97, 98, 2000, 04, 06, 07, 10 and 12.Generally the extreme and sever agricultural drought were affected each of (3.3%) and (10%) and Moderate agricultural drought and near normal agricultural drought condition were affected by (46.67%). In *kiremt* season only (36.73%) was normal and wet condition.

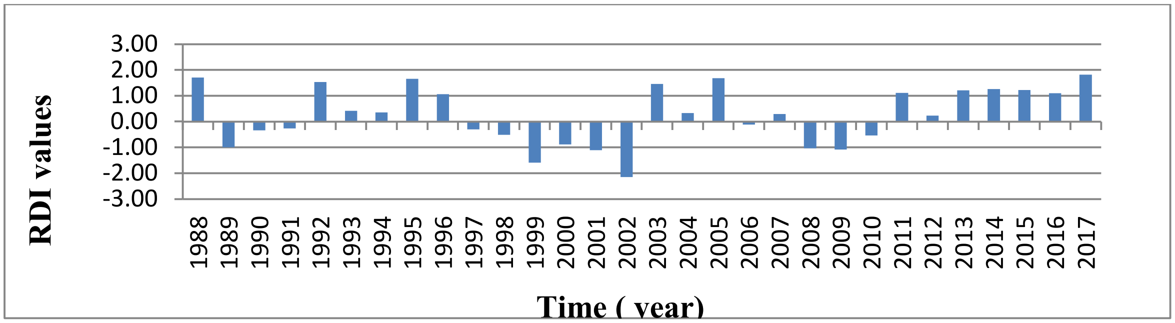

Figure 17. Kiremt agricultural drought of base period (1988_2017)

It is clear from figure18, in the near future scenarios of RCP 4.5 extreme agricultural drought was not observed in *kiremt* season and very dry or severe agricultural drought was observed in2019, 2041 and 2046 and Moderate agricultural drought was observed in 2021, 22, 31, 38 and 40 and near normal agricultural drought was observed in 2025, 27, 29, 32, 34, 35 and 42. Generally, 0% was affected by extreme agricultural drought; 10% was affected by sever agricultural drought; 16.67% was affected by Moderate agricultural drought; and 23.33% were affected by near normal agricultural drought condition. In *kiremt* season, only 50.01% was normal and wet condition. The differences between base period and near future scenarios under RCP 4.5 in *kiremt* season are the agricultural drought in base period was higher than the near future scenarios RCP 4.5.

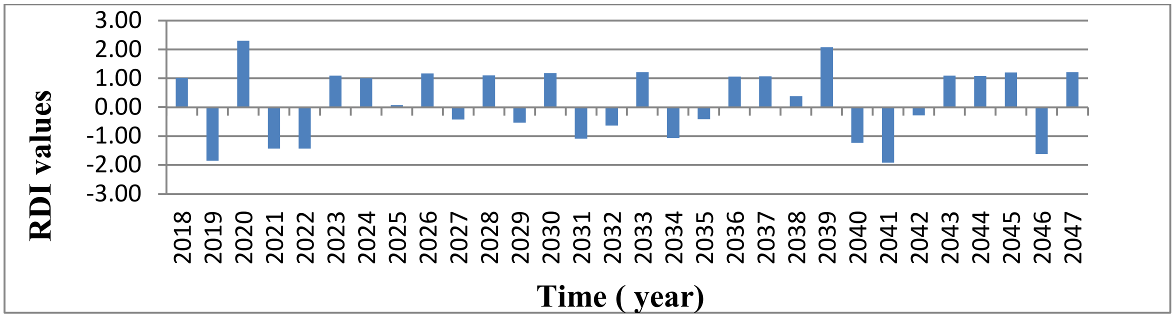

Figure 18. Kiremt agricultural drought of RCP 4.5 (2020)

As shown in Figure 19 in mid-century for RCP 4.5in*kiremt* season extreme agricultural drought was not observed and very dry or severe agricultural drought was observed in 2050 and 2072 and Moderate agricultural drought was observed in 2053, 54, 69, 73 and 77 and near normal agricultural drought was observed in 2049, 55, 58, 61, 63, 64, 66, 67 and 76. Generally, 0% was affected by extreme agricultural drought; 6.67% was affected by sever agricultural drought; 16.67% was affected by Moderate agricultural drought; and 30% was affected by near normal agricultural drought condition. The normal and wet condition in this season was only 46.66%.The agricultural droughts in near future scenarios and in mid-century of RCP 4.5 in kiremt season will increases (49.99%) to (53.34%).

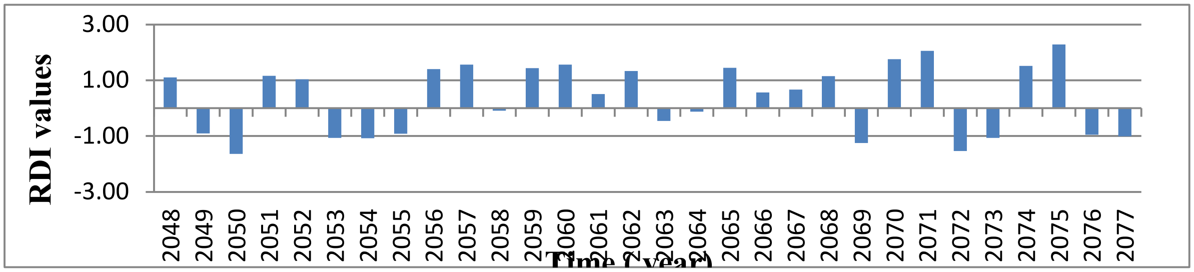

Figure 19. Kiremt agricultural drought of RCP 4.5 (2050)

From Figure 20, the RCP 8.5 (2020) it is clear that the Extreme agricultural drought was occurred in *kiremt* season in the year of 2038 and severe agricultural drought was occurred in 2021, 2026, 2033 and 2037 and Moderate agricultural drought was occurred in 2022 and 2024 and near normal agricultural drought occurred in 2028, 2030, 2032, 2036, 2040, 2043, 2044 and 2047. Under the RCP 4.5 (2020) the extreme, severe, Moderate and near normal agricultural drought will be (3.33%), (13.33%), (6.66%) and (26.67%) respectively. from this (50.00%) will be normal and wet agricultural drought.

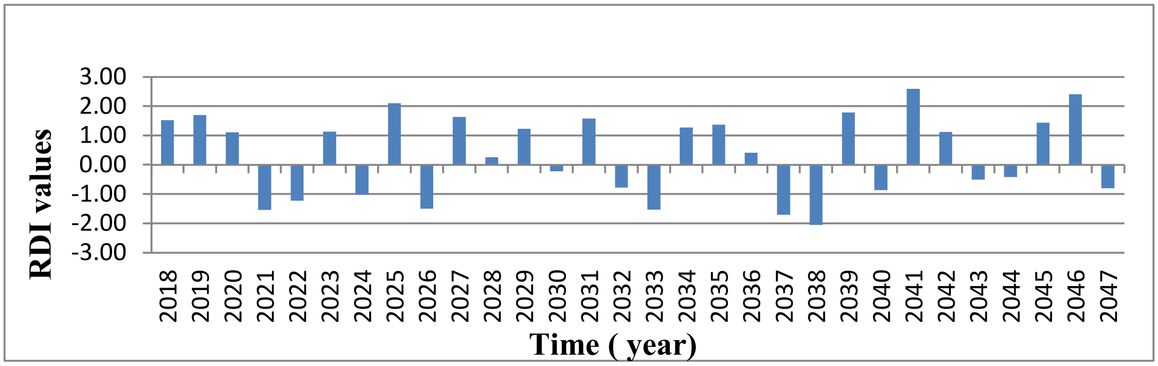

Figure 20. Kiremt agricultural drought of RCP 8.5 (2020)

In mid-century for RCP 8.5 in *kiremt* season Figure 21 shows that the Extreme agricultural drought was observed in 2065, and severe agricultural drought was observed in 2048, 2069 and 2077 and Moderate agricultural drought was observed in2049, 2052, 2055, 2067, 2073and 2075 and near normal agricultural drought was observed in 2050, 2056, 2057, 2059, 2061, 2064, 2070 and 2072. In this season the extreme, severe, Moderate and near normal agricultural drought will be (3.33%), (10%), (20%) and (26.67%) respectively. from this only (40%) will be normal and wet agricultural drought. Comparing the near future and the mid-century scenario for RCP 8.5in*kiremt* season the agricultural drought will be increases (46.65%) to (60%). Generally, in *kiremt* season the agricultural drought will increases from near future scenarios to mid-century from both RCP 4.5 and 8.5 scenarios.

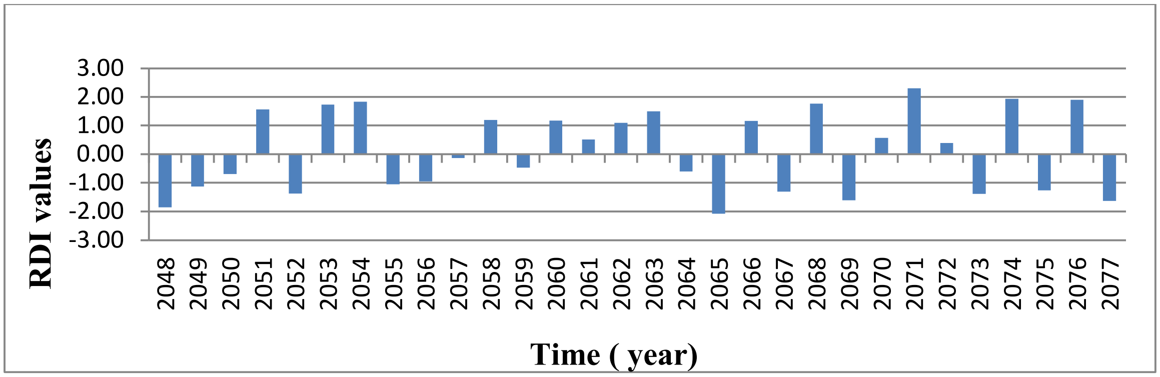

Figure 21. Kiremt agricultural drought of RCP 8.5 (2050)

4.6. The Frequency of Drought Occurrence and Return Periods

In Table 8, the results revealed the frequency of events, probabilities of occurrence and return period of different drought severity class in the two drought types for the base period mid and near future scenarios of RCP 4.5 and RCP 8.5. The return period of the drought conditions of severs and extreme droughts in the base period for meteorological and agricultural drought were 13 &20 and 10& 20 sever and extreme respectively. In the near future RCP 4.5 scenarios, the return period of severe and extreme drought for meteorological and agricultural drought were 50 severe and 6 extreme and no return period for severe and 5 extreme drought respectively. Similarly, in mid scenarios of RCP 4.5, the return period of severe and extreme drought for meteorological and agricultural drought were 33 severe and8 extreme and no return period for severe and 8 extreme drought respectively. Likely, the return period of severe and extreme drought for meteorological and agricultural drought for near future and mid-century of RCP 8.5 scenarios of 33 severe and10 extreme and 16 severe, 4 extreme and 50 severe, 20 extreme and 20 severe, 6 extreme drought respectively. These results are agreeable with (Edossa *et al*., 2010; Feyissa, 2017).

Table 13. Analysis of return period for drought classes

Period	Severity Class	Drought Type					
		Meteorological			Agricultural		
		FE	PO	T	FE	PO	T
Base period	Extreme	17	0.08	13	1	0.05	20
	Severe	21	0.1	10	1	0.05	20
	Moderate	31	0.15	7	3	0.16	6
	Near normal	133	0.65	2	13	0.72	1
	Total	202	1		18	1	
RCP 4.5 (2020)	Extreme	5	0.02	50	0	0	*
	Severe	34	0.17	6	3	0.2	5
	Moderate	49	0.25	4	5	0.33	3
	Near normal	107	0.54	2	7	0.46	2
	Total	195	1		15	1	
RCP 4.5 (2050)	Extreme	6	0.03	33	0	0	*
	Severe	23	0.12	8	2	0.12	8
	Moderate	44	0.24	4	5	0.31	3
	Near normal	105	0.58	2	9	0.56	2
	Total	178	1		16	1	
RCP 8.5 (2020)	Extreme	7	0.03	33	1	0.06	16
	Severe	21	0.1	10	4	0.26	4
	Moderate	56	0.29	3	2	0.13	8
	Near normal	108	0.56	2	8	0.53	2
	Total	192	1		15	1	
RCP 8.5 (2050)	Extreme	4	0.02	50	1	0.05	20
	Severe	10	0.05	20	3	0.16	6
	Moderate	42	0.24	4	6	0.33	3
	Near normal	113	0.66	2	8	0.44	2
	total	169	1		18	1	

FE: Frequency of Events, PO: Probabilities of Occurrences, T: return period, *: no return period

5. SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

5.1. Summary and Conclusions

Drought is mainly caused by low precipitation and high evaporation rates. Climate change is expected to primarily affect precipitation, temperature and potential evapotranspiration, and, thus, is likely to affect the occurrence and severity of meteorological and agricultural drought.

In this study, past climatic data were taken from NMA for the period of 1988-2017 and the outputs of the MarkSim GCMs model have been employed for the estimation of future precipitation and temperature time series for the periods 2018–2047and 2048–2077, under metrological and agricultural drought condition in logia river basin.

The annual mean precipitation result shows an increment of (+24.96%) from the base period to RCP 4.5(2020), +25.72% to RCP 4.5 (2050), +28.06% to RCP 8.5 (2020) and +30.19% RCP 8.5 (2050) periods. Generally, the annual mean precipitation of logia exhibited an increasing trend for all the study periods.

The average monthly maximum temperature result showed an increasing trend for all scenarios the mean annual increment of maximum temperature ranges between + 0.31ºC from the base period to RCP 4.5 2020, +1.16ºC from RCP4.5 2050, +0.56ºC from RCP 8.5 2020 and +1.27ºC from RCP 8.5 2050.In addition, there is an increment of +0.85ºC from RCP 4.5 2020 to RCP 4.5 2050 and +0.69ºC from RCP 8.5 2020 to RCP 8.5 2050 scenarios.

Also, the minimum temperature for the base period and future climate scenarios, (RCP 4.5(2020) RCP 4.5 (2050), RCP 8.5 (2020) and RCP 8.5 (2050) are the result of 16.89, 17.25, 18.06, 17.46, and 19.099mm respectively. The average annual minimum temperature would be increased by 0.36, 1.17, 0.56, and 2.2 for (RCP 4.5, (2020), RCP 4.5 (2050), RCP 8.5 (2020) and RCP 8.5 (2050)) from the base period in each scenario respectively. Generally, the average annual minimum and maximum temperature in logia will be an increasing trend for all the study periods.

The result change in annual PET shows that an increment of PET from base period to near future and mid-century of RCP 4.5 (2020), RCP 4.5 (2050), RCP 8.5 (2020) and RCP 8.5 (2050).The changes in PET are + 0.42%, +1.02%, +1.65%, and +3.36 from the base period respectively. This indicated that there is highly vulnerable to drought.

The historical meteorological drought condition from the total of 360 months 17 (4.72%) 21 (5.83%) 31 (8.61%) 133 (36.94%) months were affected by extreme, sever, moderately dry and near normal metrological drought respectively. Generally; in this study (56.12%) were affected by metrological drought and (43.88%) were wet and normal condition. Also, in the case of near future scenarios RCP4.5the result shows that out of 360 months 5 (1.39%), 34 (9.44%), 49 (13.61%) and 107 (29.72%) months were affected by extreme, sever or very dry, moderately dry and near normal metrological drought respectively. only 165 months (45.83%) are normal and wet condition. Similarly, in mid-century scenarios RCP4.5 the result shows that out of 360 months6 months (1.66%), 23 months (6.39%), 44 months (12.22%) 105 months (29.17%) will be affected by extreme, severe, moderate and near normal meteorological drought respectively. and only 182 months (50.55%) shows normal and wet conditions.

The near future scenarios RCP8.5the result shows that from the total of 360 months 7 months (1.94%), 21 (5.83%), 56 (15.55%) and 108 (30%) will affected by extreme, severe, moderate and near normal metrological drought respectively. and only 168 (46.67%) shows normal and wet conditions. Also, in the mid century scenarios RCP8.5 the result shows that from the total of 360 months affected by extreme, severe, moderate and near normal metrological drought are 4 months (1.1%), 10 months (2.77%), 42 months (11.66%) and 113 months (31.38%) respectively. Only 191 months (53.05%) will shows normal and wet conditions.

The agricultural drought in *Kiremt* season over the base period (1988-2017) the result shows the extreme and sever agricultural drought were affect each of (3.3%) and (10%) wear affected by Moderate agricultural drought and (46.67%) wear affected by near normal agricultural drought condition. For this study in *kiremt* season only (36.73%) was normal and wet condition. Also, for the near future scenarios of RCP 4.5in*Kiremt* season (0%) were affected by extreme agricultural drought and (10%) were affected by sever agricultural drought and

(16.67%) were affected by Moderate agricultural drought (23.33%) were affected by near normal agricultural drought condition. In *kiremt* season only (50.01%) was normal and wet condition. Similarly, for mid-century of RCP4.5 the result shows (0%) were affected by extreme agricultural drought and (6.67%) were affected by sever agricultural drought and (16.67%) wear affected by Moderate agricultural drought and (30%) were affected by near normal agricultural drought condition. The normal and wet condition in this season was only (46.66%).

The result of agricultural drought in *Kiremt* season over the near future of RCP8.5 scenarios shows that the extreme, severe, moderate and near normal agricultural drought will be (3.33%), (13.33%), (6.66%) and (26.67%) respectively. From this, (50.00%) will be normal and wet agricultural drought. Also, in mid-century RCP8.5 scenarios result shows that the extreme, severe, Moderate and near normal agricultural drought will be (3.33%), (10%), (20%) and (26.67%) respectively. From this, only (40%) will be normal and wet agricultural drought. Generally, in *kiremt* season, the agricultural drought will increases from near future scenarios to mid-century from both RCP 4.5 and 8.5 scenarios.

5.2. Recommendations

Based on the findings of this study, the following recommendations are suggested:

- ✓ The methods as well as results of agricultural and metrological drought condition and the frequency of events, probability of occurrence and return period are believed to be highly important for decision makers and stakeholders in the study area. However, it is recommended that future studies can build up on this work by including hydrological drought for reliable result so that stakeholders can get more information that helps to take necessary adaptation measures and reduce the impact of drought.
- ✓ It is hereby recommended that the other meteorological drought index should be taken into account to investigate the climate change impact on drought condition and the frequency of events, probability of occurrence and return period for future periods in logia river basin.
- ✓ It is suggested to investigate uncertainty of using other models such as SDSM to evaluate climate change impact on climatic drought in the study area.

- ✓ The study already found the extreme droughts having high probabilities of occurrences and very short return periods thus; any hydraulic structure design in the area should consider these extreme drought events.
- ✓ Since agricultural drought severity levels vary over the study area, selection of agricultural technologies and information (drought tolerance crops, the type of crop variety and soil moisture conservation practices) should be made to fit in to the agricultural drought severity levels in the sub basin.

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7. APPENDICES

7.1 Appendix Tables

Appendix Table 1. Mean monthly Areal RF, Tmax, Tmax and PET Base period

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax	27.89	29.6	31.43	32.67	34.46	34.66	33.93	32.8	32.85	31.3	29.54	28.63
Tmin	15.73	16.7	18.42	19.74	20.06	20.85	20.42	19.13	18.44	15.8	14.66	14.89
RF	25.32	28	60.21	65.97	38.84	18.2	147.9	183	63.77	28.4	13.94	11.76
PET	124.7	130	163.1	169.1	196.8	186	181.2	177.6	170.7	163	136.9	128.5

AppendixTable 2. Mean monthly Areal RF, Tmax, Tmax and PET RCP 4.5 2020

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax	28.33	29.9	31.44	32.83	34.71	35.47	33.996	32.96	32.78	33	29.89	29.02
Tmin	15.9	16.9	18.59	19.96	20.44	21	20.935	19.04	19.57	17.1	15.13	15.74
RF	22.8	28.1	63.22	67.80	39.61	18	156.32	196.5	59.95	31.7	19.6	12.96
PET	131.6	129	164	170.4	197.4	189.2	182.29	179.4	177	155	134.9	129.2

Appendix Table 3 . Mean monthly Areal RF, Tmax, Tmax and PET RCP 4.5 2050

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax	29.04	30.6	32.06	32.72	35.58	36.25	34.379	33.79	33.6	33.7	30.12	29.37
Tmin	16.4	17.7	18.98	19.85	20.35	20.19	20.433	20.77	20.38	18	15.85	15.89
RF	23.28	28.6	63.88	68.78	41.47	17.9	158.79	201.8	62.47	36.4	20.92	12.59
PET	131.3	128	163.7	170.4	197.9	189.4	183.96	178.7	176.3	154	134.7	129.1

Appendix Table 3. Mean monthly Areal RF, Tmax, Tmax and PET RCP 8.5 2020

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax	28.46	30.1	31.81	33.54	34.28	35.48	34.465	33.16	32.94	31.2	29.17	28.74
Tmin	15.65	17	19.37	20.55	20.74	20.84	20.842	19.26	19.79	17.4	15.29	14.84
RF	22.33	28.7	64.17	64.22	40.91	21.06	146.32	180.5	59.74	35.3	14.32	12.75
PET	132.1	129	164.6	171.5	199	189.7	182.85	180	177.6	155	135.3	130.1

Appendix Table 4. Mean monthly Areal RF, Tmax, Tmax and PET RCP 8.5 2020

month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Tmax	30	30.6	32.19	33.82	35.77	36.87	35.074	33.54	33.27	32.3	30.78	30.12
Tmin	16.38	17.6	17.98	20.72	20.9	21.27	21.469	20.75	21.45	19.1	16.87	16.54
RF	22.86	28.6	64.01	63.65	39.42	22.43	147.86	183	70.96	45.9	15.04	12.94
PET	137.7	136	172.2	181.7	196.9	190	183.04	183.2	178.5	156	137.3	132.8

Appendix Table 5. One month time scale RDI value of base period

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2018	-0.32	1.36	1.78	-0.29	0.75	-1.62	1.52	1.05	-1.75	-1.80	-0.68	-0.85
2019	0.41	1.34	1.01	-0.31	1.51	-1.48	1.40	1.38	-0.41	-1.65	-0.56	-0.71
2020	0.74	-0.19	-0.13	1.62	1.47	1.05	1.18	1.14	-0.23	-0.97	-0.44	-0.61
2021	-2.37	1.34	1.30	-0.63	0.40	0.20	-0.94	1.47	1.07	-0.86	-1.33	1.01
2022	1.09	1.31	-0.38	-1.06	1.23	1.25	-0.95	2.69	-1.25	1.00	-1.23	-1.10
2023	-1.08	-1.06	1.46	-0.93	1.10	0.37	-1.08	-1.01	-1.13	1.06	-1.10	-2.83
2024	-0.80	-1.13	1.01	1.01	0.95	0.54	-0.62	-1.05	1.22	1.45	-1.03	1.01
2025	-0.71	-1.14	1.09	-1.41	0.96	1.65	1.26	0.93	1.39	1.36	-0.33	1.33
2026	-0.40	-1.21	0.71	-1.42	1.01	1.01	1.02	1.75	1.42	-1.51	-0.18	1.02
2027	-0.14	-0.60	-1.01	-1.85	-1.99	1.07	1.04	1.78	-0.61	-1.37	1.08	1.01
2028	-0.01	1.77	1.07	1.51	-2.29	1.59	1.21	1.64	-0.45	-1.27	1.01	-0.94
2029	1.00	1.72	1.18	1.71	1.43	1.42	1.17	1.45	-1.69	-1.11	-1.60	-0.84
2030	-2.06	1.60	-1.27	0.48	1.22	1.15	1.04	1.40	-1.49	-0.21	1.51	-2.02
2031	1.82	1.08	1.09	1.29	1.18	1.22	1.60	1.38	-1.35	-0.09	-1.59	-1.76
2032	-1.62	-0.01	1.64	1.24	1.00	1.36	1.10	1.05	1.05	-0.02	1.69	-1.57
2033	-1.32	-0.15	1.56	1.11	1.02	1.47	1.09	1.05	1.15	1.14	1.03	-0.94
2034	1.89	-0.27	1.42	1.32	1.10	1.57	1.02	1.44	-0.98	1.26	-0.15	-0.86
2035	1.94	1.06	1.19	-0.10	-0.27	1.61	1.36	-1.38	-0.82	1.35	1.28	-1.00
2036	1.09	1.50	1.10	0.04	-0.35	-1.14	-0.61	-1.34	1.77	1.47	-2.16	-1.07
2037	-1.93	1.01	-0.63	1.22	1.48	-1.05	1.09	1.23	1.57	-0.56	1.47	-0.89
2038	1.01	1.07	-0.66	1.17	1.64	-0.86	1.58	-1.17	-0.68	-0.66	1.06	1.01
2039	1.79	-0.82	-0.81	1.18	1.07	1.77	0.44	1.57	-0.83	1.08	-0.78	-0.76
2040	1.09	-0.94	-0.89	1.12	-0.81	1.02	1.01	-1.96	1.09	-0.88	-0.86	-1.78
2041	1.01	1.06	1.56	1.16	-0.99	1.00	-0.82	0.82	1.01	1.01	-0.95	1.55
2042	1.70	1.08	0.51	-1.23	-1.08	-0.30	1.73	1.04	1.10	-1.06	1.12	-0.54
2043	-0.56	0.87	0.39	0.81	-1.24	-0.19	1.20	1.46	-1.22	-1.19	1.24	-1.43
2044	-0.64	0.71	0.21	0.70	-1.42	0.07	-0.34	1.30	1.29	1.25	-1.35	-0.20
2045	1.43	-1.26	-1.34	0.78	-1.52	-1.37	1.01	1.65	-0.33	-1.37	-1.51	-0.13
2046	-0.21	-1.38	-1.40	-1.77	-1.64	-1.32	-1.03	1.52	1.47	1.45	-1.38	-0.32
2047	1.16	-1.43	-1.50	-2.09	-1.78	-1.20	-0.68	1.89	-0.51	1.56	-0.11	-0.50

Appendix Table 6. One month time scale RDI value of RCP 4.5 2020

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2018	-1.85	0.40	0.72	-1.11	1.46	1.71	2.09	2.71	-1.12	-1.77	-1.96	-0.89
2019	2.10	-1.30	-1.06	-1.20	1.38	1.59	1.29	1.92	-1.22	-1.69	-1.76	-0.63
2020	1.22	-0.76	0.98	-1.33	1.31	1.53	-1.68	1.18	0.34	-1.00	-1.64	-0.35
2021	-1.00	-0.21	-0.52	-0.45	1.23	1.36	1.82	1.87	1.44	1.56	-1.21	-1.71
2022	1.22	0.26	0.78	-0.53	1.18	-1.01	-0.50	1.17	1.55	1.69	-1.02	-1.29
2023	2.10	1.36	-1.35	-1.70	1.07	-1.13	1.01	1.36	1.61	0.78	0.15	0.25
2024	1.44	-0.74	1.05	-0.79	0.97	1.13	2.04	1.41	0.71	1.09	1.23	1.08
2025	0.51	-0.48	-1.18	-1.84	0.90	-0.42	1.19	1.45	0.81	0.95	-1.37	0.97
2026	1.10	0.79	1.37	0.80	1.08	-1.53	0.14	1.41	0.86	1.08	0.49	0.89
2027	0.22	2.33	-0.02	1.64	-0.30	-0.56	1.58	-0.53	1.93	-0.61	0.60	-1.76
2028	-0.67	2.18	-0.24	-1.47	1.04	1.64	0.33	-0.16	-0.32	-0.47	0.63	1.83
2029	-0.47	0.97	-1.26	1.38	1.60	0.40	-0.25	-0.07	-1.12	-0.29	0.75	-0.98
2030	-1.07	1.96	-1.68	1.32	1.74	1.31	-0.91	-0.20	-0.04	-0.23	-1.39	-2.45
2031	1.66	1.50	0.76	-1.02	-1.08	1.06	1.04	1.07	-2.11	1.12	-1.29	-2.08
2032	-0.93	-1.00	-0.44	1.06	-0.97	1.18	1.96	-1.08	-1.90	1.03	-1.06	-1.83
2033	0.05	-0.22	1.42	1.69	-1.13	1.14	-1.09	1.45	-1.69	0.17	1.00	-0.28
2034	-1.03	-0.04	-0.58	-1.58	-1.27	1.03	1.04	-1.34	-1.47	-1.22	1.02	-0.08
2035	-0.62	1.29	-0.34	1.44	1.41	1.08	-1.82	1.04	1.03	-1.36	1.12	-1.64
2036	-0.69	-1.78	1.38	1.31	1.74	1.86	-0.84	1.56	1.15	1.19	-2.16	0.42
2037	0.05	-0.74	1.14	1.28	-1.58	0.64	1.14	1.43	-1.96	1.30	1.28	1.42
2038	-0.66	-1.57	1.20	1.13	-1.00	0.49	1.65	1.55	-1.79	1.34	1.20	0.70
2039	-2.19	-1.15	-0.63	0.99	-1.01	-1.09	1.21	-1.58	-1.61	1.43	1.29	1.61
2040	-0.20	-1.61	0.09	-1.00	-1.32	-1.93	1.69	1.18	-0.48	1.51	0.93	1.05
2041	0.62	-0.83	1.07	-1.01	-1.00	-1.01	1.31	1.02	1.96	-1.52	0.07	0.88
2042	-0.25	-0.15	1.50	-1.15	0.03	-1.08	-1.60	1.01	1.01	-1.38	-0.79	0.75
2043	-1.58	1.75	1.05	1.18	1.09	1.16	-0.84	1.35	1.04	1.25	1.71	0.78
2044	-0.08	0.11	0.03	1.33	1.18	-0.38	1.15	1.39	1.07	1.14	-0.51	1.75
2045	1.04	-0.84	1.49	1.38	-1.56	1.41	1.61	1.75	1.09	-1.98	-1.44	-0.63
2046	-1.09	-1.16	0.22	-0.48	-1.68	-1.36	1.08	1.87	1.10	1.83	-0.31	0.45
2047	-0.29	0.36	-1.07	1.63	1.84	-1.47	1.20	1.91	1.10	-1.73	1.86	1.53

Appendix Table 7. One month time scale RDI value of RCP 4.5 2050

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2048	-0.24	-0.61	1.31	1.93	1.81	-0.95	-1.45	-1.72	1.29	-2.13	-0.73	1.42
2049	-0.57	-0.63	1.13	1.91	1.73	1.40	-1.29	-2.37	1.34	-2.05	1.69	1.38
2050	-0.47	1.86	1.11	1.63	1.54	0.48	0.54	-1.04	1.47	1.26	-0.80	1.39
2051	1.27	-0.43	1.06	1.38	1.37	1.15	1.80	-1.35	1.30	1.31	0.74	0.33
2052	1.14	1.08	1.39	1.26	1.29	1.11	1.49	1.59	1.14	1.37	1.09	-0.14
2053	-0.14	1.19	1.09	1.14	1.08	0.07	1.09	-1.51	1.18	1.44	0.81	0.01
2054	0.67	-0.51	1.06	1.04	-1.01	1.38	0.75	1.43	1.20	1.60	1.64	-0.21
2055	-1.27	-0.98	1.09	1.66	-1.13	1.91	1.32	1.20	1.10	1.66	1.17	-0.20
2056	-0.27	1.35	-0.80	-0.63	-1.21	-0.78	-1.37	-1.23	-1.11	1.69	1.08	1.33

2057	-1.95	1.59	0.33	0.62	-1.22	-1.04	-1.03	1.95	1.25	1.75	1.13	1.53
2058	1.59	-1.55	1.72	1.77	-1.24	-1.31	1.55	1.56	-1.29	1.82	1.09	-0.66
2059	-0.59	-0.09	1.07	1.91	-1.34	-1.18	1.58	1.05	-1.32	1.03	1.10	1.52
2060	1.09	1.06	1.51	-0.92	-1.37	-1.06	-0.47	0.59	-1.40	1.04	-0.77	-0.39
2061	-2.65	1.24	0.08	-1.00	1.10	-1.06	1.37	1.10	-1.39	-1.76	1.06	1.19
2062	-0.34	-0.33	1.28	-1.22	1.02	1.86	1.66	1.13	-1.23	-1.55	0.50	1.18
2063	0.00	-0.39	0.28	-1.16	-0.23	-1.07	1.07	1.53	1.11	-1.33	0.31	1.02
2064	-0.99	1.09	1.02	-1.09	-0.31	1.52	0.52	1.28	1.24	-1.30	0.19	1.02
2065	-0.09	-0.89	0.15	1.34	1.37	1.08	1.69	1.94	1.33	1.09	0.11	-0.97
2066	0.52	-0.68	1.04	1.07	1.05	1.48	-1.47	1.30	1.53	1.52	1.13	-0.86
2067	-0.94	1.41	-0.35	1.08	1.07	1.31	1.82	1.57	1.07	1.04	-0.36	-0.80
2068	-1.27	-0.33	-0.59	1.07	1.79	1.41	1.57	1.26	1.08	1.04	1.04	-0.66
2069	0.49	1.10	1.06	1.04	-0.82	0.08	1.57	1.21	1.94	-0.21	-0.76	-0.83
2070	1.04	-1.02	-0.57	0.25	-0.90	1.39	-1.58	1.51	-1.97	0.89	-1.71	-1.89
2071	1.63	-1.25	-1.68	0.15	0.96	0.31	1.07	1.20	0.98	0.88	-1.10	-1.02
2072	-0.18	-0.25	-1.52	-0.09	0.90	1.00	1.30	-0.22	-0.73	-0.92	-1.09	-1.17
2073	1.49	1.40	-1.46	-0.09	0.72	1.03	1.55	1.50	1.01	1.10	-1.44	-1.85
2074	0.53	0.00	-1.95	-0.32	-0.63	1.13	1.59	1.66	1.48	1.11	-1.54	-1.53
2075	-0.83	-1.57	-1.53	-0.34	-0.50	1.64	0.70	0.63	0.45	-0.92	-1.74	-1.50
2076	0.93	-2.24	-2.15	-1.26	-0.34	2.29	1.26	1.09	10.26	1.01	-1.91	-1.60
2077	1.82	-1.80	-1.96	-1.35	-0.21	2.33	1.46	1.06	1.14	1.01	-2.09	-1.69

Appendix Table 8. One month time scale RDI value of RCP 8.5 2020

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2018	-0.32	1.36	1.78	-0.29	0.75	-1.62	1.52	1.05	-1.75	-1.80	-0.68	-0.85
2019	0.41	1.34	1.01	-0.31	1.51	-1.48	1.40	1.38	-0.41	-1.65	-0.56	-0.71
2020	0.74	-0.19	-0.13	1.62	1.47	1.05	1.18	1.14	-0.23	-0.97	-0.44	-0.61
2021	-2.37	1.34	1.30	-0.63	0.40	0.20	-0.94	1.47	1.07	-0.86	-1.33	1.01
2022	1.09	1.31	-0.38	-1.06	1.23	1.25	-0.95	2.69	-1.25	1.00	-1.23	-1.10
2023	-1.08	-1.06	1.46	-0.93	1.10	0.37	-1.08	-1.01	-1.13	1.06	-1.10	-2.83
2024	-0.80	-1.13	1.01	1.01	0.95	0.54	-0.62	-1.05	1.22	1.45	-1.03	1.01
2025	-0.71	-1.14	1.09	-1.41	0.96	1.65	1.26	0.93	1.39	1.36	-0.33	1.33
2026	-0.40	-1.21	0.71	-1.42	1.01	1.01	1.02	1.75	1.42	-1.51	-0.18	1.02
2027	-0.14	-0.60	-1.01	-1.85	-1.99	1.07	1.04	1.78	-0.61	-1.37	1.08	1.01
2028	-0.01	1.77	1.07	1.51	-2.29	1.59	1.21	1.64	-0.45	-1.27	1.01	-0.94
2029	1.00	1.72	1.18	1.71	1.43	1.42	1.17	1.45	-1.69	-1.11	-1.60	-0.84
2030	-2.06	1.60	-1.27	0.48	1.22	1.15	1.04	1.40	-1.49	-0.21	1.51	-2.02
2031	1.82	1.08	1.09	1.29	1.18	1.22	1.60	1.38	-1.35	-0.09	-1.59	-1.76
2032	-1.62	-0.01	1.64	1.24	1.00	1.36	1.10	1.05	1.05	-0.02	1.69	-1.57
2033	-1.32	-0.15	1.56	1.11	1.02	1.47	1.09	1.05	1.15	1.14	1.03	-0.94
2034	1.89	-0.27	1.42	1.32	1.10	1.57	1.02	1.44	-0.98	1.26	-0.15	-0.86
2035	1.94	1.06	1.19	-0.10	-0.27	1.61	1.36	-1.38	-0.82	1.35	1.28	-1.00
2036	1.09	1.50	1.10	0.04	-0.35	-1.14	-0.61	-1.34	1.77	1.47	-2.16	-1.07
2037	-1.93	1.01	-0.63	1.22	1.48	-1.05	1.09	1.23	1.57	-0.56	1.47	-0.89

2038	1.01	1.07	-0.66	1.17	1.64	-0.86	1.58	-1.17	-0.68	-0.66	1.06	1.01
2039	1.79	-0.82	-0.81	1.18	1.07	1.77	0.44	1.57	-0.83	1.08	-0.78	-0.76
2040	1.09	-0.94	-0.89	1.12	-0.81	1.02	1.01	-1.96	1.09	-0.88	-0.86	-1.78
2041	1.01	1.06	1.56	1.16	-0.99	1.00	-0.82	0.82	1.01	1.01	-0.95	1.55
2042	1.70	1.08	0.51	-1.23	-1.08	-0.30	1.73	1.04	1.10	-1.06	1.12	-0.54
2043	-0.56	0.87	0.39	0.81	-1.24	-0.19	1.20	1.46	-1.22	-1.19	1.24	-1.43
2044	-0.64	0.71	0.21	0.70	-1.42	0.07	-0.34	1.30	1.29	1.25	-1.35	-0.20
2045	1.43	-1.26	-1.34	0.78	-1.52	-1.37	1.01	1.65	-0.33	-1.37	-1.51	-0.13
2046	-0.21	-1.38	-1.40	-1.77	-1.64	-1.32	-1.03	1.52	1.47	1.45	-1.38	-0.32
2047	1.16	-1.43	-1.50	-2.09	-1.78	-1.20	-0.68	1.89	-0.51	1.56	-0.11	-0.50

Appendix table 9. One month time scale RDI value of RCP 8.5 2050

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2048	-0.52	1.03	-2.67	-0.50	-0.23	1.16	1.03	2.80	-1.25	-1.47	1.13	-1.14
2049	-0.59	-0.71	-0.93	1.55	-0.28	-1.87	-0.75	1.01	-1.08	1.37	1.26	-0.46
2050	1.98	1.86	1.80	-0.73	-0.42	0.38	1.08	1.20	-1.48	0.46	1.40	1.15
2051	1.96	1.04	1.25	-0.87	-0.48	1.28	-0.90	1.38	1.09	-1.34	-1.24	1.11
2052	-0.12	1.42	1.21	1.31	-0.54	1.65	-0.80	1.57	1.10	-0.46	-1.16	-0.02
2053	1.04	-0.42	-0.13	1.55	1.07	0.43	-1.20	1.65	1.06	-0.36	-1.05	1.12
2054	1.21	1.05	-0.12	-0.40	1.66	1.36	-1.38	1.82	1.21	-0.19	-0.97	-0.48
2055	1.28	1.05	1.09	1.35	1.45	1.73	1.03	-0.91	1.39	-0.89	-1.34	1.07
2056	1.08	-0.97	1.09	0.20	-0.97	0.24	1.11	1.05	-0.85	1.08	1.57	-0.46
2057	1.09	1.01	-0.64	0.10	-1.06	1.47	1.19	1.54	-0.68	-0.67	1.70	1.00
2058	-0.56	-1.01	1.04	1.07	-1.06	-2.46	1.30	1.85	-0.63	-0.57	1.83	1.05
2059	-0.23	-1.48	1.34	1.19	-1.14	0.65	1.46	-0.34	1.46	-1.19	-0.47	1.04
2060	-0.24	0.11	1.09	1.13	-0.03	1.10	-1.37	-0.37	-0.31	-1.10	-0.38	1.06
2061	1.66	1.60	1.03	1.00	1.02	-0.53	-1.57	1.22	-0.20	-1.01	1.03	1.03
2062	1.64	-0.91	-0.63	-1.18	-0.12	-0.86	1.02	-0.17	-0.16	-0.13	1.02	-0.61
2063	1.34	1.22	-0.07	-1.22	-1.43	-1.24	1.12	1.14	1.06	1.23	1.06	-0.86
2064	-0.29	-0.39	1.04	-1.42	-0.22	-1.54	-0.29	-1.99	1.08	1.38	1.01	-0.80
2065	-0.60	1.22	1.08	-0.18	1.10	1.28	1.20	1.30	1.21	1.53	1.08	-1.09
2066	-0.65	1.04	-0.28	1.29	1.01	0.03	-0.35	1.30	1.07	-1.38	-0.24	-2.48
2067	-0.80	1.40	1.03	1.08	1.08	1.25	1.03	1.42	1.10	-1.43	1.15	-0.77
2068	-0.90	1.00	1.30	1.08	-0.67	1.10	1.40	-1.41	1.06	1.04	-0.06	-0.99
2069	1.01	-0.78	1.00	1.51	-0.65	-0.08	1.37	1.84	1.34	1.07	1.06	-1.12
2070	1.10	-0.79	-0.33	1.37	-0.80	-0.35	1.35	1.86	-1.48	1.04	1.08	-1.00
2071	1.01	-0.64	-0.34	-0.99	-0.91	1.39	1.25	1.92	-1.27	1.00	1.01	-1.54
2072	-1.07	1.06	1.17	1.10	-0.89	0.22	-0.51	1.04	-1.22	1.11	-1.50	-0.83
2073	-1.21	-0.83	1.10	1.08	1.05	0.37	1.06	1.07	-1.04	1.00	-1.47	-1.59
2074	-1.10	1.06	1.32	-0.08	0.30	0.31	1.28	2.29	-0.95	-0.12	-0.88	1.08
2075	-0.93	-0.59	1.03	-1.59	0.22	1.20	1.05	2.83	1.53	-0.21	-0.80	1.05
2076	-0.68	-1.57	1.09	-1.67	1.15	0.62	-1.47	-1.39	1.66	1.68	1.06	1.13
2077	-0.83	-1.72	-0.48	-1.84	-1.20	-2.65	-1.73	1.45	1.76	1.77	-0.58	-0.24

Appendix table 10. Dubti station RDI value of base period

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Annual
1988	182.5	159.6	138.7	143.1	145.0	197.8	199.3	225.4	216.6	203.9	188.6	194.9	**2195.3**
1989	192.8	154.6	126.7	132.2	139.2	154.0	147.5	205.9	221.2	221.5	235.4	223.3	**2154.6**
1990	207.2	154.1	125.9	128.5	141.8	170.8	188.9	217.5	222.1	205.3	215.4	222.5	**2200.0**
1991	206.0	144.2	121.6	125.5	142.2	170.1	189.6	217.9	221.6	205.0	214.7	222.3	**2180.9**
1992	184.9	147.2	147.0	118.7	89.7	136.2	182.9	216.2	225.2	233.0	213.1	203.3	**2097.4**
1993	206.8	165.0	136.3	118.2	107.1	168.0	160.3	193.3	230.0	219.4	234.8	224.1	**2163.5**
1994	198.6	161.4	127.3	128.1	127.4	161.3	175.1	219.3	230.4	217.5	215.1	213.7	**2175.3**
1995	195.9	153.4	148.2	120.5	119.4	161.7	173.2	223.5	227.8	206.6	188.5	207.8	**2126.4**
1996	200.7	147.6	135.7	142.2	132.8	165.0	183.4	204.1	227.1	225.5	233.7	225.0	**2222.7**
1997	191.0	150.9	131.3	105.5	132.0	171.1	169.9	215.4	217.4	224.4	227.4	227.4	**2163.8**
1998	198.0	160.6	138.2	112.7	121.5	154.2	186.8	219.9	219.1	226.8	233.4	238.9	**2210.3**
1999	202.3	170.4	150.9	112.8	108.8	143.6	177.5	218.6	218.7	225.7	233.9	239.2	**2202.3**
2000	200.0	144.2	130.0	142.4	132.5	162.4	183.7	223.1	236.4	223.8	209.3	221.1	**2208.8**
2001	199.5	150.8	143.3	113.2	121.7	153.3	177.3	227.1	231.2	238.1	232.5	216.3	**2204.3**
2002	212.2	170.9	132.9	123.8	126.5	167.4	182.0	227.5	242.0	241.9	235.2	230.0	**2292.4**
2003	209.7	164.3	126.6	127.6	138.0	174.7	182.2	222.5	235.2	246.4	219.2	225.9	**2272.2**
2004	209.5	163.2	144.7	120.9	121.6	163.9	167.8	227.5	96.1	207.2	224.8	233.4	**2080.6**
2005	210.6	158.6	142.4	123.1	124.6	166.4	172.7	221.8	101.4	209.3	249.8	234.1	**2114.9**
2006	206.4	149.5	133.7	126.3	139.5	172.1	172.1	218.9	234.3	232.5	213.6	221.9	**2220.7**
2007	207.5	160.8	135.3	122.7	126.3	171.3	197.8	231.8	232.1	209.3	225.8	230.6	**2251.2**
2008	219.6	166.2	146.1	122.4	102.4	146.9	196.0	229.7	239.3	243.4	245.0	239.4	**2296.4**
2009	218.9	169.2	148.3	133.6	127.1	169.0	177.6	231.6	238.7	234.1	240.8	239.8	**2328.6**
2010	209.6	153.7	120.5	129.9	127.9	184.1	190.3	211.6	223.5	201.9	203.9	210.1	**2166.9**
2011	207.8	161.9	135.1	104.1	118.2	126.0	161.9	194.4	208.8	225.5	216.9	223.2	**2083.9**
2012	204.2	160.2	155.4	131.5	125.4	152.2	171.8	215.5	223.5	222.3	220.5	220.3	**2203.0**
2013	212.0	165.6	141.4	133.4	126.4	165.9	171.9	214.4	166.7	215.2	208.9	220.7	**2142.6**
2014	188.6	162.7	130.8	125.3	119.0	159.6	192.3	219.6	230.3	207.3	224.1	197.8	**2157.3**
2015	171.0	134.9	132.4	137.4	133.3	178.8	196.7	233.2	203.4	177.9	213.2	199.8	**2111.9**
2016	187.7	140.3	154.1	131.9	144.6	189.9	208.4	243.4	198.2	208.1	204.9	194.5	**2205.9**
2017	165.2	145.5	136.4	155.3	163.3	208.9	222.7	211.8	177.7	202.3	212.1	181.4	**2182.6**
Average	**200.2**	**156.4**	**137.2**	**126.4**	**127.5**	**165.6**	**182.0**	**219.4**	**213.2**	**218.7**	**221.2**	**219.4**	2187.2

Appendix Table 11. Merssa station RDI value of base period

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Annual
1988	153.2	123.4	133.6	141.8	124.1	169.6	170.1	177.9	155.5	148.9	160.5	169.4	**1828.1**
1989	153.5	122.7	132.7	141.5	136.5	159.8	139.0	179.7	183.0	170.1	171.1	164.1	**1853.7**

1990	153.5	122.7	132.7	141.5	136.5	159.8	139.0	179.7	183.0	170.1	171.1	164.1	**1853.7**
1991	153.5	122.7	132.7	141.5	136.5	159.8	139.0	179.7	183.0	170.1	171.1	164.1	**1853.7**
1992	129.2	120.8	104.2	141.5	136.8	159.0	160.4	171.7	164.4	167.0	150.2	136.1	**1741.2**
1993	132.2	118.5	103.8	113.0	105.3	141.1	135.2	158.7	165.4	178.0	155.3	136.9	**1643.5**
1994	147.0	123.8	126.9	136.7	137.2	142.2	159.8	181.9	181.8	161.2	156.0	153.7	**1808.1**
1995	146.4	128.1	122.2	134.3	123.1	151.9	164.8	170.6	167.8	161.9	146.6	155.8	**1773.3**
1996	153.6	134.0	121.8	117.7	124.0	146.0	153.1	153.7	171.1	179.1	163.1	155.4	**1772.6**
1997	140.5	129.6	129.7	117.7	133.4	145.9	150.9	180.4	175.9	178.3	163.5	160.4	**1806.3**
1998	144.7	137.8	129.1	111.9	120.8	146.7	165.5	180.5	199.8	175.0	152.4	150.7	**1814.8**
1999	151.3	138.9	137.4	111.9	121.0	141.4	193.9	202.0	198.2	182.0	182.3	170.8	**1931.1**
2000	150.0	129.9	133.2	147.5	146.4	179.2	177.1	193.1	198.6	182.8	175.4	163.9	**1977.2**
2001	160.8	138.4	138.6	125.3	136.8	165.1	180.3	193.3	184.6	178.3	183.7	171.0	**1956.2**
2002	170.4	143.3	130.4	121.6	128.0	173.1	178.8	203.9	200.9	197.2	185.4	164.8	**1997.9**
2003	154.9	137.3	130.8	120.3	126.9	162.9	170.8	188.1	193.7	186.0	160.5	160.0	**1892.2**
2004	179.4	134.7	124.7	128.8	130.6	165.8	159.9	198.1	202.3	190.3	186.2	188.5	**1989.3**
2005	157.5	142.5	120.8	128.8	130.3	155.8	166.0	169.5	188.1	171.8	166.7	171.1	**1869.0**
2006	167.4	125.7	131.5	131.1	127.4	156.7	148.5	175.7	183.7	173.9	179.8	165.4	**1867.0**
2007	166.5	132.3	135.9	119.9	133.6	164.8	166.9	195.2	183.6	162.4	175.7	168.0	**1904.6**
2008	169.2	130.6	123.2	134.9	130.5	169.7	172.9	192.5	182.5	184.4	173.9	168.2	**1932.7**
2009	171.9	135.1	125.6	133.4	140.1	171.1	166.2	200.5	196.5	170.3	181.8	173.1	**1965.4**
2010	171.9	129.4	124.1	126.9	129.8	150.5	168.7	184.0	188.6	177.6	176.8	182.6	**1911.0**
2011	173.0	121.4	123.3	120.8	142.5	170.2	174.2	180.1	182.9	183.5	181.3	176.3	**1929.5**
2012	173.6	133.5	136.6	120.5	137.9	166.6	156.9	180.7	182.6	171.8	180.6	178.4	**1919.7**
2013	171.4	138.7	129.3	131.9	138.2	165.0	169.1	191.8	183.8	176.2	177.8	179.5	**1952.7**
2014	174.8	144.2	131.1	134.8	131.9	178.7	175.1	174.5	182.5	191.5	172.6	181.1	**1972.7**
2015	174.7	143.5	131.3	139.0	142.4	172.5	184.4	208.1	183.8	191.7	172.7	181.5	**2025.5**
2016	174.3	142.8	130.6	137.5	137.7	173.8	182.9	209.1	183.7	190.4	173.3	182.0	**2018.1**
2017	173.9	143.4	126.6	138.6	137.3	173.8	183.1	208.8	183.7	190.7	173.4	182.5	**2015.8**
Average	**159.8**	**132.3**	**127.8**	**129.8**	**132.1**	**161.3**	**165.1**	**185.4**	**183.8**	**177.1**	**170.7**	**167.3**	1892.6

Appendix table 12. Mille station RDI value of base period

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Annual
1988	183.1	147.8	134.4	138.1	152.3	188.5	197.6	229.4	217.4	195.3	182.6	199.2	**2165.8**
1989	189.2	157.0	131.3	152.0	141.0	173.7	171.2	215.2	221.0	214.9	216.2	193.8	**2176.5**
1990	190.5	158.1	132.9	151.0	156.2	190.9	206.7	229.0	223.8	203.1	182.0	190.2	**2214.4**
1991	190.5	158.1	130.7	151.0	156.2	190.9	206.7	229.0	223.8	203.1	182.0	190.2	**2212.2**
1992	172.2	144.4	140.8	138.7	125.8	175.6	191.2	216.8	211.9	203.1	183.8	186.3	**2090.6**

1993	187.6	160.1	130.1	141.2	133.8	190.4	184.5	201.9	222.1	213.3	212.5	196.5	**2174.1**
1994	176.9	142.7	139.1	137.6	146.6	181.3	191.3	219.0	248.6	228.9	188.0	191.2	**2191.3**
1995	171.7	123.3	130.8	144.9	139.1	178.7	189.3	216.6	221.8	200.9	182.7	185.2	**2085.0**
1996	181.8	146.6	135.2	161.9	146.7	181.4	192.3	204.1	215.5	220.8	206.5	191.8	**2184.6**
1997	175.5	153.5	147.0	135.0	139.4	179.3	189.6	236.8	207.2	222.5	215.7	208.7	**2210.2**
1998	190.8	165.4	156.4	119.4	132.2	181.1	187.1	209.1	220.7	227.0	216.8	208.3	**2214.1**
1999	191.9	165.9	156.1	132.9	137.2	182.3	196.7	219.7	214.9	218.5	212.1	208.6	**2236.9**
2000	188.6	148.1	136.9	145.3	142.7	181.5	205.5	220.3	221.0	217.8	194.5	195.5	**2197.6**
2001	197.1	152.5	139.0	130.5	140.1	173.5	200.5	223.3	215.7	229.0	213.3	195.0	**2209.6**
2002	199.2	165.2	153.2	139.3	153.1	187.8	195.7	230.6	226.2	236.8	221.1	200.1	**2308.4**
2003	201.8	161.3	150.5	150.6	159.3	193.8	199.0	217.5	222.2	231.3	191.4	211.6	**2290.6**
2004	179.8	159.8	153.8	154.4	139.8	181.7	180.8	220.1	65.2	206.9	220.0	210.7	**2072.9**
2005	203.3	167.4	155.6	145.6	156.1	183.3	184.7	219.7	81.0	199.4	224.8	207.1	**2127.8**
2006	194.0	153.9	149.9	143.9	159.8	180.9	194.5	226.1	225.3	228.3	198.6	199.8	**2255.1**
2007	193.8	167.6	153.0	130.3	137.9	195.6	197.7	220.5	232.6	209.8	202.0	202.6	**2243.4**
2008	202.1	164.2	152.9	144.5	136.7	185.5	188.5	211.7	233.7	242.9	224.2	212.1	**2299.0**
2009	203.5	173.4	164.0	154.4	154.1	204.5	201.7	223.2	223.7	227.8	228.8	213.3	**2372.4**
2010	186.2	151.3	142.6	150.0	146.4	184.5	199.8	223.8	226.6	200.6	186.6	183.0	**2181.3**
2011	189.5	159.0	145.3	127.4	136.5	161.4	191.5	195.4	200.2	212.2	198.0	200.8	**2117.4**
2012	192.5	158.6	157.3	149.5	144.5	183.2	191.0	207.4	211.5	215.6	207.0	196.2	**2214.4**
2013	198.7	164.4	155.7	141.9	156.9	186.6	191.5	214.9	154.7	207.7	186.9	199.8	**2159.7**
2014	178.5	157.2	134.6	142.1	140.4	182.3	205.2	213.5	217.3	204.3	212.7	172.7	**2160.7**
2015	160.2	128.1	137.3	152.7	158.3	199.3	212.6	229.0	184.7	174.3	201.1	175.0	**2112.7**
2016	173.7	133.5	152.4	148.6	164.8	213.4	218.4	230.6	187.0	211.2	188.3	163.7	**2185.4**

2017	134.4	137.3	147.2	166.6	185.1	231.7	233.3	205.6	153.2	188.9	188.8	139.7	**2111.9**
Average	**186.0**	**154.2**	**144.9**	**144.0**	**147.3**	**186.8**	**196.5**	**218.7**	**204.3**	**213.2**	**202.3**	**194.3**	**2192.5**

Appendix table 13.Sirinka station RDI value of base period

Year	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	Jun.	Jul.	Aug.	Sep.	Annual
1988	150.1	129.6	125.8	130.0	125.3	174.8	171.1	195.4	195.3	179.1	172.5	164.0	**1912.9**
1989	126.9	118.6	113.6	98.3	94.4	149.6	138.9	164.4	165.2	144.1	137.0	134.0	**1585.1**
1990	126.2	118.7	114.5	104.1	99.5	149.7	139.8	164.6	165.0	143.7	137.4	133.5	**1596.6**
1991	126.2	118.7	114.5	96.5	89.8	129.8	139.8	164.6	165.0	143.7	137.4	133.5	**1559.4**
1992	125.5	118.7	104.6	96.5	88.5	134.9	139.2	165.6	165.5	139.2	139.2	133.5	**1550.8**
1993	126.4	111.4	126.1	89.4	88.9	130.7	140.8	166.6	166.0	143.0	137.8	136.7	**1563.7**
1994	126.4	111.4	126.5	134.7	133.1	130.7	140.8	166.6	166.0	143.0	137.8	136.7	**1653.5**
1995	126.5	126.3	115.6	140.8	136.3	132.4	140.8	166.6	166.0	143.0	137.8	136.7	**1668.7**
1996	126.8	126.7	107.9	109.8	129.1	141.5	140.6	167.2	166.2	140.4	139.0	136.6	**1631.8**
1997	130.8	114.9	114.4	102.7	126.8	138.9	141.4	170.9	170.4	142.9	141.1	135.1	**1630.3**
1998	130.3	114.5	114.1	103.5	131.8	139.1	141.1	171.0	171.2	141.5	140.8	135.2	**1634.1**
1999	130.2	118.5	117.5	112.7	132.9	139.1	141.1	171.0	171.2	141.5	140.8	135.2	**1651.7**
2000	129.9	118.0	117.1	115.6	132.6	154.6	140.5	172.3	171.0	140.0	141.0	135.1	**1667.7**
2001	130.3	117.9	111.9	102.1	117.8	154.8	140.7	171.8	171.3	139.9	141.2	135.1	**1634.9**
2002	130.3	117.8	111.9	99.4	115.3	154.8	140.7	171.8	171.3	139.9	141.2	135.1	**1629.4**
2003	133.4	113.8	112.3	101.5	117.3	139.8	169.2	181.2	152.9	141.6	145.7	132.2	**1641.1**
2004	133.0	114.0	104.7	112.2	111.6	140.0	169.1	181.3	152.9	141.8	145.6	131.9	**1638.1**
2005	133.7	114.5	113.7	110.6	112.6	144.7	169.5	181.2	152.6	141.5	145.9	132.4	**1653.0**
2006	133.7	114.2	104.7	114.3	118.4	140.5	133.8	181.2	152.6	141.5	145.9	132.4	**1613.3**
2007	134.1	113.8	108.4	100.7	114.4	140.0	132.3	181.6	152.9	141.6	146.3	132.9	**1598.9**
2008	133.0	114.2	101.3	98.4	113.9	140.5	133.8	181.2	152.6	141.5	145.9	132.4	**1588.7**
2009	134.1	113.3	110.0	98.4	114.3	140.0	132.3	181.6	152.9	141.6	146.3	132.9	**1597.7**

2010	145.5	131.0	105.0	112.0	118.1	135.2	151.8	163.1	175.3	155.3	161.3	141.6	**1695.1**
2011	132.5	114.3	108.1	106.3	115.4	161.2	139.1	180.7	152.6	141.2	145.4	132.1	**1629.0**
2012	132.4	114.8	109.3	103.7	112.5	162.5	139.1	180.7	152.6	141.3	143.9	130.6	**1623.4**
2013	133.8	113.7	107.2	98.2	115.2	140.4	132.1	181.7	152.8	141.7	146.1	132.9	**1595.8**
2014	133.8	113.7	109.1	97.8	119.8	140.4	132.1	181.7	152.8	141.7	146.1	132.9	**1602.0**
2015	133.8	113.8	113.2	97.8	119.8	140.4	132.1	181.7	152.8	141.7	146.1	132.9	**1606.1**
2016	147.5	125.1	118.3	111.0	126.4	152.8	160.6	180.7	152.6	141.2	145.4	132.7	**1694.4**
2017	147.7	125.7	114.5	116.7	102.7	151.9	160.5	180.9	152.7	141.5	146.0	132.8	**1673.5**
Average	**132.8**	**117.7**	**112.5**	**107.2**	**115.8**	**144.2**	**144.2**	**175.0**	**162.0**	**143.4**	**144.1**	**135.1**	**1634.0**