Addis Ababa University

College of Social Sciences

Department of Geography and Environmental Studies

Validation of Kiremt Season Rainfall Forecast using GIS and Remote Sensing Techniques over the Abbay Basin of Ethiopia

Prepared By: Bayu Nebsu

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VALIDATION OF KIREMT SEASON RAINFALL FORECAST USING GIS AND REMOTE SENSING TECHNIQUES OVER THE ABBAY BASIN OF ETHIOPIA

BY

BAYU NEBSU

ADVISOR

PROFESSOR WELDAMLAKE BEWUKET

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APPROVAL SHEET

This is to certify that the thesis prepared by Bayu Nebsu entitled as Validation Kiremt Season Rainfall Forecast Using GIS and Remote Sensing Techniques over Abbay Basin of Ethiopia is submitted in partial Fulfillment of the Requirements for the Degree of Master of Art in Geography and Environmental Studies (Specialization in Geographic Information Systems, Remote Sensing and Digital Cartography) compiles with the regulation of the university and meets the accepted standards with respect to originality and quality.

Signed by the Examining Committee:

Candidate	Signature	Date
Bayu Nebsu		August, 2021
Chairman	Signature	Date
Advisor	Signature	Date
Professor Weldamlake Bewuket		
Internal Examiner	Signature	Date

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Lists of Acronyms

ARC	African Rainfall Climatology
CHG	Climate Hazards Group
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
ENSO	El Nino Southern Oscillation
GIS	Geographical Information System
ITCZ	Inter Tropical Convergence Zone
NMSA	National Meteorological Services Agency
NOAA	National Oceanic and Atmospheric Administration
RFE	African Rainfall Estimate
ROC	Relative Operating Characteristics
RPS	ranked probability score
RPSS	ranked probabilities skill score
SOI	Southern Oscillation Index
SST	Sea Surface Temperature
UBN	Upper Blue Nile
USGS	U.S. Geological Survey
WMO	World Meteorological Organization

Abstract

Drought and flood are the most frequently occur and cause harmful impact on the socio-economic and infrastructure in Ethiopia. Theses climate related risk mainly cause due to failure of seasonal rainfall and erratic nature in distribution. This suggested that prediction of climate variability in advance of onsets of each rainfall season is the most crucial inputs for any mitigation actions. The National Meteorology Agency (NMA) of Ethiopia has been providing seasonal rainfall forecasts three times per year since 1987. This issued seasonal climate forecast needs to validate for its quality and values of the forecast. Forecast verification is an essential component in a forecasting system since it provides qualitative and quantitative measures to seasonal forecast reliability. This thesis aims to evaluate the overall performance of the kiremt season rainfall forecast based on observed stations and CHIRPS datasets over the Abbay basin issued by NMA for the last eighteen years using Geographical Information Systems and Remote sensing techniques. This verification is done by comparing observed with forecast data based on NMA monthly rainfall and CHIRPS dataset and probabilistic kiremt seasonal rainfall forecast issued from 2000 to 2018 using 38 rain-recording stations over Abbay basin.

This study uses the different attributes of seasonal rainfall forecast quality verification techniques. The verification techniques are tendency diagram, relative operating characteristics (ROC), and Ranked Probabilities Skill Score (RPSS). Based on the verification result of the kirmet season rainfall forecast, the tendency diagram reveals that forecasters tend to issue forecast probabilities for the three often favoring the normal categories as the most likely for both stations and CHIRPS datasets. This suggested that there is no difference in the quality of the kiremt season rainfall forecast when used as input stations and CHIRPS datasets. The study further showed that negative RPSS values based on station and CHIRPS datasets which indicates that kiremt season rainfall forecast are worse than the climatology predictions. RPSS values based on CHIRP datasets performed much better than station-based RPSS values.

Keywords: Kiremt, Season, Rainfall, Forecast, CHIRPS, Verification, Stations

Chapter One

Introduction

1.1. Background of the Study

The climate across Africa varies from arid conditions in the east of Africa to more humid conditions in the west (Adhikari, Nejadhashemi and Woznicki, 2015). A semi-arid transect is found in the Sahel region in central and southern Sudan, as well as a north-south transect running through central Ethiopia, Kenya and Tanzania and pockets of arid and semi-arid conditions are found elsewhere (Daron, 2014). The Climate of this sub region is typically equatorial with high temperatures and highly humid throughout the year but highly seasonal variation. Ethiopia is among the largest countries of Africa and it is characterized by a wide variety of landscapes, with marked contrasts in relief and altitudes ranging from about 125 m below sea level of Assale Lake, in the Danakil depression, to about 4,620 m a.s.l. at Ras Dejen (Fazzini, Bisci and Billi, 2015). The relief of the country is characterized by massive highland complex of mountains and dissected plateaus divided by Great Rift Valley running generally south west to north east(Westphal, 1975). For these reasons and given its geographic position close to the equator and the Indian Ocean, the country is subjected to large spatial variations in temperature and precipitation(Mohamed et al 2014). The climate of Ethiopia is therefore mainly controlled by the seasonal migration of the Inter Tropical Convergence Zone (ITCZ) and associated atmospheric circulations as well as by the complex topography of the country.

The spatial variations caused by altitude create rainfall variations in Ethiopia leading to the existence of various microclimates. Altitude is an important factor in creating various climatic zones in Ethiopia. According to traditional agrocecological classification Ethiopia have five climate zones(EARI, 1998). These are Wurch, Dega, Weina-dega, Kola and Bereha. The Wurch or cool zone ranges between 3,300 and above in elevation, and it has mean annual temperature highs between less than 10 ^{o}C. The Dega (also known as the Cool Temperate zone) occupies the central sections of the western and eastern parts of the northwestern plateau.

The elevation of this region is mostly above 2400 m, and daily temperatures range from near freezing to 16 °C. The weina dega or the temperate zone ranges between 1500 m and 2400 m in elevation, and consists of parts of the central plateau. It has daily temperature highs between 16 and 30 °C. The kolla or hot zone generally comprises areas lower than 1500 m in elevation, the Denakil Depression, and the tropical valleys of the Blue Nile(Bower et al, 2000). Within each climatic zone, seasonal variations and atmospheric pressure systems contribute to the creation of three seasons, which are known as the Kiremt, Belg, and Bega.

Season is defined as, meteorologically, a period when an air mass characterized by homogeneous weather elements such as temperature, relative humidity, wind, rainfall etc., dominate a region or part of a country (NMSA, 1996). According to National Meteorological Agency of Ethiopia (NMA, 1996) season classification varies with spatial location, i.e. Central, northeastern and eastern Ethiopia and have three seasons: namely, main rainy season (Kiremt) from June to September, dry season (Bega) from October to January and small rainy season (Belg) from February to May.

Kiremt: - This is the main rainy season which contributes 50 to 90% of the annual rainfall over major rainfall areas of the country and responsible for 85 to 95% of the production of food crops of Ethiopia(Abdisa, 2015). The season covers the period from June to September. This seasonal rainfall, except the south and southeast other portions of the nation benefited, particularly for the southwest, west, north, central and east regions of Ethiopia. However, the onset, cessation and the spatial and temporal distribution of Kiremt rainfall varies from place to place.

Belg: - This is small rainy season that covers the period from mid-February to mid-May. However, the rainfall is highly characterized by inter annual and inter seasonal variation(Getaneh, 2015). Belg season rainfall makes a significant contribution to total annual rainfall in the northeast, east and central portions of Ethiopia, as seen clearly in the annual rainfall cycle. Inhabitants of these parts of the country are agricultural and hydrological beneficiaries despite that the largest share of rainfall occurs during Kiremt season (Korecha and

Barnston, 2007). During this season the southern and southeastern part of Ethiopia enjoy their main rainy season.

Bega: - This is generally the dry season that covers the period from October to January. However, there is occasionally untimely rain over various parts of the country. During this season, most part of the country predominantly falls under the influence of dry and cool north-easterly winds.

The timing, variability, and quantity of seasonal and annual rainfall are important factors in the relationship between climate and key developmental sectors such as agriculture, health, transport and water resources. The performance of a given rainy season, for optimal crop growth, does not only lie in the overall total amount, but requires an adequate distribution of the rains during the year. This is particularly so in the semi-arid and sub-humid zones where irrigation is underdeveloped and the rains fall within a limited period of time. The causes of the rains' failure range from a delayed onset of the rains, an early withdrawal, or short but intense rainfall events separated by long dry spells (Camberlin et al, 2009). If there is an unexpected break in rainfall early in the growing season, farmers may be able to recover and resume production despite the loss of some of their crops. However, if such a break occurs in the middle or latter part of the growing season, all of the crops sown may suffer irreparable damage, with dire economic consequences for farmers (Bower *et al.*, 2000).

Seasonal climate forecasts are being increasingly used to benefit decision-making in more climate-sensitive sector, where climatic variations, experiences frequent droughts resulting in food shortages. Seasonal climate forecast is one of the tools, which can help farmers and decision makers better prepare for seasonal rainfall variability, on the proper levels of input planning and use of appropriate mitigating measures for anticipated seasonal climate condition (Abdisa, 2015).

Since 1987 NMA of Ethiopia has issued its seasonal forecast using analogue-based statistical approach keying to the Southern Oscillation Index (SOI) during past years. The seasonal forecast is mainly about rainfall and its spatial and temporal distribution. The long-range forecast unit of the NMA prepares and issues monthly and seasonal forecasts in Ethiopia. At present, NMA issues seasonal rainfall prediction information for February-May (FMAM), June-September (JJAS) and October–January (ONDJ) seasons(Belay, 2017) and for all months the year. Seasonal climate prediction provides an indication of how variable the rainfall might be, compared to the 'normal' or the 'climatology' and is therefore considered as information that could help to adapt to climate variability (Goddard et al., 2001). The methods of forecasting which are applied in preparing seasonal forecasts in the NMA are based on the analogue, trend analysis, statistical assessments, and teleconnections of the different variables weather producing systems and climatology (Bekele, 2014).

Analogue method

This forecasting method is a statistical downscaling method based on the hypothesis that two relatively similar synoptic situations may produce similar local effects(Horton, Obled and Jaboyedoff, 2017). The Analog method consists of finding past situations that are similar to the target day of interest in terms of atmospheric circulation or other synoptic predictors. Therefore, a proper selection of the analogue year is very important. As seasonal climate predictors, NMA uses indices of sea surface temperatures (SSTs) over the tropical Pacific Ocean, the Southern Oscillation Index (SOI), and the ENSO (El Niño -La Nina) outlook obtained from NOAA/CPC. Historical and current Niño 3.4 SSTs (the Niño 3.4 region is located in the central equatorial tropical Pacific Ocean) are used to select years with ENSO evolution similar to the current year (Korecha and Sorteberg, 2013). ENSO information is used in this method to facilitate the selection of analogue years. After obtaining sufficient information about the status of the ENSO event of the current year, which had the same ENSO status would be identified from past records. Then, the rainfall distribution and synoptic features of the preseason months of the current year would be compared with rainfall distribution and synoptic features of the preseason months of the analogue years. Monthly SSTs are compared for several months in advance of the season to be predicted (Korecha and Sorteberg, 2013). For example, in order to predict rainfall of the June–September (JJAS) season, Niño 3.4 SSTs for January–May of the current year are compared with SSTs for the same months in targeted years and analogue (years with similar ENSO evolution) are identified. Once the analogue year has identified, onset and cessation of the rains or seasons projected based on the observed climatology data of the analogue year.

1.2. Statement of the problem

The Ethiopian climate has large interannual variability, which is reflected in frequent droughts and flood incidents(MICHAEL et al, 2015). It has been documented that food shortage and scarcity of water have led to local and nationwide famines, mainly due to complete or partial failures of short (Belg, February-May) and long (Kiremt, June-Sep) rainy seasons over various parts of Ethiopia (NMSA, 1996). The failure of seasonal rainfall is often caused by either misplacement or the weakening of large-scale seasonal rain-producing systems. Stephanie et al. (2016) documented that droughts and famines, such as the socio-economic catastrophe of 2011, call attention to the need for reliable seasonal forecasts for rainfall in Ethiopia to allow for agricultural planning and drought preparedness. For example, the devastating droughts during the 1970s and 1980s resulted in a humanitarian catastrophe.

In response, since the 1980s, NMA of Ethiopia has introduced various methods of weather forecasting. The seasonal forecast in particular NMA uses the analog method where the forecast is based on the hypothesis that two relatively similar synoptic situations may produce similar local effects(Horton et al, 2017). For use of an analog method and to improve the reliability of weather forecast the historical rainfall dataset are the primary sources of information in addition to information about weather producing systems. However, station measurements represent mainly the weather conditions close to the stations and because they are often reliant on human observers, are prone to human and other measurement errors. Therefore, high quality, long-term, and spatial representative rainfall dataset are vital to supporting the weather forecast model. It would be ideal to have a dense rain gauge network for monitoring rainfall records in Ethiopia. However, this is very expensive and practically impossible to have dense stations where there are remote and inhabited areas with station security issues. Satellite rainfall estimates by blending with sparsely distributed station's rainfall data could reduce the challenge related to lack of rainfall record. Most satellite rainfall estimation methods do blend satellite rainfall data with station measurements and these include the Climate Hazards Group Infrared Precipitation with Station (CHIRPS), the African Rainfall Estimate (RFE), and the African Rainfall Climatology (ARC), among others. However, many global centers can only access the limited number of station data from Africa countries, making these improvements in blended products more limited for the region. CHIRPS could be the exception, in that it was able to access many more stations relative to other similar products.

Therefore this study has incorporated CHIRPS monthly rainfall dataset in NMA seasonal rainfall forecast as one of the inputs for the analog method. The main rainy seasonal rainfall forecast has considered for the purpose of this study. The study used both NMA ground meteorological stations and CHIRPS rainfall dataset for the selected analog year for purpose of validating the seasonal forecast issued by NMA for the last five years in the study area. The study used GIS and remote sensing techniques to extract, preprocessing, and analysis rainfall datasets from ground stations and CHIRPS.

1.3. Objective of the study

1.3.1. General Objective

The general objective of this study is to validate the National Meteorological Agency of Ethiopia (NMA) kiremt seasonal rainfall forecast issued for the last eighteen years (2000 – 2018) over Abbay basin of Ethiopia using GIS and Remote Sensing techniques.

1.3.2. Specific Objective

The specific objectives of this study are the following;

- To validate the kiremt season rainfall forecast using observed selected stations kiremt season total rainfall datasets over Abbay basin of Ethiopia
- To validate the kiremt season rainfall forecast using observed CHIRPS kiremt season total rainfall datasets over the Abbay basin of Ethiopia
- Compare the result of seasonal forecast based on two datasets for its effectiveness

1.4. Research Questions

1. What was the quality of the kiremt season rainfall forecast that has been issued for the last eighteen years when compared with the observed rainfall datasets from selected stations over the Abbay basin of Ethiopia?
2. What was the quality of the kiremt season rainfall forecast that has been issued for the last eighteen years when compared with the observed CHIRPS datasets over the Abbay basin of Ethiopia?
3. What is the difference in the effectiveness level of the two seasonal forecasting approaches?

1.5. Significant of the study

Seasonal rainfall is a key element to ensure Ethiopian agriculture production and productivity development. This is partly because a majority of cereal and livestock production relies on seasonally expected rainfall, and partly because of essential water sources for recharging water bodies which in turn significantly serve for off-season agricultural production and livestock watering. Thus, this suggested that improper understanding of seasonal rainfall distribution; intensity, magnitude, and its prediction have an impact on nations' effort to ensure food security in particular and poverty eradication and enhance prosperity in general.

Seasonal rainfall forecast in Ethiopia is an important part of climate information services produced and disseminating for three seasons every year by the national meteorological agency of Ethiopia. These seasonal rainfall forecasts provide indispensable information for smallholder and pastoralists to plan when to perform land preparation, planting, and harvesting. The timing and quality of seasonal rainfall forecast information is a critical concern by the user of this information. Timing means that the seasonal rainfall forecast should be disseminated before actual season data approaches. It is a good practice that a month before since actual seasonal rainfall forecast information reaches farmers. Quality of information on the other hand means that the forecasted information has to compare with the observed information. This because if the wrong information disseminates it significantly affects the livelihood of smallholder and pastoralists. Once this happened dependability and accessibility of forecast information by smallholder and pastoralists will be diminished and useless. Thus, it's important to assess already disseminated seasonal rainfall forecast for users and to improve future forecast information. This helps to understand reasons for the poor quality of the information, and accordingly to propose potential solutions to improve the quality of forecast information.

This study exerted efforts to assess quality seasonal rainfall forecasted information which was produced and disseminated for the last twenty years by the national meteorology agency of Ethiopia. This study uses different quality assessment parameters and techniques which are suggested by world meteorological organization and frequently used by many meteorological offices around the globe to assess their forecast information quality. Therefore, this study significantly contributes to the improvement of seasonal rainfall forecast in Ethiopia by suggesting the current quality of forecasted information and potential solution to improve the quality of information.

1.6. Scope of the study

The study conducted validation of NMA's eighteen years kiremt season rainfall forecast using rainfall forecast verification techniques over the Abby basin of Ethiopia. The verification is done based on data sources which are comprised of monthly datasets of ground-based, and gridded; pictorial datasets for past forecasted kiremt seasonal rainfall forecast for eighteen years. The ground-based datasets were collected from selected 39 meteorological stations over the Abbay basin of Ethiopia. The 39 meteorological stations selected over 99 meteorological stations in the Abbay basin on available monthly observed rainfall data. The CHIRPS datasets have a relatively high resolution (0.05° ≈ 5 km) and longer years of data recording which a range from 1981 to the present(Geleta, 2021). The monthly datasets for eighteen years were extracted from CHIRPS data using the point location of 39 meteorological stations over the Abbay basin. Kiremt seasonal rainfall forecast datasets produced by NAM of Ethiopia for the last eighteen years were collected. Regarding verification techniques, this study used commonly known verification techniques that can help evaluate the quality of seasonal rainfall forecasts. Accordingly, the study focus on assessing bias, reliability, association, and Skill of kiremt season rainfall forecast against observed seasonal rainfall.

1.7. Limitation of the study

This study was conducted based on the collection of rainfall datasets from different sources. The quality and availability of time-series datasets from such different sources have their own benefit and shortcoming on the output of the study. The data sources with longer time-series data availability and good quality (no missing data) leading reliable result that could be assists to recommend a solution for better forecast production. Contrary, if the datasets have low quality and not much time-series data available results to come with poor recommendations. affect the study negatively. The monthly observed rainfall datasets which recorded in the selected meteorological station have its own limitation. The limitation includes the lack of more than 25 years of monthly rainfall data records and missing data among years and months of data records almost for all meteorological stations in the study area.

Thus, the study limited on consideration of a shorter period of rainfall for datasets usage for purpose evaluates the quality of kiremt season rainfall forecast. The lack of longer time series data has an additional impact on the selected number of meteorological stations for the study. Last but not the least; different verification techniques required various ranges of time series datasets to run the statistical methods to evaluate the quality of the forecast. Thus, the study is limited by considering the small number of verification techniques because lack of a longer period of time series recorded rainfall datasets.

1.8. Organization of the study

Including this introductory chapter, this thesis is organized into six chapters. Each chapter has its own heading and subheadings. Chapter one gives background information about the study. Chapter two presents a review of literature where theoretical and related works of literature are reviewed. Chapter three presents a description of the study area, data acquisition and software packages, and data processing and analysis methods. Chapter four presents the results of the study. Chapter five will deal with a discussion of the results, where the relevance of the findings is discussed in relation to the literature. Chapter six presents the conclusion and recommendations of the research output for consideration by various stakeholders and government agencies for their engagement in improved seasonal rainfall forecasting.

Chapter Two

Literature Review

2.1. Ethiopian Seasonal Climate Forecast

2.1.1. Weather producing systems during different seasons

Ethiopia's rainfall climatology is determined mainly by seasonal changes in large-scale circulation, part of which involves the seasonal north–south movement of the inter-tropical convergence zone (ITCZ) (Korecha & Barnston, 2007). This resembles what is generally thought to occur in the traditional Sahel region from Sudan to Senega (Rouault et al., 2019). Tropical rainfall varies from daily, inter-annual, inter-decadal, and longer time scales. Following breakthroughs in weather forecasting in the 1950s and 1960s, as environmental monitoring capabilities improved, physical modeling of the inter-annual variability of sea surface temperature (SST) over the eastern tropical Pacific Ocean has revealed predictability of the El Niño–Southern Oscillation. ENSO predictability then led to the potential predictability of seasonal climate over many tropical and extra-tropical regions (Mark A. Cane, 1986). According to various researches in the 1990s, assessment of Sahel drought focused heavily on the impact of regional and global SST anomalies on inter-decadal time scales. Some studies also have addressed the additional influence of land surface forcing (Zeng et al. 1999). Sharon (1995) suggested an extension of the Sahel drought toward Ethiopia on the basis of synoptic circulations. In addition, Giannini et al, (2008) attributed the Sahel's recent drying trend to warmer than average low-latitude waters around Africa, which, by forcing deep convection over the ocean, decrease monsoon-related continental convergence and rainfall from Senegal to Ethiopia. Studies by Haile (1988) have suggested that ENSO events have significant impacts on displacement and weakening of rain-producing systems of Ethiopian Climate through global atmospheric circulation triggered by sea surface temperature anomalies. For instance, the study by Kruzhkova (1981) showed weak, shallow, and a shift to southeastward in the major rain-producing mechanism of Ethiopia and its vicinity, the Inter-Tropical Convergence Zone (ITCZ), during drought years where the principal cause is asserted to be ENSO phenomena.

Moreover, due to frequent drought and increased inter-seasonal rainfall variability, NMSA has begun to use ENSO information to support seasonal rainfall forecasts and supplement its meteorological early warning system since 1987. According to NMSA (1996) reports, a cool event (La Nina) leads to decreased rainfall during February-May and heavy rainfall during the main rainy season (June-September). On the other hand, a positive SST anomaly that lasts at least a year is always associated with severe June-September droughts in Ethiopia and heavy rainfall during March, April, and May (Bekele, 2000). In addition, the study showed the occurrence of heavy rainfall during the belg season and reduced the main season rainfall amount during ENSO years in Ethiopia. Likewise, in a normal season, belg rainfall is variable and the main seasons' rainfall is stable (Woldegeorgis, 1996; Bekele, 2000). Hence, fluctuations of atmospheric circulation triggered by SST anomalies in the equatorial Pacific Ocean (ENSO) which have a significant impact on the position, magnitude, and intensity of rain-bearing atmospheric systems in Ethiopia have resulted in frequent meteorological, agricultural, and hydrological drought (Bekele, 2000; Cheung et al., 2008). In addition to the national influence, the local climate of an area is also highly influenced by the ENSO phenomenon, which accounts for the strong inter-annual variability in climate patterns (Vimont et al, 2014). Such studies that include Ethiopia could be confirmed using gauge rainfalls from a newly assembled dense station network—data that could be included in the Sahel rainfall indices (Korecha et al, 2007).

2.1.2. Kiremt seasonal rainfall forecast in Ethiopia

Ethiopia‘s climate is prone to both extended deficits and excessive rainfall. In extreme cases, significant crop production reduction or total crop failure and humanitarian disasters are common and lead to the calling for massive food aid. Typical examples include catastrophic droughts that impose economic and social crises (Korecha & Barnston, 2007; Belay, 2017). Ethiopia’s vulnerability to inter-annual variability in rainfall means that reliably of predicting regional rainfall several months ahead of a season would be enormously valuable under the motto ‘to be early warned is to be early armed’ The National Meteorological Agency (NMA) of Ethiopia uses a statistical method based on analog years that takes account of the multivariate El Nino-Southern Oscillation (ENSO) index. The outputs of this method are both probabilistic and categorical forecasts. Seasonal forecasts are an estimation of probabilities of key variables in future seasons. These variables could be a dynamical model's own rainfall and temperature forecasts, or large-scale patterns that can be either dynamically or statistically downscaled to temperature and rainfall over a specific area.

2.3. Verification of seasonal rainfall forecast

2.3.1. Essences of seasonal rainfall forecast Verification

In order to determine whether or not the forecast is valuable, there is a need to monitor the quality of the seasonal forecasts and their use or value (Ogutu, 2017). As Stanski (1989) stated, it's valuable that review six attributes of a weather forecast that make up the total forecast quality which are reliability, accuracy, skill, resolution, sharpness, and uncertainty. He further stated that it is important to make note that no single verification measure provides complete information about the quality of a seasonal forecast. Value on the other hand is the degree to which the forecasted seasonal rainfall assists decision-maker to understand certain incremental economic and social benefits (Jolliffe et al., 2003). Unlike quality, the value of seasonal forecasts depends on user necessities to make a decision (Ogutu, 2017). It shows that there is a difference between seasonal forecast quality and seasonal forecast value. A seasonal forecast has a high quality if it predicts the observed conditions well according to some objective or subjective criteria and it has value if it helps users to make better decisions. Thus, it's required by a user to give due attention to that combination of quality and value statistics are both equally important so that choose best seasonal forecast providers and to limits for performance-related contracts.

The value of seasonal forecasts to a particular activity is measured by the expected increase in economic benefits arising from the use of these seasonal forecasts in the decision-making process (Klopper, 1999). A seasonal forecast structure has economic value if user's decisions are influenced by various seasonal forecasts. If the quality of the seasonal forecast is such that the user makes the same decision with or without the seasonal forecast, then the seasonal forecast is of no value. In general, seasonal forecasts of a variety of weather variables over a wide range of time scales possess positive economic value for a spectrum of decision-makers (Klopper, 1999).

According to the classification proposed by Brier and Allen (1951), at least three main purposes to perform forecast verification can be identified: administrative, economic, and scientific (or diagnostic, following the definition by Murphy et al., 1989 and Murphy and Winkler, 1992). The first reason is related to the monitoring of the performance of the operational NWP system that produces the forecast. The aim is to evaluate the improvement, through time, of the operational forecasting chain due, for instance, to the implementation of updated numerical schemes, or the porting of the forecasting system to another platform, etc. Thus, the aim is to judge and financially justify, the changes and the improvement of the forecasting system. The second reason focuses instead on the value of the forecast. It concerns the support that a correct forecast can give to a decision-making activity (e.g., civil defense activities, flooding management, agriculture, etc.) from an economic point of view. Therefore, it motivates a user-oriented approach, based on the consideration that a forecast could be "good" for a user and "bad" for another, depending on their different needs. The last purpose of forecast verification focuses on observations and forecasts and their relationships, in order to underline the ability of a forecast system to correctly forecast meteorological events. Forecast verification provides this way, skillful feedback to the operational weather forecasters, giving insight into how the atmospheric physical processes are modeled. Generally, such an approach requires the application of more sophisticated measures compared with the ones usually employed for administrative and economic verification tasks.

Kiremt rains during June–September (JJAS) account for 50%–80% of annual rainfall totals over the regions having high agricultural productivity and major water reservoirs. Thus, the most severe droughts are usually related to a failure of the JJAS rainfall to meet Ethiopia's agricultural and water resources needs. World Meteorological Organization has recommended using the area under the relative operating characteristics (ROC) curve as a scoring rule for probabilistic forecasts. However, because ROC curves are for dichotomous (yes/no) event outcomes, they do not generalize naturally into a metric for multi-category or continuous climate variables such as temperature and precipitation.

2.3.2. Attribute of seasonal forecast need to be verified

Scientists will be more concerned with understanding and improving the seasonal forecast system (Jolliffe et al., 2003). Many meteorological scientists are busy implementing new forecasting models and verification can deduct whether a forecast has quality or not. There is a need for using different skill scores in verifying the seasonal forecast and the result can show whether these models have problems or not. Sometimes the models can lack skill in predicting the season and this can lead to a lack of information. In the following paragraph will be presented key probabilistic forecasts attributes;

Resolution

When measuring the quality of a series of forecasts, the most important attribute is resolution (Does the outcome differs given different forecasts?). It's also one of the most basic attributes of a good set of the probabilistic forecast is that the outcomes must be different if the forecast is different. Resolution is the ability of the forecast to sort or resolve the set of sample events into subsets with different frequency distributions (Stanski, 1989). Resolution is related to the standard deviation or variance of the observations stratified by the forecast. Resolution is tied to the overall experience, and understanding of the forecaster, i.e. resolution measures the state of the art (Murphy, 1997). Resolution can be determined by measuring how strongly the outcome is conditioned upon the forecast. If the outcome is independent of the forecast, the forecast has no resolution and is useless – it can provide no indication of what is more or less likely to happen. It is quite possible for forecasts to have a good resolution in the wrong sense: if the above-normal rainfall occurs less frequently as the forecast probability has increased the outcome may be still strongly conditioned on the forecast, but the forecast is pointing to changes in probability in the wrong direction. In this case, the forecasts have good resolution, but would otherwise be considered "bad". Again, a probability forecast is said to have a resolution if the observed frequency of the event when 20% is forecast is noticeably different from the observed frequency when 70% is forecast. Forecasts with no resolution are neither good nor bad, but are useless. Metrics of resolution distinguish between potentially useful and useless forecasts, but not all these metrics distinguish between good and bad forecasts (Mason, 2015).

Discrimination

A similar perspective to resolution is to ask “Do the forecasts differ given different outcomes?” rather than “Do the outcomes differ given different forecasts?” Discrimination, along with resolution, can be considered one of the most basic attributes of a good set of probabilistic forecasts: If, on average, a forecaster issues the same forecast when rainfall is above-normal compared to when rainfall is below-normal the forecasts cannot “discriminate” between these different outcomes. Just as for resolution, it is not necessarily the case that forecasts with good discrimination are good forecasts: a forecaster may issue lower probabilities of above-normal rainfall when above-normal rainfall occurs compared to when below-normal rainfall occurs. Again measures of discrimination distinguish between potentially useful and useless forecasts, but not all these metrics distinguish between good and bad forecasts (Mason, 2015). It is generally easier to measure discrimination than it is to measure resolution because discrimination can be measured more accurately with smaller samples than can resolution. The generalized discrimination score is therefore recommended as an initial score for assessing forecast quality. This score measures the ability of the forecasts to discriminate between the wetter, and warmer, of two observations. Since forecast quality can be conditional upon the outcome, it is also recommended that the score be calculated for the individual categories.

Reliability

The purpose of issuing probabilistic forecasts is to provide an indication of the uncertainty in the forecast. The forecast probabilities are supposed to provide an indication of how confident the forecaster is that the outcome will be within each category, and so they could be interpreted as the probability that a deterministic forecast of each category will be “correct” (Korecha et al, 2007). Reliability is simply the average agreement between the stated forecast value (label) of an element and the observed value (label) (Stanski, 1989). For example, given probabilities of 40% for below-normal, 35% for normal, and 25% for above-normal, if someone were to issue a deterministic forecast of below-normal, the probabilistic forecaster thinks there is a 40% chance that the deterministic forecast will be correct. Similarly, if someone were to forecast above-normal, there is thought to be a 25% probability (s) he will be correct. Forecasts are reliable, or well-calibrated if the observation falls within the category as frequently as the forecast implies (Murphy 1993). More often than not seasonal forecasts are unreliable. The commonest situation is that the forecasts are over-confident – increases and decreases in probability are too large. Overconfidence occurs when the forecaster thinks that the probability of a specific category is increased (or decreased), but over-estimates that increase (or decrease), and thus issues a probability that is too high (or too low)(Mason, 2015).

2.3.3. Three main principles of verification

Allan Murphy, (1997), who built his scientific career on the science of verification, has said: "Verification activity has value only if the information generated leads to a decision about the forecast or system being verified." This immediately suggests that there must be a user for the verification output, someone who wants to know something specific about the quality of a forecast product, and who is in a position to make a decision based on verification results. In general, as stated by Force, 2004, different users of verification results will have quite different needs, which means that the target user or users must be known before the verification system is designed, and also that the verification system design may need to be varied or broadened to ensure that the needs of all the users can be met.

To summarize briefly, the first principle of verification is: Verification activity has value only if the information generated leads to a decision about the forecast or system being verified. Thus, the user and the purpose of the verification must be known in advance. Preferably, users and purposes should be defined in great detail, as specifically as possible.

The second principle of verification is that no single verification measure provides complete information about the quality of a forecast product. Scores that are commonly used in verification are limited in the sense that they measure only a specific aspect or attribute of the forecast quality. The use of a single score by itself can lead to misleading information; the forecast can be improved according to the score, but at the same time the performance degraded in other ways not measured by the score(Stanski, 1989). Thus it is advisable to use two or more complementary scores to obtain a more complete picture of the forecast accuracy.

The third principle of verification is that the forecast must be stated in such a way that it is verifiable, which implies a completely clear statement about the exact valid time or valid period of the forecast, and the location or area for which the forecast is valid, along with the nature of the predicted event.

2.3.4. Methods of seasonal forecast verification

Forecast verification is the process of assessing the quality of a forecast. The forecast is compared, or verified, against a corresponding observation of what actually occurred, or some good estimate of the true outcome. (Force, 2004). A wide variety of seasonal forecast verification structures exist, but all involve measures of the relationship between a seasonal forecast or a set of seasonal forecasts and the corresponding observation(s) of the predictand (Ogutu, 2017). Any seasonal forecast verification method thus necessarily involves comparisons between matched pairs of seasonal forecasts and the observations to which they pertain.

Chapter Three

Materials and Methods

3.1. Study area description

Abbay basin is located in the Ethiopian highlands with a drainage area of about 176, 000 km^2 out of 1,100,000Km^2 (Conway *et al.*, 2000). It shares a boundary with the Tekeze basin to the north, the Awash basin to the east and southeast, the Omo-Gibe basin to the south, and the Baro-Akobo basin to the southwest. It extends from 7^0 45’ N to 12^0 45’ N, and 34^0 05’ E to 39^0 45’ E (Fetene et al, 2013). The altitude of the basin ranges from 475ma.s.l. at the Sudanese border to 4257ma.s.l. at the summit of Mt Guna. More than 83% of the basin is located at an elevation above 1000ma.s.l (Teferi et al, 2015). The topography of UBN is very complex, with elevation ranging from 500 m in the lowlands at the Sudan border to 4160 m in the upper parts of the basin. Due to the topographic variations, the climate of the basin varies from cold to hot, with large variations in a limited elevation range. The mean annual precipitation and evaporation over the basin are estimated to be in the ranges of 1200 to1600 mm. The distribution of annual precipitation increases from northeast to southwest (Birhan et al, 2019). It is the largest river basin in Ethiopia in terms of volume of discharge and provides a vital source of fresh water to the downstream users, Sudan and Egypt (Habte et al, 2013). The river extends from its origin at Lake Tana to the Sudanese border at Diem with a contribution of 60 percent of the Nile flow measured at Aswan (Link, 2019). The country’s largest freshwater lake, Lake Tana, the source of the Blue Nile (Abbay) river is located to the north of the basin. The river has an average annual runoff of about 49 billionm3. The major tributaries of the Blue Nile River in Ethiopia are Gilgel Abay, Megech, Ribb, Gomera, Beshilo, Welaka, Jemma, Muger, Guder, Fincha, Didessa, Anger, Dabus, and Belles. It is one of the most important major basins of Ethiopia because it contributes to 45% of the countries surface water resources, 20% of the population, 17% of the landmass, 40% of the nation’s agricultural product, and a large portion of the hydropower and irrigation potential of the country(Mekonnen et al, 2018). The Abbay basin accounts for a major share of the country’s irrigation and hydropower potential. The basin is subdivided into 16 sub-basins based on the major rivers in the basin, the Abbay River, and its tributaries(NMA, 2014).

The livelihood of the people in the basin is heavily dependent on rain-fed agriculture and small-scale irrigation scheme. Over 95% of the land cover in the basin consists of rain-fed cropland, grassland, wooded grassland, woodland, shrubs, and bushes (Jung et al., 2019). Cropland is the major land use and the land cover type, occupying more than 44% of the total area of the basin. A variety of annual crops are grown under rainfed conditions, including wheat, barley, sorghum, teff, maize, finger millet, oilseeds, chickpeas, and beans. Eucalyptus plantation mainly for wood and fuelwood is common in areas near villages (Teferi et al., 2015).

3.1.1. Topography

The topography of the Abbay basin signifies two distinct features; the highlands, rugged mountainous areas in the center and eastern part of the basin, and the lowlands in the western part of the basin. The basin has two main landscapes, the highlands (i.e. altitude greater than 1500 m a.s.l.) and the lowlands (i.e altitude less than 1500 m a.s.l.). Towards the border with Sudan and extending westwards to the Main Nile, the topography is almost flat or slightly undulating, with just the occasional granite rising above the clay plain(Demessie, 2015).

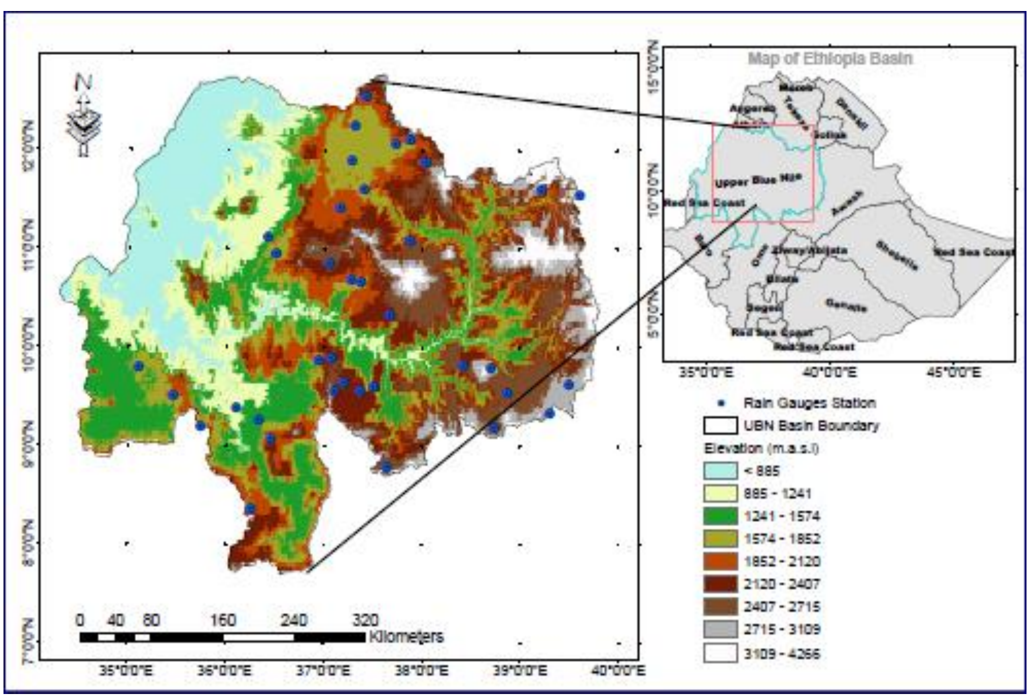


Figure 1: Topography of Abbay Basin

3.1.2. Climate

The basin is characterized as a humid climate and strong intertropical convergence zone (ITCZ) which is a rain-producing feature and there is a wide range of seasonal rainfall distribution in the basin (Habte, 2013). According to Köppen's system, the basin is characterized by tropical, warm temperate and cool highland climate zones (Demessie, 2015). The basin has long-term mean annual rainfall, minimum temperature, and maximum temperature of 1452mm, 11.4, and 24.7 0C respectively (Yilma and Awulachew, 2009).The eastern part of the basin has a bimodal rainfall regime with the short rainy season (belg) lasting from February to May and the long rainy season (Kermit) lasting from June to September. The western part of the basin has a unimodal rainfall regime with the kermet lasting from June to September. The mean seasonal rainfall based on the above data showed that about 238, 1065, and 148mm occurred in Belg (October– January), Kiremt (June–September), and Bega (February– May) respectively, in which about 74% of rainfall is recorded between June and September (Kiremit season) and 85-95 percent of annual crops are produced during this season (Jung et al., 2019).

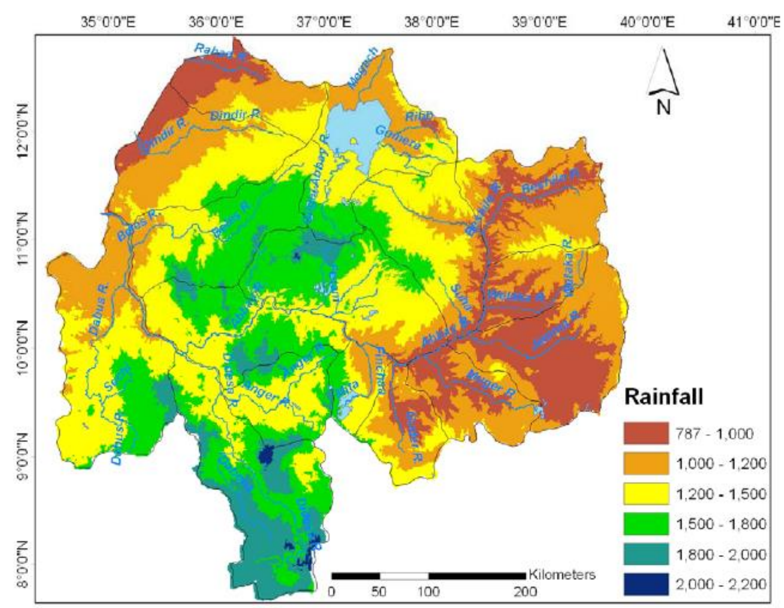


Figure 2: Rainfall of Abbay Basin (Sources: Gebrekristos, 2015**)**

3.1.3. Temperature

The mean temperature of the basin is 18.5^{0}C, with mean minimum and maximum daily temperatures of 11.4^{0}C and 25.5^{0}C, respectively.

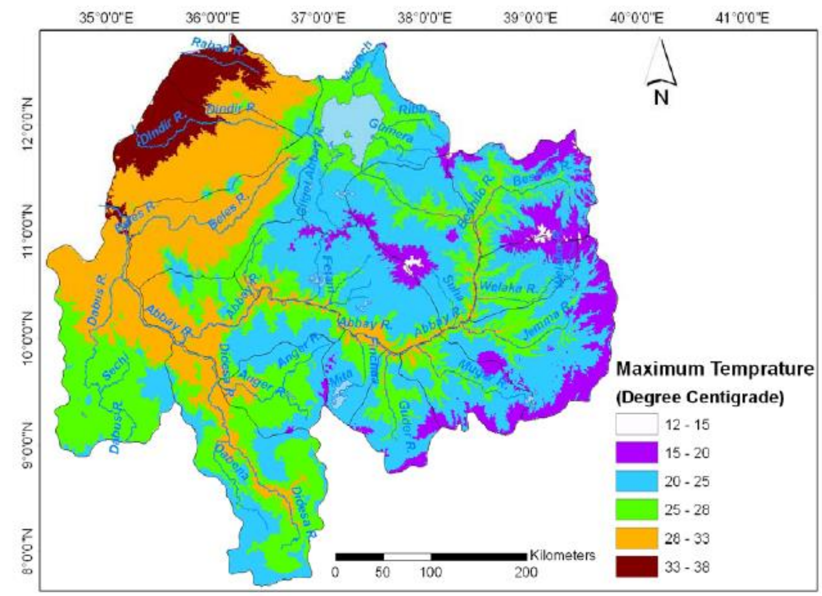


Figure 3: Maximum Temperature of Abbay Basin (Sources: Gebrekristos, 2015)

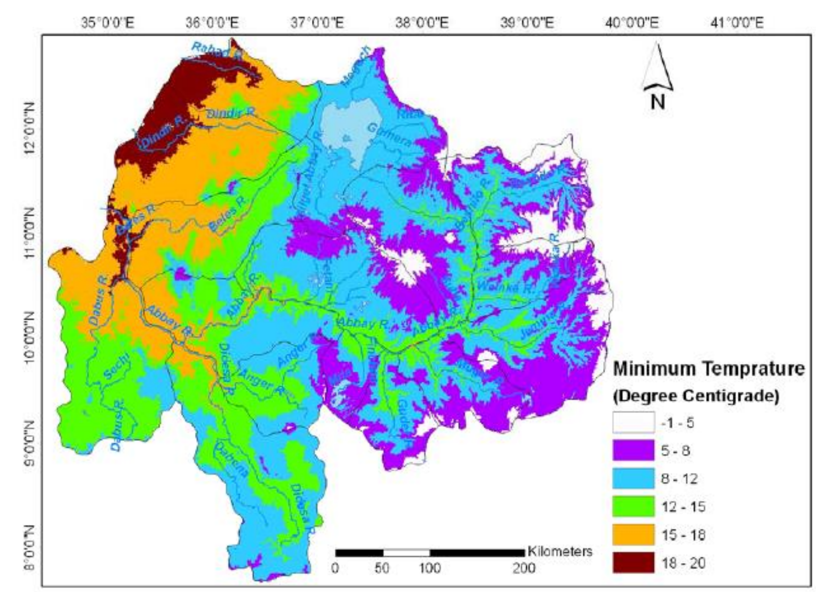


Figure 4: Minimum Temperature of Abbay Basin (Sources: Gebrekristos, 2015)

3.1.4. Meteorological stations in the study area

Abbay basin has around 94 Meteorological stations with 89 stations that are now functional. The station data were available for many years since 1978. The minimum data available in these stations is for 20 years. The details of the station information will present in the study.

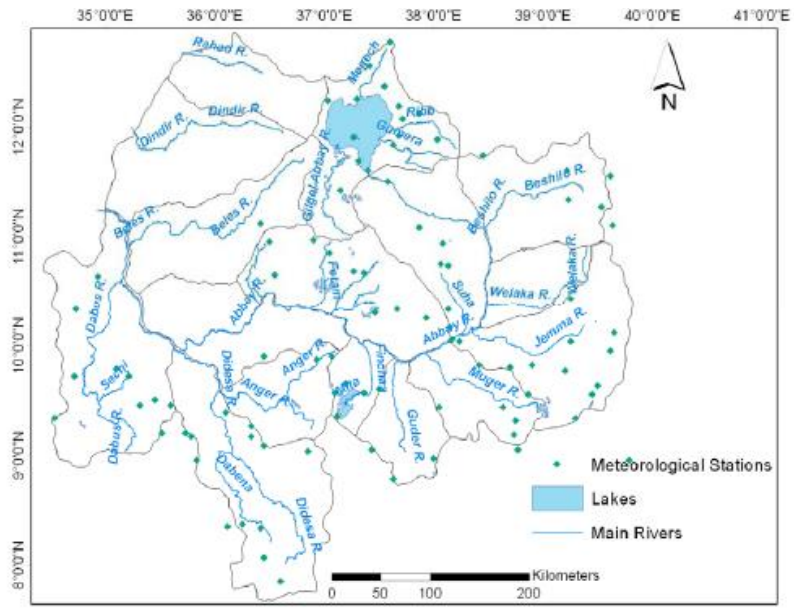


Figure 5: Meteorological Stations Distribution in Abbay Basin

3.2. Datasets and sources

In this study rainfall data from remote sensing-based combined with stations rainfall data sets (i.e CHIRPS) and 32 ground-based weather stations were used. The datasets covered the temporal resolution of the main rainfall seasons from 2013 to 2018 for both datasets.

3.2.1. Ground-based station datasets

Rain-gauge based observed month rainfall data from 32 first- and second-class stations from 2000 to 2018 has collected from the NMA. First-class stations (synoptic stations) are those stations where all meteorological parameters are recorded every hour, while second-class stations are those where observations are taken every 3 h. The monthly and daily rainfall data was used for identified analog years. The monthly rainfall was used to calculate the tercile probability. The daily rainfall was used to define the onset and cessation dates and for the possibility of extreme events.

3.2.2. Gridded rainfall data

The high-resolution satellite rainfall product selected for this study was CHIRPS. CHIRPS is a quasi-global (50^0 S–50^0N) gridded product available from 1981 (over 30 years data records) to near present at 0.05^0 spatial resolution (≈ 5 km) and daily, pentad (five days), decadal, and monthly temporal resolution. The CHIRPS dataset is developed by the U.S. Geological Survey (USGS) and the Climate Hazards Group (CHG) at the University of California(Funk *et al.*, 2015).

3.2.3. Forecasted dataset for year 2000 – 2018

The Ethiopian national meteorology agency issued three seasonal rainfall forecasts each year. The forecast issues for each season approximately before a month started the season in consideration with three climatological-based probability categories (above normal, normal, and below normal). The forecast is disseminated only as of the picture with forecast tercile probabilities shown as above normal, normal, and below normal). Therefore, these pictures should be converting into data before they can use for verification purposes. To extract the forecast value for each station in the study area from the pictured forecasted kiremt season rainfall, it is recommended to divide the Ethiopia map squared grid based on the forecasted gridded interval. Accordingly, divide Ethiopia's boundary 4 to 14^0 latitudes and from 34 to 48 ^{0} longitudes into 20 × 20 grids for stations in the study area. The gridded were then filed with values from the picture. As shown in the figure below the forecast picture is presented in form of a gridded map as the same as the one from the right side which draws for extraction of values from forecasted pictures. For about twenty years 2000 to 2018 kiremt season rainfall forecast issued by NMA were extracted for this thesis study. Thus, twenty years tercile probabilities for thirty-five stations which about 2100 values extracted. In figure 6, the station sample value extracted is presented.

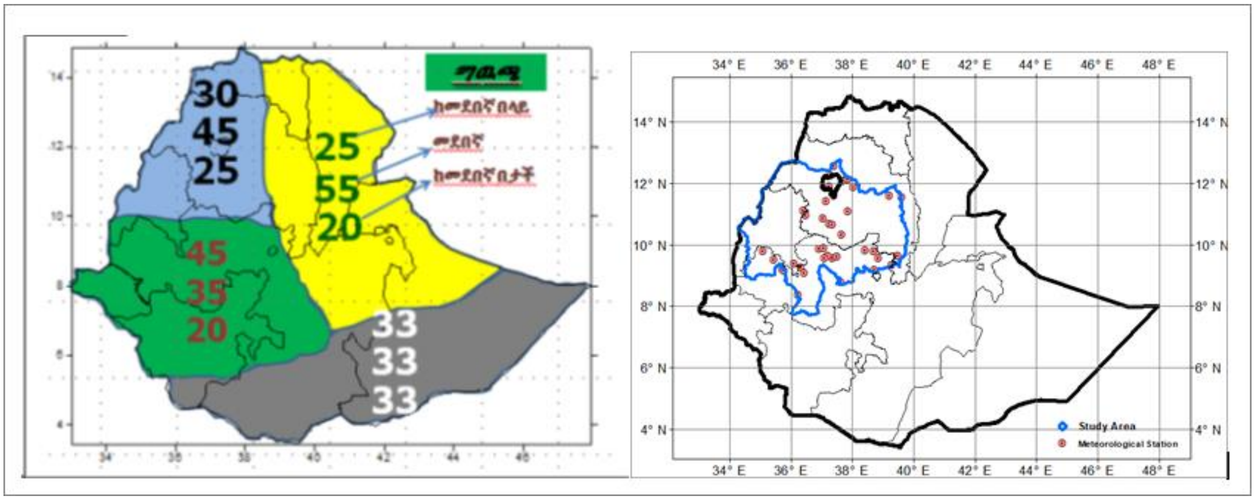


Figure 6: Extraction of kiremt season rainfall forecast using stations location

3.3. Methods of Data Analysis and verification

3.3.1. Observed Monthly Rainfall Datasets from Selected Meteorological Stations and Data Analysis

Ethiopia's NMA is used ground-based observed rainfall datasets for the purpose of making seasonal rainfall forecast from sample nationally available stations. The sample stations are selected based on the criteria's includes quality of data, the number of years of data recording, and the representative of different agro-ecological contexts. The quality of data means that the rainfall datasets recorded for the give time period have negligible or no missing data and have manageable errors which could be occurred during the recording and data sharing process. The number of year's data recorded by the meteorological station is an essential parameter for any weather and climate analysis. This because analysis of weather and climate based on stations datasets required a minimum of thirty-year data recording of the station with acceptable quality. Most often this time series recorded data is not common to find from stations available in Ethiopia especially remote areas where data collation capacity low and frequent data recording instrument checking minimum. The agro-ecological orientation of available stations is also another variable to consider in the selection of stations for study. In Ethiopia majority of the station, available in the most highland area and sparsely located in low land area. For the purpose of this study around thirty-two meteorological stations were selected which are located or installed in the Abbay basin of Ethiopia. The selected stations have minimum and maximum years of data recording twenty-seven and thirty-eight of a time period, respectively (Appendix 5). In order to have full-time series datasets for selected meteorological stations assigned common time series periods to avoid data gaps for those selected periods and meteorological stations. Accordingly, about eighteen year's periods datasets which are range from 2000 to 2018, and 32 meteorological stations were selected for the purpose of the study

The monthly observed rainfall datasets for kiremt seasons were collected from NMA and data entered and processed by Microsoft Excel. The data quality or assessment of any missing data was conducted carefully for completeness, spatial and temporal consistency in all stations. The next step was data preparation; at this stage, all the data were organized and arranged in the desired order to make it ready for analysis. For every station, the seasonal rainfall totals were calculated in excel sheets. There are around eighteen years monthly datasets used for the study area. This data were used as input for calculates the tercile probabilities of the observed seasonal rainfall total. The spatial and temporal distribution of the rainfall total of the season for each station was mapped using Arcmap 10.5.

3.3.2. Gridded dataset analysis

The evaluation of the kiremt season rainfall forecast was conducted based on data sources from ground-based and gridded datasets. The intended objectives here to evaluate the quality of NMA's kiremt seasonal rainfall forecast produced for the last eighteen years based on observed datasets sourced from the ground base and gridded. The result from the use of different rainfall dataset sources where statistical analysis was performed based on is the interest of this study. A CHIRP is a gridded dataset used in this study in order to estimate rainfall forecast verification statistics and then compare them with statistical outputs from ground-based observed rainfall datasets. Climate Hazards Group InfraRed Precipitation with Station data (CHIRPS) is a 30+ year quasi-global (50°S-50°N) and high resolution (0.05°) rainfall dataset. CHIRPS datasets are developed by the United States Geological Survey (USGS) and the Climate Hazards Group at the University of California, Santa Barbara. CHIRPS incorporates 0.05◦ resolution satellite imagery with in-situ station data to create gridded rainfall time series for trend analysis and seasonal drought monitoring (Geleta, 2021). CHIRPS datasets are available free to use and with the time scale of daily, pentad, and monthly precipitation dataset since 1981 to present. CHIRPS datasets are widely used because it is blended with observation rainfall and it is relatively new and with high spatiotemporal (Latest 2 chips). It is blended with observation rainfall; it is relatively new and with high spatiotemporal resolution. For this study, monthly time scale rainfall CHIRPS (CHIRPS v.2) datasets were downloaded from //chg.geog.ucsb.edu/data/chirps for the time period of 2000 to 2018.

Once monthly rainfall datasets downloaded, the extraction of monthly point datasets based on the location of each selected meteorological station in the study area was done. The process of extraction of point datasets was conducted using ArcMap 10.5 software and further analysis of verification statists performed using Microsoft Excel. Check Appendix 1 for datasets extracted for each selected meteorological station.

3.4. Verification Techniques

There are different forecast verification techniques available and their details described in the pieces of literature. The types of verification techniques choose mainly rely on datasets used and the sample size of the forecast for verification purposes (Taylor et al., 2013). Based on the datasets format available for this thesis the following verification techniques used so that examine the bias, reliability, association, accuracy, and skill of kiremt season rainfall forecast against observed seasonal rainfall.

3.4.1. Bias of seasonal rainfall forecast verification techniques

Bias can be defined as a systematic difference between forecasts and outcomes; biases can be conditional or unconditional(WMO, 2018). Unconditional bias is s systematic difference between the forecasts and the outcomes that are independent of the forecast. Over- and under-forecasting are examples of unconditional bias (WMO, 2018). Over forecasting is a tendency to overestimate the probability of an event regardless of whether the probabilities suggest that the event is more or less likely to occur than climatologically. If an event is over forecast it occurs less frequently than implied by the forecasts. Conditional bias whereas is a systematic difference between the forecasts and the outcomes that are dependent upon the forecast. Over- and under-confidence is examples of conditional bias. Overconfidence is a tendency to overestimate differences from climatology of the probability of an event, resulting in probabilities that are too high that is increased above their climatological value and too low when the probabilities are decreased (Kumar et al., 2013).

A tendency diagram can be used to assess the unconditional bias of the kiremt seasonal rainfall forecast. The biases can be graphed in a “tendency diagram” by showing the average forecast probability and the observed relative frequency of each category over the verification period. The diagram shows for each tercile category the average forecast probability and the corresponding observed relative frequency over the verification period as vertical bars(Coelho, 2013). The tendency diagram can be answered the question- How has the verification period differed from the climatological period? And are the forecast probabilities systematically too high or low? The tendency diagram will have six bars of which three bars for the forecast category (above normal, normal, and below normal) and the remaining three bars designated for the observing category. The horizontal axis is assigned for forecast probabilities and the vertical axis for the observed probabilities. A perfectly well-calibrated and unbiased forecast probability could have exactly the same height for the two bars for each of the categories in the tendency diagram.

In this study the tendency diagram will be graphed for both ground data sets and gridded-CHIRPS data sets based on observed probabilities. Ground data set that is sample stations rainfall data used as input to produced observed kiremt seasonal rainfall forecast. Gridded-CHIRPS data sets by extract points rainfall data sets for each sample station in the study are used as input observed kiremt seasonal rainfall will be produced. Once observed tercile probabilities calculated for ground and gridded data sets based, evaluation of bias forecast using tendency diagram will proceed. The evaluation commenced by evaluating ground-based observed tercile probabilities against forecasted tercile probabilities (sourced from NMA) using a tendency diagram. The comparison will be continuing for gridded data sets based on observed tercile probabilities against forecasted tercile probabilities. The result from the discussion section of this thesis will be presented detailed analysis for bias analysis for both data sets using a tendency diagram.

3.4.2. Reliability of seasonal rainfall forecast verification techniques

Reliability is an attribute of the quality of probabilistic forecasts; specifically, the correspondence between the forecast probabilities and the conditional observed relative frequencies of events. To say forecasts are reliable if, for all forecast probabilities, the observed relative frequency is equal to the forecast probability (that is, an event must occur on 40% of the occasions that the forecast probability is 40%, 50% of the occasions the probability is 50%, and so on). Thus, reliability is answered questions like 'do the forecast probabilities give an accurate indication of the uncertainty in the observation'. The reliability quality of the forecast can be measure using relative operating characteristics (ROC). ROC curve indicates the degree of correct probabilistic discrimination in a set of the forecast, which is recommended by WMO for verification of categorical forecasts either deterministic or probabilistic. ROC is plotted as a graph with the hit rate shown on the vertical axis and the false alarm rate shown on the horizontal axis. A hit implies the occurrence of an event of interest such as below-normal precipitation, while a false alarm implies the non-occurrence of such an event. A ROC curve is plotted for each forecast category individually. The underneath the ROC curve is the ROC score. ROC score above 0.5 reflects positive discrimination skill, 1.0 representing the maximum possible score.

The curve thus arches upward concerning the diagonal line representing a higher hit rate to a false alarm and the area under the curve would be greater than 0.5 (indicating positive skill). Forecast sets having no probabilistic skill (equal hit and false alarm) would be expected to have roughly the same slop (equating 1) across the entire plot, and thus to hover near the diagonal line connecting the lower left and the upper right corners, and to have an area close to 0.5. Forecast with negative skill would have a lower left part of the plot and therefore would be located mainly below the diagonal line and would have an area less than 0.5 (indicating negative skill). It should be noted that forecasts having good discriminative ability will produce high ROC scores regardless of whether or not the probability values are well-calibrated.

The geometrical area under the ROC provides a summary of statistics for the performance of probability forecast and is often referred to as the ROC score. For a perfect forecast, all ensemble members will correctly predict the event all years and the ROC point will coverage to a single point. Forecast with little or no skill will obtain a ROC score of approximately 0.5 the area under the diagonal.

3.4.3. Skill of seasonal rainfall forecast verification techniques

Forecast skill is any measure of the accuracy and/or degree of association of prediction to an observation or estimate of the actual value of what is being predicted. Forecast skill is usually measured against a naïve forecasting strategy, such as random guessing, perpetual forecasts of one category, or climatological probabilities of all categories, but can be calculated using any reference set. To conduct skill verification for probabilistic forecasts, it is good practice to use climatological probabilities as bases of reference forecast so that the skill of series of forecast measures. Climatological probabilities are the best sources of information for purpose of skill assessment in absence of any forecast. The skill of forecast can be measure using ranked probabilities skill score (RPSS).

Ranked probabilities skill score (RPSS)

RPSS measures the cumulative squared error between categorical forecast probabilities and the observed categorical probabilities relative to a reference (or standard baseline) forecast. As God-dard (2003) defined as the difference in ranked probability score between the forecast and a chosen reference forecast. RPSS computes the relative skill of the probabilistic forecast over that of climatology in terms of forecast ability to assign high probabilities to actual outcomes. Before computing RPSS it is recommended that the probability of the three forecast categories; below near and above average are arranged in ascending order. The ranked probability score (RPS) is then calculated. As Wilks (2006), suggested a ranked probability score (RPS) can be calculated using the following equation.

$$\mathrm{RPS} = \sum_{k=1}^{N} (f_k - o_k)^2$$

(Equ. 2)

Where Ok is 1 if the forecasted and observed category coincided (for instance, both have above average rainfall as the most probable category) or 0 otherwise. fk is the predicted probability in forecast category k (For K= 1, 2 or 3) for each forecast year, and N is the number of forecast categories (in this case N=3). The score has a range from 0.0 in the case that all the forecasts correctly indicated with 100% probability the verifying categories, to 1.0 given perfectly bad forecasts (those which always indicated with 0% probability the verifying category). This suggested that low scores are better than higher scores. The RPSS is calculated as

$$\mathrm{RPSS} = \frac{\mathrm{RPS} - \mathrm{RPS}_r}{0 - \mathrm{RPS}_r} = 1 - \frac{\mathrm{RPS}}{\mathrm{RPS}_r}$$

(Equ. 3)

Where RPSr is the RPS value obtained from the climatological forecast. In Ethiopia's case, RPSr is 0.33 (any of the three terciles; below, normal, and above normal equally likely to occur). The value of RPSS ranges from minus infinity to 1, 0 which indicates no skill when compared to reference forecast. When the value for RPSS is equal to 1 it suggests that the result is a perfect score.

Table 1: Forecast Verification Techniques

Attribute of quality seasonal forecast	Forecast Verification Techniques	Questions Addressed
Bias of seasonal rainfall forecast	Tendency Diagram	Are the forecast probabilities systematically too high or low?
Reliability of forecast	Relative Characteristic Curve	How does the relative frequency of occurrence of an event depend on the forecast probability? How frequently are different probabilities issued?
Skill of forecast	Ranked Probabilities Skill Score	What is the relative improvement of the probability forecast over climatology in predicting the category that the observations fell into?
Association	Pearson correlation coefficient	Is there statistical association between the forecasted and observed relative frequencies in each tercile?

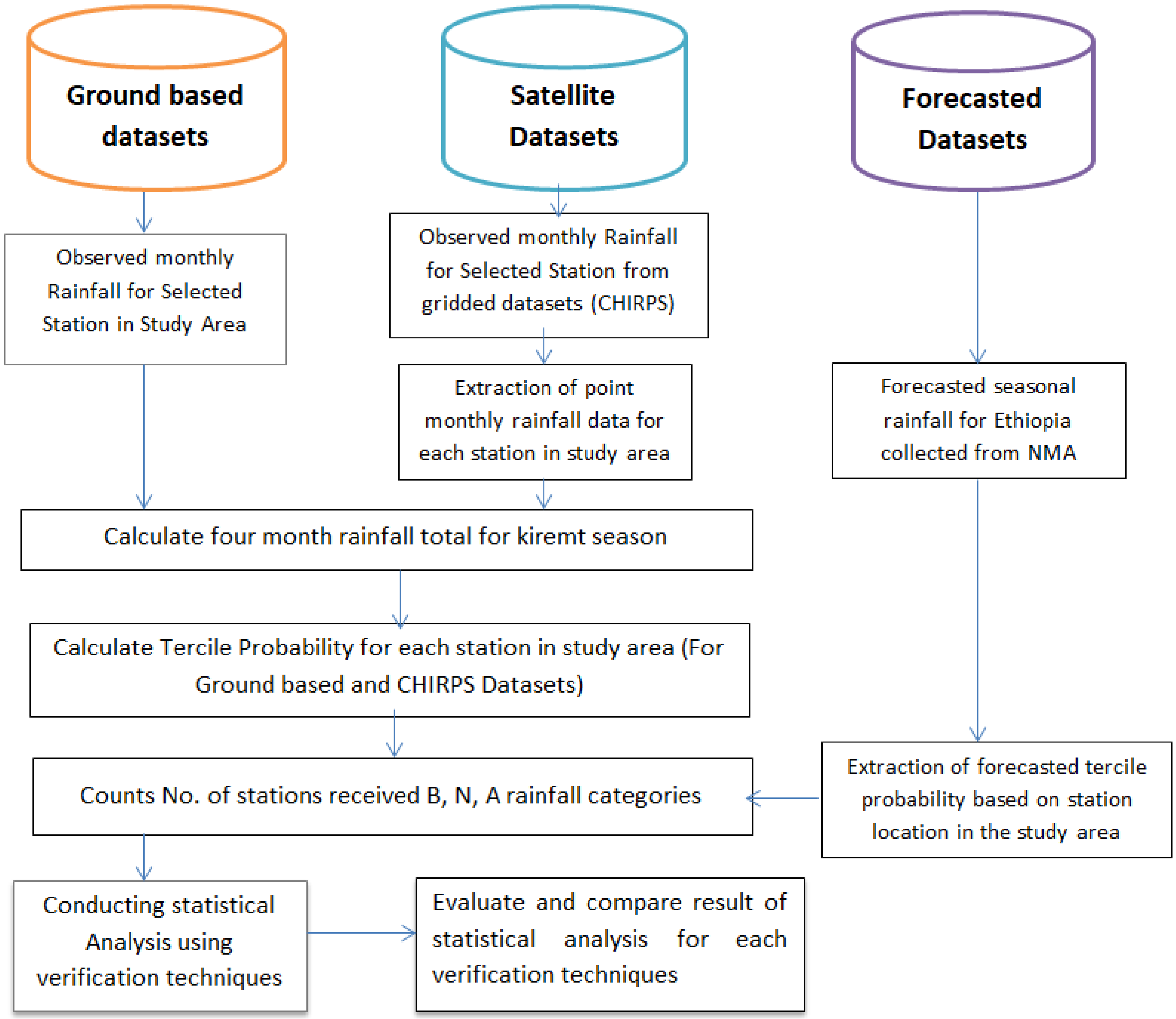


Figure 7: Schematic Diagram showing flow chart of the study

CHAPTER Four

RESULTS AND DISCUSSIONS

This chapter has given emphasis on the results and discussions based on data analysis conducted for purpose of validating kiremt season rainfall forecast issued by NMA for the last eighteen years over Abbay basin.

4.1. Analysis of data used for validation of Kiremt Seasonal rainfall Forecast

4.1.1. Analysis of ground based observed rainfall datasets used

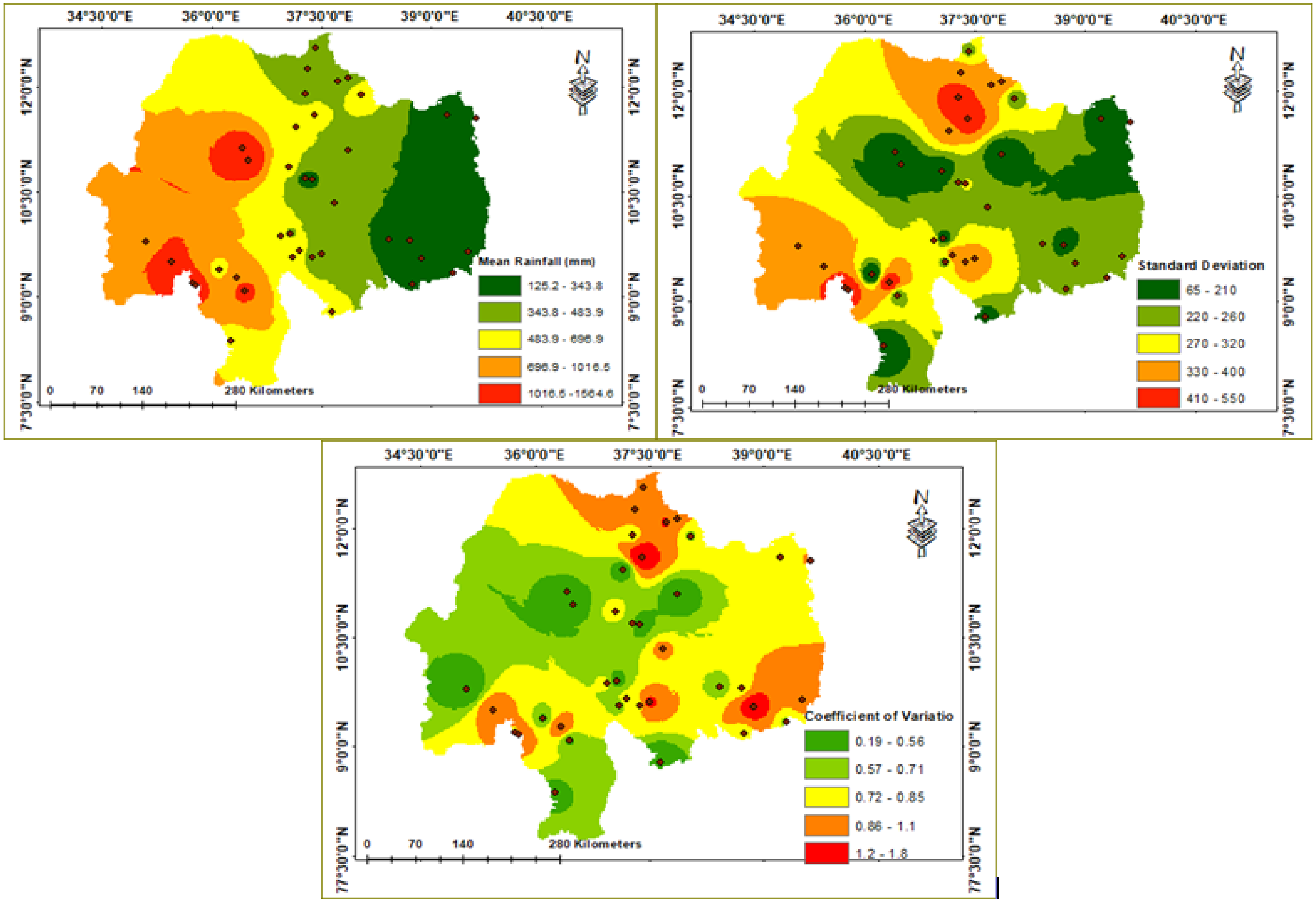
Analysis of 18 years kiremt season total rainfall datasets from 32 meteorological stations were considered for this study. The analysis focused on estimates descriptive statistics and variability analysis for kiremt season total rainfall. The mean, standard deviation and coefficient of variation for the kiremt season (JJAS) was calculated (See table 2). The maximum and minimum mean of kiremt season total rainfall recorded in the area during the study period was 1555.3 mm (Mendi) and 124 mm (Dedesa), respectively. Analysis of coefficient of variation for kiremt total rainfall indicated that the value ranges from 20 (Mendi) to 180% (Bahir Dar). There are about eight stations having a coefficient of variation above 100 % which has an impact on that area where rainfed agriculture major livelihood strategies. This because kiremt season rainfall is the major source of water for agricultural production in many parts of Ethiopia.

The standard deviation and ranges of its values indicate the variability of the kiremt total rainfall. A high standard deviation suggests that year-to-year fluctuations are high while a low standard deviation indicates that fluctuations are lower. In other words, rainfall with a high standard deviation is considered more unstable than rainfall with a low figure. Analysis of standard deviation for eighteen years of kiremt total rainfall for all meteorological stations in the study area indicates the ranges of 63.9mm (Dedesa) to 553.5mm (Angerguten).

Table 2: Mean, Standard Deviation and Coefficient of Variation for Kiremt Season total rainfall for 32 meteorological station

Name of Station	Kiremt Season Rainfall			Name of Station	Kiremt Season Rainfall		
	Mean	Std.	CV		Mean	Std.	CV
Abdella	191.5	88.6	50	Gondor	261.9	238.8	90
Addis Zemen	454.8	396.4	90	Gorgora	324.7	339.8	100
Alibo	370.9	132.5	40	Kombolcha	281.5	354.8	130
Angerguten	481.5	553.5	110	Mendi	1555.3	358.9	20
Bahir Dar	311.1	546.5	180	Miker Turi	150.5	234.1	160
Chagni	349.2	139.1	40	Mota	248.1	66	30
Dangla	307.8	156.7	50	Nejo	353.5	389.2	110
Debro Tabor	309.5	209.7	50	Nekemet	398.8	203	50
Dedesa	124	63.9	50	Neshi	501.9	395	80
Dega Istifaos	696.8	495.5	70	Shambo	350	226	60
Dengoro	618.1	445.3	70	Sheno	357.8	239.9	70
Fiche	241.5	174	70	Sirinka	216.1	186	90
Finchaa	499.3	383.4	80	Sululta	340	252.9	70
Finote Selam	327.2	222.8	70	Tikure Inchet	941.7	178.3	20
Gebre Gura	383.7	224.2	60	Tilitli	141.7	117.2	80
Gidayana	407.3	317.7	80	Wegen Tena	241.2	185	80
Gimbi	413.4	505.5	120				

Figure 8: Mean, Standard Deviation and Coefficient of Variation of kiremt total rainfall (2000 - 2018)



4.1.2. Analysis of Gridded (CHIRPS) rainfall data set used

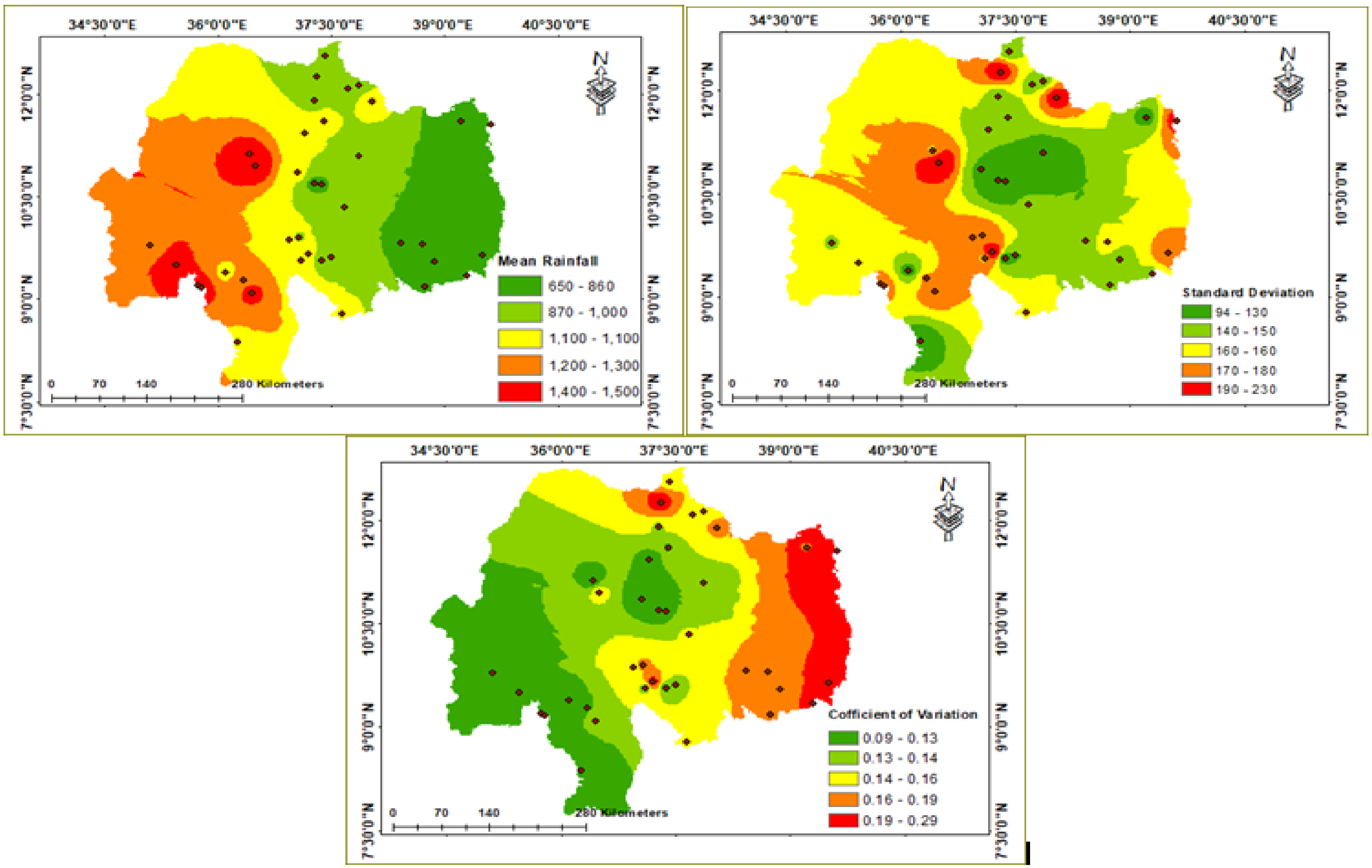
Analysis of 18 years of kiremt season total rainfall datasets based on CHIRPS datasets for study was conducted. The analysis focused on estimates descriptive statistics and variability analysis for kiremt season total rainfall. The mean, standard deviation, and coefficient of variation for the kiremt season (JJAS) were calculated. The maximum and minimum mean of kiremt season total rainfall recorded in the area during the study period was 1455.9 mm (Changi) and 644.9 mm (Sirinka), respectively. Analysis of coefficient of variation for kiremt total rainfall indicated that the value ranges from 9.9 (Abdella) to 29.5% (Sirinka). The standard deviation and ranges of its values indicate the variability of the kiremt total rainfall. A high standard deviation suggests that year-to-year fluctuations are high while a low standard deviation indicates that fluctuations are lower. In other words, rainfall with a high standard deviation is considered more unstable than rainfall with a low figure. Analysis of standard deviation for eighteen years of kiremt total rainfall for CHIRPS datasets in the study area indicates the ranges of 93.5mm (Finote Selam) to 230.1mm (Changi).

Table 3: Mean, Standard Deviation and Coefficient of Variation for Kiremt Season total rainfall for 32 CHIRPS Datasets

Name of Station	Kiremt Season Rainfall			Name of Station	Kiremt Season Rainfall		
	Mean	Std.	CV		Mean	Std.	CV
Abdella	1085.0	107.5	9.9	Gorgora	897.2	208.6	23.3
Addis Zemen	877.3	139.0	15.8	Jiga	831.7	109.2	13.1
Alibo	981.3	170.0	17.3	Kombolcha	933.5	130.5	14.0
Anger Gulti	1229.1	161.7	13.2	Mendi	1220.4	147.0	12.0
Bahir Dar	1080.2	140.9	13.0	Merawi	1073.2	133.2	12.4
Chagni	1455.9	230.1	15.8	Metema	807.6	172.4	21.3
Dangla	1321.7	155.4	11.8	Miker Turi	808.5	140.1	17.3
Debre Birth	776.5	178.1	22.9	Mota	853.1	115.2	13.5

Debre Mark	919.5	137.0	14.9	Nejo	1297.6	148.7	11.5
Debro Tabor	1164.2	201.1	17.3	Nekemet	1304.4	176.0	13.5
Dedesa	1078.3	121.8	11.3	Neshi	1031.3	226.8	22.0
Dega Istifaos	955.1	137.6	14.4	Shambo	1147.1	154.3	13.5
dengoro	1309.9	170.4	13.0	Sheno	696.6	144.2	20.7
Fiche	836.4	158.3	18.9	Sirinka	644.9	190.1	29.5
Finchaa	926.8	113.5	12.2	Sululta	831.3	138.6	16.7
Finote Selam	794.1	93.5	11.8	Tikure Inchet	1081.4	158.9	14.7
Gebre Gura	800.6	136.3	17.0	Tilitli	1120.1	130.6	11.7
Gidayana	1133.7	174.0	15.4	Wegen Tena	654.8	126.0	19.2
Gimbi	1299.7	163.0	12.5	Yifag	916.2	141.9	15.5
Gondor	882.8	132.0	15.0				

Figure 9: Mean, Standard Deviation and Coefficient of Variation for Kiremt Season total rainfall for 38 CHIRPS Datasets



4.1.3. Comparison of CHIRPS datasets performance over ground-based rainfall datasets

For purpose of conduct, a comparison of CHIPRS and ground-based rainfall datasets of five meteorological stations selected from 38 stations. These five stations selected based on assumption that representing all study area and have a full range of recording rainfall datasets. Lists of stations selected shows in the table below.

Table 4: Location of Five Selected Meteorological Stations

No	Station	Longitude (o)	Latitude (0)	Altitude (m)
1	Wegen Tena	11.6	39.2	2952
2	Nejo	9.5	35.5	1800
3	Fiche	9.8	38.7	2784
4	Finote Selam	10.7	37.3	1840
5	Addis Zemen	12.1	37.9	1940

A kiremt seasonal mean total rainfall comparison of ground-based and CHIRPS rainfall datasets was conducted. As shown in figure 10 ground-based slightly overestimates at the majority of the station when compare with CHIRPS datasets. It overestimates at Wegen Tena and Nejo stations and underestimates at Fiche, Finote Selam, and Addis Zemen stations the kiremt season rainfall.

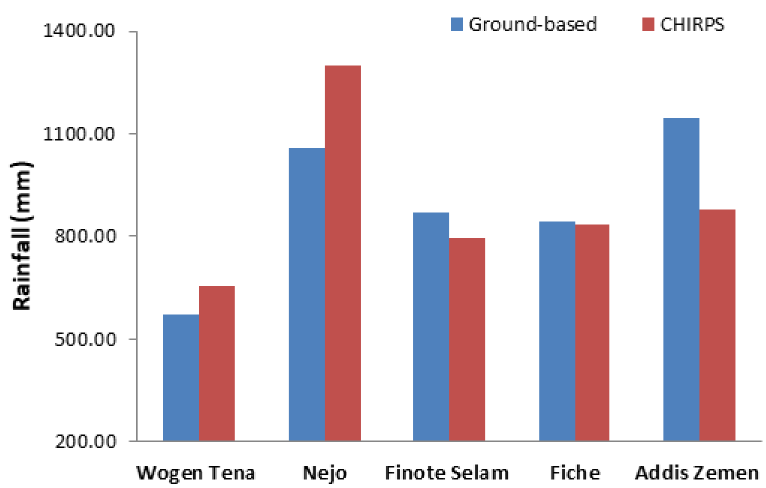


Figure 10: Comparison of ground-based and CHIRPS Kiremt season total rainfall

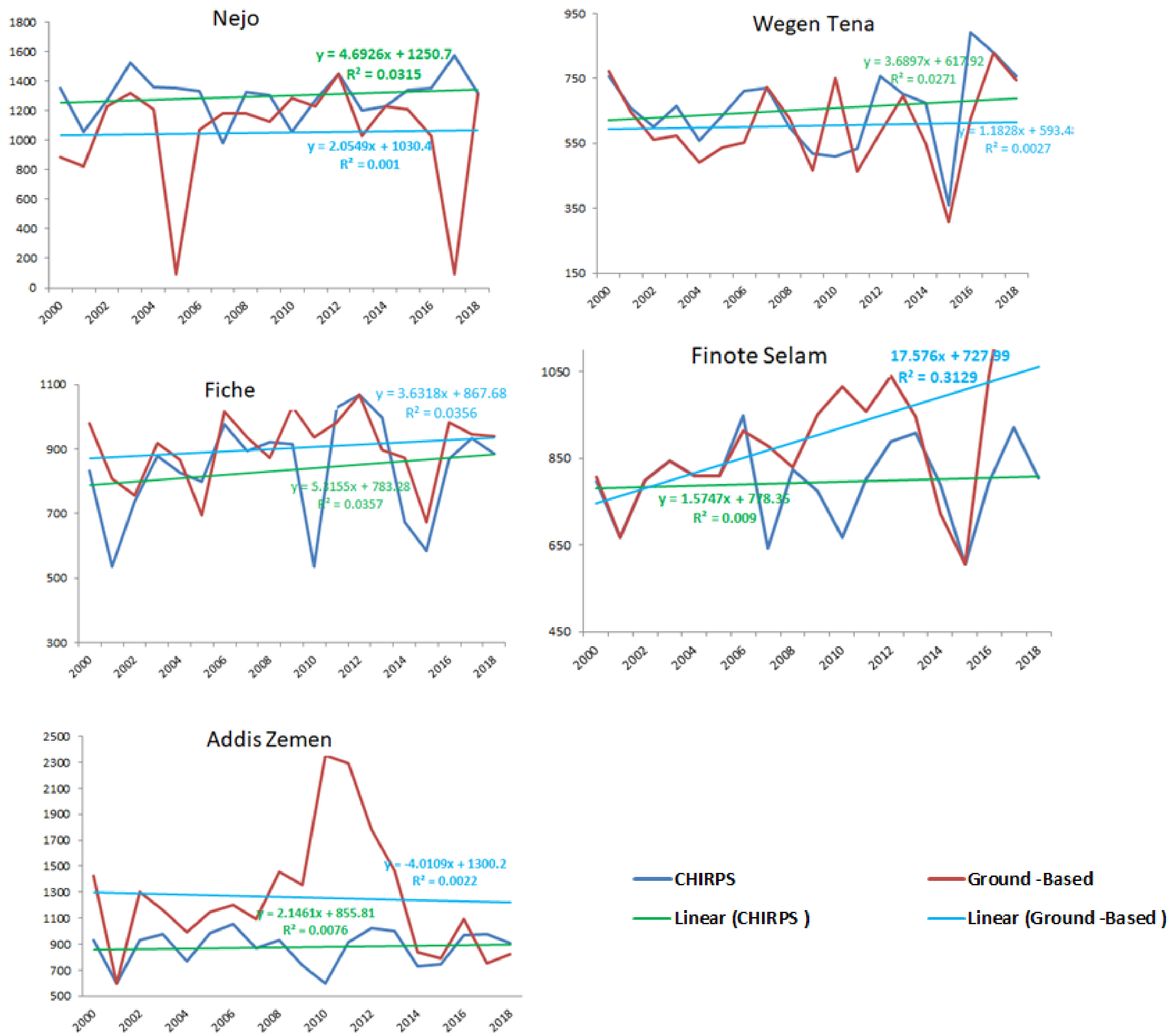


Figure 11: Comparison of ground-based and CHIRPS total kiremt rainfall for Nejo, Wegen Tena, Finote Selam, Fiche and Addis Zemen Station

4.2. Calculating tercile probability for observed rainfall datasets

Tercile probabilities for observed seasonal rainfall total were estimated based on station-based and CHIRPS seasonal total rainfall datasets. Then the tercile categories were calculated for each station in the study areas. Tercile is two values that divide the historical time series record into three parts which leaving one-third of the values below the so-called lower tercile values, one-third of the values above the so-called upper tercile value, and one-third of the values between the lower and upper tercile values. The tercile-based seasonal forecast indicates forecast probabilities for three categories: Below normal, near normal, and above normal.

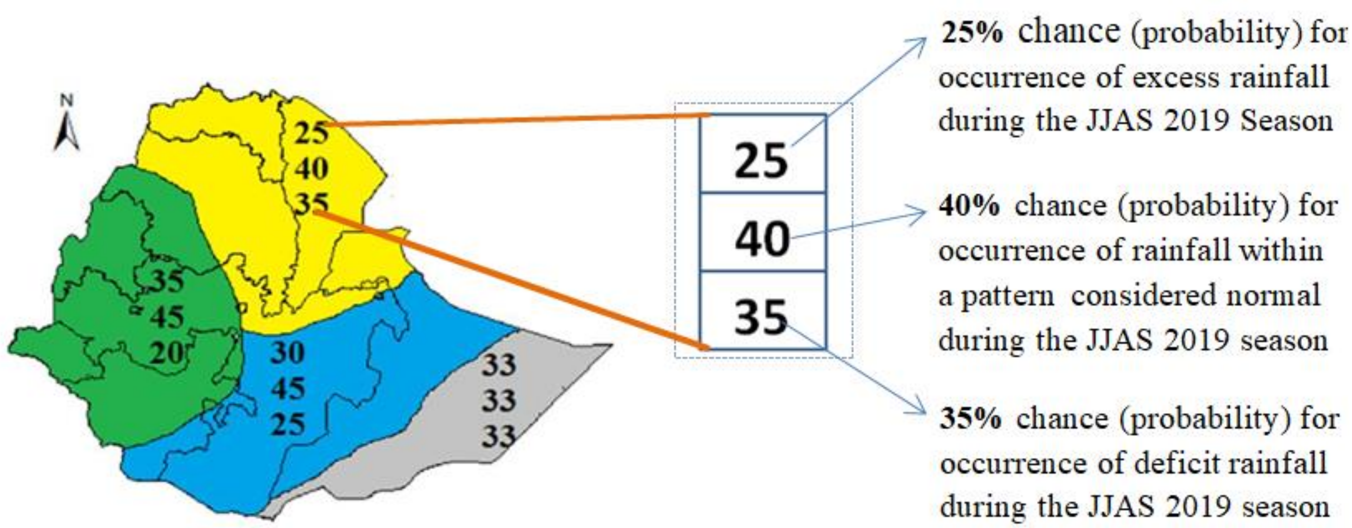


Figure 12: Tercile probabilities description

The tercile probabilities of observed seasonal rainfall based on ground-truth and gridded (CHIRPS) datasets were calculated (Appendix 3 & 4 presented full result of tercile probabilities based on ground-truth and gridded (CHIRPS) datasets).

4.3. Analysis Kiremt Seasonal Rainfall Forecast Based on Quality Attributes of Seasonal Rainfall forecast

4.3.1. Analysis of Bias of Kiremt Seasonal Rainfall Forecast

The Kiremt seasonal rainfall forecast was evaluated to see if there is any systematically too high or low forecast. Tendency diagram can be used for the analysis of bias of probabilistic forecast where the diagram is shown for each tercile category the average forecast probability and the corresponding observed relative frequency over the verification period as vertical bars. It is important to know if the forecasting system under-forecast and forecast any particular categories. The tendency diagram for both ground-truth and gridded (CHIRPS) datasets plotted and a comparison was done to evaluate the bias of kiremt seasonal rainfall.

Figure 12 (a) shows a tendency diagram for tercile probability kiremt rainfall forecast over the study area (Abbay Basin) for kiremt season based on stations. Average forecast probabilities for stations datasets (red bars) for above normal, normal, and below normal for kiremt season are 29, 48, and 23 %. The figure below also, suggested that the forecasters tend to issues forecast probabilities for the three often favoring the normal categories as the most likely. This comparison suggests that the kiremt season forecast always over-forecast the normal category (red bars are longer than blue bars).

The figures also portray that kiremt season forecasts under-forecast the below-normal categories (red bars are shorter than blue bars) Figure 12 (b) shows a tendency diagram for tercile probability kiremt rainfall forecast over the study area (Abbay Basin) for kiremt season based on CHIRPS datasets. Average forecast probabilities for the CHIRPS dataset (red bars) for above normal, normal, and below normal for kiremt season are 30, 52, and 18 %, respectively. The figure below also, suggested that the forecasters tend to issues forecast probabilities for the three often favoring the normal categories as the most likely. This comparison suggests that the kiremt season forecast always over-forecast the normal category (red bars are longer than blue bars). The figures also portray that kiremt season forecasts under-forecast the below-normal categories (red bars are shorter than blue bars).

The finding from the tendency diagram based on both station and CHIRPS datasets are in agreement with (Korecha & Sorteberg, 2013) that normal kiremt season rainfall probabilities were the highest for the majority area of the study area. Low and high kiremt season rainfall events are mostly missed by the forecast system. Therefore, the result suggested that low skills were attained for strong rainfall events for kiremt season based on both stations and CHIRPS datasets.

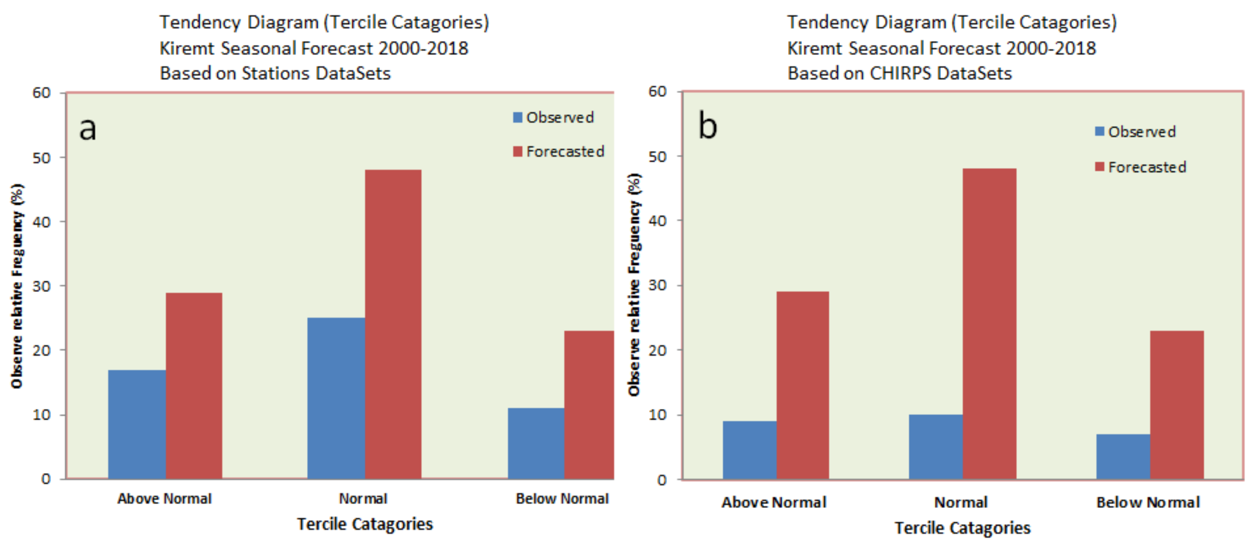


Figure 13: Average Kiremt season rainfall tercile probability for forecast (red bars) and observed tercile probabilities based on stations (figure a) and CHIRPS (figure b) datasets in study area.

4.3.2. Analysis of Reliability Kiremt Seasonal Rainfall Forecast

Relative operating characteristics (ROC) curve indicates the degree of correct probabilistic categories in sets of forecast. A ROC curve is plotted for each category individually. The geometrical area under the ROC provides a summary statistics for the performance of probability forecast, and it often referred to as ROC score. Figure 15, shows a ROC score for three tercile categories kiremt season rainfall forecast over the study area (Abbay Basin) for kiremt season based on CHIRPS rainfall datasets. The figure reveled that below normal is above 0.5 ROC score which shows that below normal category has better performance over Abbay basin. It suggested that below normal kiremt season rainfall forecast over Abbay basin is more reliable than above normal and normal kiremt season rainfall forecast. Furthermore, the figure depicts that above normal category kiremt season rainfall forecast reliable than normal as the ROC score situated above diagonal line. From figure 15 again portrays that normal category less reliable when compare to above and below kiremt season rainfall forecast over Abbay basin.

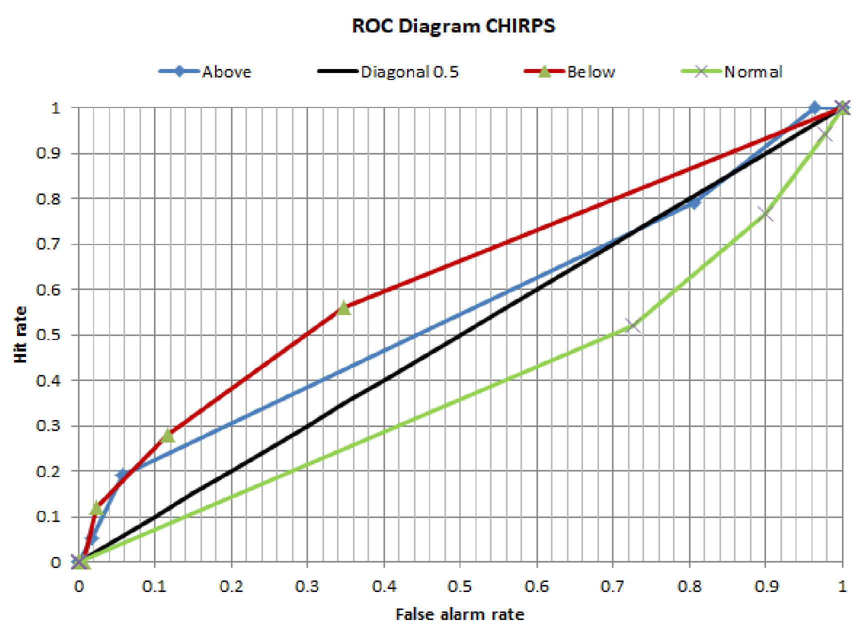


Figure 14: ROC showing skill of Kiremt season rainfall forecast using CHIRPS rainfall datasets

Figure 16, shows a ROC score for three tercile categories kiremt season rainfall forecast over the study area (Abbay Basin) for kiremt season based on selected stations rainfall datasets. In the figure 16 shows that the ROC scores for all tercile categories are tends to below 0.5 ROC score. The above normal category shows positive ROC score to the right top side of the ROC curve this suggested that above normal category has better performance and more reliable than other tercile category. The rest of tercile categories have negative ROC score this reveals that the below normal and normal tercile categories have poor performance and less reliable to make any action. Overall the reliability of kiremt season rainfall forecast based on selected stations rainfall dates has poor performance as compared with reliability assessment based on CHIRPS rainfall datasets.

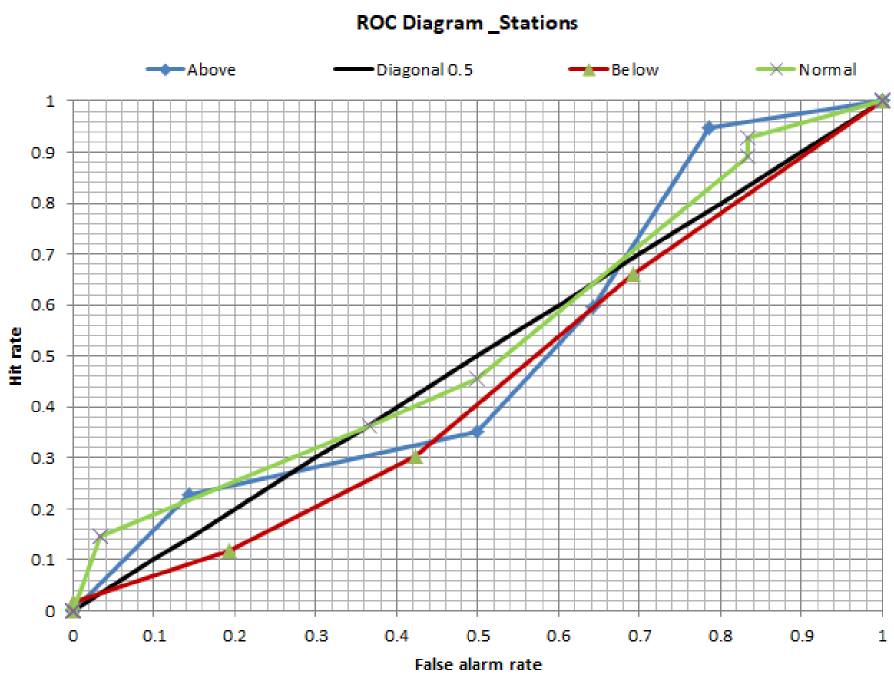


Figure 15: ROC showing skill kiremt season rainfall using selected stations rainfall datasets

4.3.3. Analysis of Skill of Kiremt Seasonal Rainfall Forecast

The skill of the kiremt season rainfall forecast was assessed using ranked probability skill score (RPSS) to understand the level of improvement of the multi-category probabilistic forecast relative to reference forecast over the study area. The requirement for improvement in existing forecasting system assessed relative to reference forecast- usually the long term or simple climatology. The RPSS values range from minus infinity to 1 where positive values show an improvement relative to the climatology, with a value of 1 indicating a perfect forecast; and negative values indicate forecasts that are worse than the climatology. The aggregated RPSS values for each station sourced both from station records and CHIRPS datasets in the study area are shows negative (Table 6). Average values for aggregated RPSS for stations and gridded-based values are -0.46 and -0.25, respectively.

The station's record-based RPSS value (-46%) indicating that 46% of worse than the climatological prediction. Where us, for the gridded (CHIRPS) dataset the RPSS values are -0.25 which indicating that 25 % worse than the climatological prediction. Therefore, the Kiremt season rainfall forecast has better skill when the gridded (CHIRPS) datasets are used for purpose of issued national seasonal rainfall forecast.

Table 5: RPSS values for each station in the study area based on observed Stations and CHIRPS datasets

RPSS Value based on Stations datasets				RPSS Value based on CHIRPS datasets			
Station Name		Station Name		Station Name		Station Name	
Abdella	-0.20	Gondor	-0.35	Abdella	-0.166	Gondor	-0.341
Addis Zemen	-0.22	Gorgora	-0.35	Addis Zemen	-0.322	Gorgora	-0.341
Alibo	-0.21	Jiga	-0.40	Alibo	-0.202	Jiga	-0.391
Anger Gulti	-0.81	Kombolcha	-0.21	Anger Gulti	-0.202	Kombolcha	-0.197
Bahir Dar	-0.18	Mendi	-0.31	Bahir Dar	-0.228	Mendi	-0.296
Chagni	-0.26	Merawi	-0.23	Chagni	-0.114	Merawi	-0.216

Dangla	-0.26	Miker Turi	-0.23	Dangla	-0.259	Miker Turi	-0.215
Debre Birth	-0.26	Mota	-0.21	Debre Birth	-0.259	Mota	-0.186
Debre Mark	-0.26	Nejo	-0.23	Debre Mark	-0.259	Nejo	-0.309
Debro Tabor	-0.11	Nekemet	-0.26	Debro Tabor	-0.309	Nekemet	-0.309
Dedesa	-0.30	Neshi	-0.21	Dedesa	-0.309	Neshi	-0.209
Dega Istifaos	-0.34	Shambo	-0.21	Dega Istifaos	-0.324	Shambo	-0.209
dengoro	-0.26	Sheno	-0.27	dengoro	-0.309	Sheno	-0.261
Fiche	-0.23	Sirinka	-0.34	Fiche	-0.215	Sirinka	-0.331
Finchaa	-0.15	Sululta	-0.27	Finchaa	-0.209	Sululta	-0.263
Finote Selam	-0.40	Tikure Inchet	-0.26	Finote Selam	-0.391	Tikure Inchet	-0.185
Gebre Gura	-0.23	Tilitli	-0.26	Gebre Gura	-0.215	Tilitli	-0.248
Gidayana	-0.20	Wegen Tena	-0.32	Gidayana	-0.202	Wegen Tena	-0.345
Gimbi	-0.20	Yifag	-0.32	Gimbi	-0.202	Yifag	-0.309

Figures 14 a and 14b show the spatial RPSS patterns with climatology as the reference for kiremt season rainfall forecast based on observed stations record and CHIRPS rainfall datasets. Spatial RPSS patterns indicate that the forecast system performs better than climatology in much of the study area. Figure 14a show the spatial RPSS patterns based on observed CHIRPS rainfall datasets. As stated in above paragraph the RPSS values are negative and this negative values spatial distribution varies across the study area. As shown in the figure 14a, most south and southern east part of the study area have better forecast skill relative to other parts of study area. Figure 14b, shows the spatial RPSS patters based on observed stations recorded rainfall datasets. As shows the figure, most of southern parts of the study area have better forecast skill relative to rest of study area.

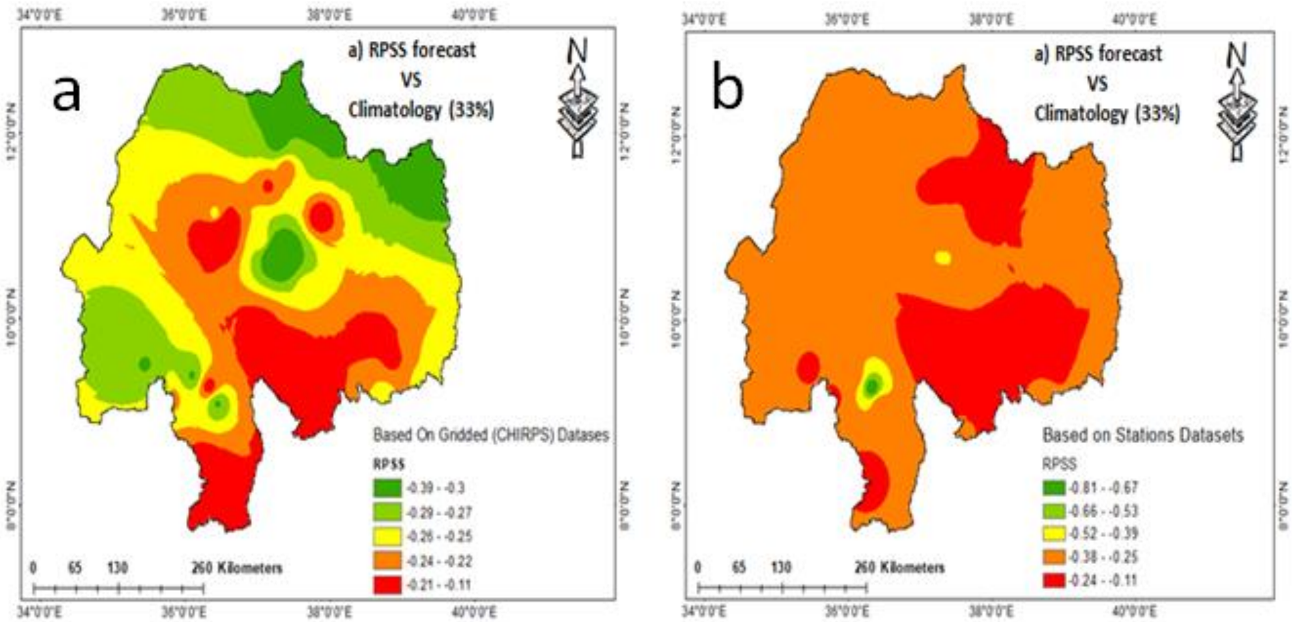


Figure 16**:** Ranked Probability Skill Score (RPSS) for Kiremt season rainfall forecast; a) RPSS values based on CHIRPS datasets and b) RPSS value based on Stations datasets.

Chapter Five

Conclusions and Recommendations

5.1. Conclusion

Seasonal rainfalls forecast by using the analog method have been issued in Ethiopia since 1987 for three times per year. In this study, emphasis has been given to evaluate the skill of NMA's tercile probabilistic kiremt season rainfall forecasts that have been issued during the periods 2000 – 2018 using stations and CHIRPS rainfall datasets over the Abbay basin of Ethiopia. Based on bias verification techniques it is revealed that tends to forecast normal rainfall distribution over the study area when using both selected stations and CHIRPS rainfall datasets. The tendency diagram has been shown that the normal tercile probabilistic highest score over the rest of tercile categories (Below and above Normal) using the selected station and CHIRPS datasets as inputs for plotting tendency diagram. Over forecasting of normal tercile category as highest outputs of forecast system, has revealed that there is a tendency to avoid risk related with below and above normal rainfall forecast.

The study also assessed the reliability of kiremt seasons rainfall using relative operating characteristics (ROC) based on selected stations and CHIRPS rainfall datasets as inputs for eighteen years over the study area. ROC diagram based on selected stations and CHIRPS rainfall dataset shows above 0.5 ROC score for above normal and below-normal categories. This suggested that below normal and above normal have good forecast skills over the study area. Whereas, the normal category which is based on both selected stations and CHIRPS rainfall datasets in the study area ROC diagram shows below o.5 ROC score. Hence, the normal tercile category has poor forecast skill over the study area based on selected stations and CHIRPS rainfall datasets.

5.2. Recommendation

Key recommendations could be potentially drawn from the study which would help as a flavor for consideration of further study and reflection of needs for measures to improve current kiremt seasonal rainfall forecast methods.

- This study has used monthly CHIRPS rainfall datasets for comparison seasonal rainfall forecast quality with stations-based rainfall datasets for eighteen years for the study area. Thus, it is recommended that to conduct further researches on the use of daily or decadal CHIRPS rainfall datasets to assess the quality of seasonal rainfall quality.
- This study has used fewer seasonal rainfall forecast verification techniques which are more critical. Therefore, recommended to further study using all sets of verification techniques so that improved quality validation seasonal rainfall forecast.
- The temporal resolution has been used for this study for eighteen years to assess the quality of the kiremt season rainfall forecast over Abbay Basin. But the quality of validation of seasonal rainfall forecast could be improved if the temporal resolution of the study considers more than eighteen years. Thus, it recommended further study by considering a high temporal resolution of datasets consideration so that improved output of validation process.
- This study has validated the kiremt season rainfall forecast for quality of forecast to understand quality components of the forecast, but not assessed for its values-that means socio-economic impacts of rainfall forecast in the study area.
- Prediction of onsets and cessation of seasonal rainfall forecast is an essential part of the forecast so that to inform in advance relevant stakeholders to plan any mitigation measures and cope up with any discrepancy forecast result. This study has not covered the assessment of onsets and cessation of kiremt seasonal forecast for the study area. Thus, further researches on assessment onsets and cessations study would improve the output of the validation process.
- This study is done only for validation of the kiremt season rainfall forecast for its quality. It is highly recommended that a study should be further conducted to cover all remaining seasons.

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Appendix

Appendix 1: Observed Datasets extracted from CHIRPS datasets

Name of Station	2018	2017	2016	2015	2014	2013	2012	2011	2010	2009	2008	2007	2006	2005	2004	2003	2002	2001	2000
Abdella	1038.65	1251	1009.47	1108.33	983.46	1038.2	1202.66	1285	937	1134	1089	1059	1172.37	1099.84	1212.17	1098.12	1059	937	901
Addis Zemen	907.51	980.31	966.77	743.83	734.26	1004.3	1021	917	596	742	933	871	1055.14	988.06	768.9	976.08	933	596	934
Alibo	815.16	970.03	804.4	653.34	852.71	823.89	1020	955	826	1020	1042	966	1234.76	1148	1072.99	1202.7	1148	826	1263
Anger Gulti	1163.34	1394.2	1183.63	1096.46	1100.73	1192	1479	1262	993	1248	1372	978	1327.64	1338.11	1307.08	1384.61	1060.83	993	1479
Bahir Dar	1140.84	1264.44	1041.77	930	1064.59	1197.7	1313	1116	862	941	1244	939	1299.52	1068.65	1039.85	1155.64	1055.22	862	988
Chagni	1467.76	1779.56	1481.43	1631.88	1504.9	1606.42	1695	1423	1218	1379	1613	1276	1724.33	1460.54	1556.4	1490.75	1361.46	1218	774
Dangla	1329.6	1586	1269.5	1460.1	1327.59	1472.14	1508	1266	1086	1223	1444	1122	1508.7	1354.19	1411.44	1353.2	1200.42	1086	1105
Debre Birth	783.85	927.78	964.8	469.46	505.15	880	887	787	447	781	886	990	902.32	798.2	829.55	842.45	710.45	447	915
Debre Mark	895.13	955.85	814.24	606.23	792.81	1019.48	1040	950	738	916	1015	919	1224.68	936.57	976.81	976.04	936.57	738	1020
Debro Tabor	1281.04	1297.65	1295.43	1002.73	1054.4	1364	1420	1240	842	988	1268	1184	1444.63	1263.39	1051.62	1356.62	1135.99	842	788
Dedesa	1013.85	1223.23	1050.51	1011.78	1009.23	1046.98	1291	1093	921	1035	1194	826	1188.24	1161.72	1137.64	1196.74	982.24	921	1184
Dega Istifaos	1007.47	1079.1	933.33	795.82	882.78	1014.03	1160.66	1046	739	901	1099	907	1228.04	964.6	885.72	1060.87	907	739	795.82
dengoro	1334.84	1635.51	1329.69	1313	1256.32	1342.69	1467	1323	1076	1351	1385	981	1442.08	1423.26	1372.22	1521.54	1223.79	1076	1035
Fiche	886.12	934.2	868.45	586.53	672.24	999.16	1068	1029	534.7	915	920	894	976.62	798.2	827.06	877.25	736.95	534.7	834
Finchaa	801.69	954.68	805.1	706.45	794.66	872.16	969.36	1024	837	957	986	929	1157.42	959.34	959.16	999.56	934.53	837	1125
Finote Selam	803.75	920.72	793.35	604.26	788.7	908	889	802	667	774	823	642	947.42	809.22	807.95	845	798.51	667	797
Gebre Gura	846.45	879	751.82	593.44	685.67	955.16	1005	962	561	834	880	797	968.29	771.73	801.2	893.5	789.42	561	675
Gidayana	1027.8	1194.62	966.95	830.79	1016.9	983.16	1198	1103	933	1184	1182	105	1431.28	1350.19	1313.74	1455.71	1208.	933	1169

	4											9					44		
Gimbi	1318.36	1591.67	1296.98	1278.16	1172.77	1261	1268	1406	1030	1169	1399	1031	1432.09	1396.62	1410.8	1572.81	1273.74	1030	1356
Gondor	887.8	938.86	863.25	739.92	727.31	955.69	934	853	842	788	933	793	921.64	921.18	826.26	862.97	793	842	1351
Gorgora	863.13	932.92	812.05	732.33	749.65	896.5	999	1323	1076	1351	911	681	937.25	896.14	772.95	845.85	681	1076	510
Jiga	851.58	931.21	828.71	621.63	820.42	933.37	918	851	683	797	843	674	984.38	816.42	824.86	888	811.23	683	1042
Kombolcha	823.71	958.3	811.75	617.19	779.47	899	1007	1073	863	989	1060	956	1203.38	987.22	996.22	1015.69	996.22	863	837
Mendi	1199.29	1479.99	1226.49	1193.75	1122.83	1124	1338	1244	1009	1263	1248	1030	1277.98	1256.71	1347.36	1482.29	1347.36	1009	989
Merawi	1151.89	1276.61	1047.54	943.8	1070.15	1220	1221.54	1040	865	934	1151	864	1277.3	1031.86	1056.45	1089.35	1151	865	1134
Metema	757.83	854.24	789.5	737.22	731.02	685	994	670	633	724	937	761	880.3	746.7	714.14	943.12	774.2	633	1379
Miker Turi	895.58	943.47	870.68	565.89	570	845.5	957	883	562	837	847	854	926.43	713.58	804.64	915.73	915.73	562	892
Mota	934.69	978.9	926.6	671.48	817.44	1014.14	928	921	669	782	902	838	1046.51	818.85	817.69	937.56	812.24	669	724
Nejo	1315.21	1574.33	1353.39	1340	1229	1204.25	1448	1271	1056	1302	1327	983	1332.96	1354.06	1361.75	1523.66	1272.66	1056	1351
Nekemet	1272.46	1586.95	1218.63	1181.91	1194.02	1289.36	1545	1371	1140	1356	1502	1091	1424.16	1453.38	1436.94	1489.6	1133.25	1140	957
Neshi	329.54	1073.66	902.79	764	909.52	946	1113.1	1065	897	1125	1130	1094	1363.06	1178.22	1180.41	1260.27	1143.63	897	1222
Shambo	1045.83	1216.3	1010.75	891.8	1007.35	1030.34	1241	1225	917	1222	1232	1096	1456.98	1252.91	1246.75	1306.55	1257.2	917	1223
Sheno	691.28	869.73	716.81	436.4	451.9	762	766	762	451	675	831	782	850.2	756.01	724.33	832.46	644.12	451	782
Sirinka	726.93	753.41	878.84	331	628.8	624.77	688	508	439	510	1198	723	644.89	565.18	521.91	636.85	644.89	439	790
Sululta	904.5	1066.26	833.23	566.24	599	841.4	925.46	976	642	892	924	816	979.25	789.47	820.88	917.94	917.94	642	742
Tikure Inchet	1003.4	1276.38	927.08	835.4	882	1206.2	1099	1284	967	1105	1294	1048	1302.37	1113.15	1124.5	1173.3	1157.3	967	781
Tilitli	1209.45	1343.61	1126.48	1029.81	1127.85	1270.11	1257	1101	962	1042	1175	908	1363.87	1124.44	1130.66	1142.42	1065.47	962	941
Wegen Tena	757.26	831.71	890.95	358.8	675	703	756	533	509	520	599	721	711.81	634.76	559.79	664.77	599.76	660	756
Yifag	949.57	1078.51	964.27	796.45	821.1	1034.8	1027.39	956	640	790	988	834	1109.21	993.45	785.51	974.67	1109.21	640	916

Appendix 2: Forecasted datasets extracted from NMA Kiremt season rainfall forecast

Station Name	**Year**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Abdella	Fcst A	35	25	35	35	25	20	20	25	35	25	30	25	30	35	30	25	35	35	40
	Fcst N	45	45	45	40	60	60	65	45	55	55	45	55	45	45	45	40	45	40	35
	Fcst B	20	30	20	25	15	20	15	30	15	20	25	20	25	20	25	35	20	25	25
Addis Zemen	Fcst A	25	25	25	20	25	20	20	30	35	25	25	35	30	25	30	20	25	35	40
	Fcst N	40	35	45	45	60	60	65	45	55	45	55	45	45	45	45	35	40	40	35
	Fcst B	35	40	30	35	15	20	15	25	15	30	20	20	25	30	25	45	35	25	25
Alibo	Fcst A	35	35	35	35	25	20	20	25	35	25	30	25	30	35	30	25	35	35	40
	Fcst N	45	45	45	45	60	60	65	45	55	55	45	55	45	45	45	40	45	40	35
	Fcst B	20	20	20	20	15	20	15	30	15	20	25	20	25	20	25	35	20	25	25
Anguer Guilta	Fcst A	25	25	25	20	25	20	20	30	35	25	25	35	30	25	30	20	25	35	40
	Fcst N	40	35	45	45	60	60	65	45	55	45	55	45	45	45	45	35	40	40	35
	Fcst B	35	40	30	35	15	20	15	25	15	30	20	20	25	30	25	45	35	25	25
Bahir Dar	Fcst A	40	25	35	35	25	20	20	25	35	25	25	35	20	25	30	25	35	35	40
	Fcst N	35	55	45	40	60	60	65	55	55	45	55	45	55	45	45	40	45	40	35
	Fcst B	25	20	20	25	15	20	15	20	10	30	20	20	25	30	25	35	20	25	25
Wogen Tena	Fcst A	25	25	25	20	20	25	20	30	20	20	20	35	30	25	30	20	25	20	40
	Fcst N	40	35	45	45	55	55	60	45	50	55	65	45	45	45	45	35	40	55	35
	Fcst B	35	40	30	35	25	20	25	25	30	25	15	20	25	30	25	45	35	25	25
Nejo	Fcst A	40	25	35	35	25	20	20	25	35	25	30	25	30	35	30	25	35	35	40
	Fcst N	35	45	45	40	60	60	65	45	55	55	45	55	45	45	45	40	45	40	35
	Fcst B	25	30	20	25	15	20	15	30	10	20	25	20	25	20	25	35	20	25	25
Dengro	Fcst A	40	25	35	35	25	20	20	25	35	25	30	25	30	35	30	25	34	35	40
	Fcst N	35	45	45	40	60	60	65	45	55	55	45	55	45	45	45	40	45	40	35
	Fcst B	25	30	20	25	15	20	15	30	10	20	25	20	25	20	25	35	20	25	25
Dedesa	Fcst A	40	25	35	35	25	20	20	25	35	25	30	25	30	35	30	25	35	35	40
	Fcst N	35	45	45	40	60	60	65	45	55	55	45	55	45	45	45	40	45	40	35
	Fcst B	25	30	20	25	15	20	15	30	10	20	25	20	25	20	25	35	20	25	25

Guidaynan	Fcst A	35	35	35	35	25	20	20	25	35	25	30	25	30	35	30	25	35	35	40
	Fcst N	45	45	45	45	60	60	65	45	55	55	45	55	45	45	45	40	45	40	35
	Fcst B	20	20	20	20	15	20	15	30	10	20	25	20	25	20	25	35	20	25	25
Nekemet	Fcst A	40	25	35	35	25	20	20	25	35	25	30	25	30	35	30	25	35	35	40
	Fcst N	35	45	45	40	60	60	65	45	55	55	45	55	45	45	45	40	45	40	35
	Fcst B	25	30	20	25	15	20	15	30	15	20	25	20	25	20	25	35	20	25	25
Finchaa	Fcst A	35	35	25	35	25	20	20	25	35	25	30	35	30	35	30	25	30	35	40
	Fcst N	45	45	45	45	60	60	65	45	55	55	45	45	45	45	45	40	45	40	35
	Fcst B	20	20	30	20	15	20	15	30	15	20	25	20	25	20	25	35	25	25	25
Neshi	Fcst A	35	35	25	35	25	20	20	25	35	25	30	35	30	35	30	25	30	35	40
	Fcst N	45	45	45	45	60	60	65	45	55	55	45	45	45	45	45	40	45	40	35
	Fcst B	20	20	30	20	15	20	15	30	10	20	25	20	25	20	25	35	25	25	25
Shembo	Fcst A	35	35	25	35	25	20	20	25	35	25	30	35	30	35	30	25	30	35	40
	Fcst N	45	45	45	45	60	60	65	45	55	55	45	45	45	45	45	40	45	40	35
	Fcst B	20	20	30	20	15	20	15	30	10	20	25	20	25	20	25	35	25	25	25
Dangla	Fcst A	40	25	35	35	25	20	20	25	35	25	25	25	20	25	30	25	35	35	25
	Fcst N	35	45	45	40	60	60	65	55	55	55	55	55	55	45	45	40	45	40	45
	Fcst B	25	30	20	25	15	20	15	20	10	20	20	20	25	30	25	35	20	25	30
Tikure Inchet	Fcst A	40	25	35	35	25	20	20	25	35	25	25	25	20	25	30	25	35	35	25
	Fcst N	35	45	45	40	60	60	65	55	55	55	55	55	55	45	45	40	45	40	45
	Fcst B	25	30	20	25	15	20	15	20	10	20	20	20	25	30	25	35	20	25	30
Fiche	Fcst A	35	35	25	35	25	20	20	30	35	25	30	35	30	35	30	25	30	35	40
	Fcst N	45	45	45	45	60	60	65	45	55	45	45	45	45	45	45	40	45	40	35
	Fcst B	20	20	30	20	15	20	15	25	10	30	25	20	25	20	25	35	25	25	25
Gebre Gure	Fcst A	35	35	25	35	25	20	20	30	35	25	30	35	30	35	30	25	30	35	40
	Fcst N	45	45	45	45	60	60	65	45	55	45	45	45	45	45	45	40	45	40	35
	Fcst B	20	20	30	20	15	20	15	25	15	30	25	20	25	20	25	35	25	25	25
Sheno	Fcst A	25	35	25	20	20	25	15	30	30	25	30	35	30	35	25	20	30	20	40
	Fcst N	45	45	45	45	55	55	60	45	50	45	45	45	45	40	45	35	45	55	35
	Fcst B	30	20	30	35	25	20	25	25	20	30	25	20	25	20	30	45	25	25	25
Mota	Fcst A	35	35	25	35	25	20	20	25	35	25	30	35	30	35	30	25	30	35	40
	Fcst N	45	45	45	45	60	60	65	45	55	55	45	45	45	45	45	40	45	40	35

	Fcst B	20	20	30	20	15	20	15	30	15	20	25	20	25	20	25	35	25	25	25
Chagni	Fcst A	40	25	35	35	25	20	20	25	35	25	25	25	20	25	30	25	35	35	40
	Fcst N	35	45	45	40	60	60	65	55	55	55	55	55	55	45	45	40	45	40	35
	Fcst B	25	30	20	25	15	20	15	20	10	20	20	20	25	30	25	35	20	25	25
Finote Selam	Fcst A	40	25	25	35	25	20	20	30	35	25	25	35	30	25	30	25	25	35	40
	Fcst N	35	35	45	45	50	60	65	45	55	45	55	45	45	45	45	40	40	40	35
	Fcst B	25	40	30	20	25	20	15	25	10	30	20	20	25	30	25	35	35	25	25
Tiliti	Fcst A	40	25	35	35	25	20	20	25	35	25	25	25	20	25	30	25	35	35	40
	Fcst N	35	45	45	40	60	60	65	55	55	55	55	55	55	45	45	40	45	40	35
	Fcst B	25	30	20	25	15	20	15	20	10	20	20	20	25	30	25	35	20	25	25
Debre Tabore	Fcst A	25	25	25	20	25	20	20	30	35	25	25	35	30	25	30	20	25	35	40
	Fcst N	40	35	45	45	60	60	65	45	55	45	55	45	45	45	45	35	40	40	35
	Fcst B	35	40	30	35	15	20	15	25	10	30	20	20	25	30	25	45	35	25	25
Gonder	Fcst A	40	25	35	35	25	20	20	25	35	25	25	35	20	25	30	25	35	35	25
	Fcst N	35	35	45	40	60	60	65	55	55	45	55	45	55	45	45	40	45	40	43
	Fcst B	25	40	20	25	15	20	15	20	10	30	20	20	25	30	25	35	20	25	30
Goregora	Fcst A	40	25	35	35	25	20	20	25	35	25	25	35	20	25	30	25	35	35	25
	Fcst N	35	35	45	40	60	60	65	55	55	45	55	45	55	45	45	40	45	40	43
	Fcst B	25	40	20	25	15	20	15	20	10	30	20	20	25	30	25	35	20	25	30
Sirinka	Fcst A	25	25	25	20	20	25	20	30	20	20	20	35	30	25	30	20	25	20	40
	Fcst N	40	35	45	45	55	55	60	45	50	55	65	45	45	45	45	35	40	55	35
	Fcst B	35	40	30	35	25	20	20	25	30	25	15	20	25	30	25	45	35	25	25
Yifag	Fcst A	25	25	25	20	25	20	20	30	35	25	25	35	30	25	30	20	25	35	40
	Fcst N	40	35	45	45	60	60	65	45	55	45	55	45	45	45	45	35	40	40	35
	Fcst B	35	40	30	35	15	20	15	25	10	30	20	20	25	30	25	45	35	25	25
Mendi	Fcst A	40	25	35	35	25	20	20	25	35	25	30	25	30	35	30	25	35	35	40
	Fcst N	35	45	45	40	60	60	65	45	55	55	45	55	45	45	45	40	45	40	35
	Fcst B	25	30	20	25	15	20	15	30	10	20	25	20	25	20	25	35	20	25	25
Kemboloe cha	Fcst A	35	35	25	35	25	20	20	25	35	25	30	35	30	35	30	25	30	35	40
	Fcst N	45	45	45	45	60	60	65	45	55	55	45	45	45	45	45	40	45	40	35
	Fcst B	20	20	30	20	15	20	15	30	10	20	25	20	25	20	25	35	25	25	25
Miker turi	Fcst A	35	35	25	35	25	20	20	30	35	25	30	35	30	35	30	25	30	35	40

	Fcst N	45	45	45	45	60	60	65	45	55	45	45	45	45	45	45	40	45	40	35
	Fcst B	20	20	30	20	15	20	15	25	10	30	25	20	25	20	25	35	25	25	25
Sululta	Fcst A	25	35	25	20	20	25	15	30	30	25	30	35	30	35	25	20	30	20	40
	Fcst N	45	45	45	45	55	55	60	45	50	45	45	45	45	40	45	35	45	55	35
	Fcst B	30	20	30	35	25	20	25	25	20	30	25	20	25	20	30	45	25	25	25
Merawi	Fcst A	40	25	35	35	25	20	20	25	35	25	25	35	20	25	30	25	35	35	40
	Fcst N	35	55	45	40	60	60	65	55	55	45	55	45	55	45	45	40	45	40	35
	Fcst B	25	20	20	25	15	20	15	20	10	30	20	20	25	30	25	35	20	25	25
Dega Istefanos	Fcst A	40	25	35	35	25	20	20	25	35	25	25	35	20	25	30	25	35	35	25
	Fcst N	35	35	45	40	60	60	65	55	55	55	55	45	55	45	45	40	45	40	45
	Fcst B	25	40	20	25	15	20	15	20	10	20	20	20	25	30	25	35	20	25	30

Appendix3: Tercile categories for observed seasonal rainfall based on Ground-Truth Datasets

Station Name	**Tercile Categories**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Degastifaos	A	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	6	6	5
	N	0	50	33	50	60	50	57	63	67	70	73	75	77	79	73	69	65	67	63
	B	100	50	67	50	40	50	43	38	33	30	27	25	23	21	27	31	29	28	32
Merawi	A	100	50	33	25	20	17	14	13	11	10	18	25	31	29	27	25	24	22	26
	N	0	50	67	75	80	67	71	75	78	80	73	67	62	64	60	56	59	61	58
	B	0	0	0	0	0	17	14	13	11	10	9	8	8	7	13	19	18	17	16
Suluta	A	100	50	33	25	20	17	14	13	11	10	18	25	31	29	27	25	24	22	26
	N	0	50	67	75	80	67	71	75	78	80	73	67	62	64	60	56	59	61	58
	B	0	0	0	0	0	17	14	13	11	10	9	8	8	7	13	19	18	17	16
Miker turi	A	0	0	0	25	20	17	29	25	22	20	27	25	23	21	20	19	18	17	16
	N	0	50	67	50	60	67	57	63	56	50	45	50	54	50	53	50	53	50	53
	B	100	50	33	25	20	17	14	13	22	30	27	25	23	29	27	31	29	33	32
Kombolecha	A	100	50	33	25	20	17	14	13	11	20	18	17	15	14	13	13	18	17	21
	N	0	50	67	75	60	67	71	75	67	60	55	58	62	64	67	63	59	61	58
	B	0	0	0	0	20	17	14	13	22	20	27	25	23	21	20	25	24	22	21
Mendi	A	100	100	100	100	80	83	71	63	56	50	55	50	46	43	40	38	35	33	32
	N	0	0	0	0	20	17	14	25	33	40	36	42	46	50	47	50	47	50	53
	B	0	0	0	0	0	0	14	13	11	10	9	8	8	7	13	13	18	17	16
Yifag	A	0	0	33	25	20	17	14	13	11	10	9	8	8	14	20	25	29	28	32
	N	100	100	67	75	80	83	71	75	78	70	73	75	69	64	60	56	53	50	47
	B	0	0	0	0	0	0	14	13	11	20	18	17	23	21	20	19	18	17	16
Sirinka	A	100	50	33	25	20	17	14	25	22	20	18	17	23	29	27	25	29	28	32
	N	0	50	67	75	80	83	86	75	78	70	64	67	62	57	60	56	53	56	53
	B	0	0	0	0	0	0	0	0	0	10	18	17	15	14	13	19	18	17	16
Gorgora	A	0	50	67	50	40	33	29	38	33	30	36	33	31	29	33	38	35	33	37

	N	100	50	33	50	60	67	71	63	67	70	64	67	69	70	67	63	65	67	63
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
Gonder	A	100	50	33	50	60	50	43	50	56	50	45	42	46	43	40	38	35	39	37
	N	0	0	33	25	20	33	43	38	33	40	36	42	38	36	40	38	41	39	37
	B	0	50	33	25	20	17	14	13	11	10	18	17	15	21	20	25	24	22	26
Debre Tabor	A	100	50	33	25	20	33	43	50	44	40	45	40	46	43	40	38	35	33	32
	N	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
	B	0	50	67	75	80	67	57	50	56	60	55	58	54	57	60	63	65	67	68
Tilitil	A	0	0	0	0	20	17	14	13	22	20	18	17	15	14	20	19	24	22	26
	N	100	100	100	75	60	67	57	63	56	60	64	67	62	57	53	56	53	56	53
	B	0	0	0	25	20	17	29	25	22	20	18	17	23	29	27	25	24	22	21
Jiga	A	0	0	0	0	0	0	0	0	0	0	0	8	15	14	13	13	18	22	26
	N	100	50	33	50	60	67	71	75	78	80	73	75	69	71	67	63	59	56	53
	B	0	50	67	50	40	33	29	25	22	20	18	17	15	14	20	25	24	22	21
Finote Selam	A	0	0	0	0	0	0	0	0	0	0	0	8	15	14	13	13	18	22	26
	N	100	50	33	50	60	67	71	75	78	80	73	75	69	71	67	63	59	56	53
	B	0	50	67	50	40	33	29	25	22	20	18	17	15	14	20	25	24	22	21
Changni	A	0	0	0	25	20	17	29	25	22	20	27	25	23	29	27	25	24	28	26
	N	0	50	67	50	40	50	43	50	56	50	45	50	54	50	53	56	59	56	58
	B	100	50	33	25	40	33	29	25	22	30	27	25	23	21	20	19	18	17	16
Mota	A	0	0	0	25	20	17	29	25	22	20	27	25	23	29	27	25	24	28	26
	N	0	50	67	50	40	50	43	50	56	50	45	50	54	50	53	56	59	56	58
	B	100	50	33	25	40	33	29	25	22	30	27	25	23	21	20	19	18	17	16
Sheeno	A	0	0	0	25	20	17	14	25	22	20	18	17	23	21	27	25	24	22	26
	N	100	100	100	75	80	83	86	75	78	80	73	75	69	71	67	63	65	67	63
	B	0	0	0	0	0	0	0	0	0	0	9	8	8	7	7	13	12	11	11
Gebre Gura	A	100	50	33	25	20	33	43	38	33	30	27	33	31	29	27	31	29	28	26
	N	0	0	33	25	20	17	14	25	22	30	36	33	38	43	47	44	47	50	53
	B	0	50	33	50	60	50	43	38	44	40	36	33	31	29	27	25	24	22	21
Fiche	A	100	50	33	25	20	17	29	25	22	30	27	33	38	36	33	31	35	39	37
	N	0	0	0	25	40	33	29	38	44	40	45	42	38	43	47	44	41	39	42

	B	0	50	67	50	40	50	43	38	33	30	27	25	23	21	20	25	24	22	21
Tikure Inchet	A	100	50	33	50	60	67	71	63	67	70	64	67	69	71	73	69	71	72	68
	N	0	50	67	50	40	33	29	38	33	30	36	33	31	29	27	30	29	28	32
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Dangla	A	0	0	0	0	0	0	14	13	22	20	18	17	23	29	33	31	29	28	26
	N	100	100	67	75	80	83	71	75	67	70	64	67	62	57	53	56	59	61	58
	B	0	0	33	25	20	17	14	13	11	10	18	17	15	14	13	13	12	11	16
Shambo	A	0	0	33	25	20	17	14	13	11	10	9	8	15	14	13	13	12	17	16
	N	100	50	33	50	60	67	71	75	78	70	64	67	62	64	67	69	65	61	58
	B	0	50	33	25	20	17	14	13	11	20	27	25	23	21	20	19	24	22	26
Neshi	A	0	0	0	0	0	0	14	13	11	20	18	17	23	29	27	31	29	28	32
	N	100	100	67	75	80	83	71	75	78	70	73	75	69	64	67	63	65	67	63
	B	0	0	33	25	20	17	14	13	11	10	9	8	8	7	7	6	6	6	5
Finches	A	0	0	0	0	0	0	0	0	0	0	9	8	8	7	7	6	6	6	5
	N	100	50	33	50	40	33	43	50	44	50	45	42	46	43	47	38	35	33	32
	B	0	50	67	50	60	67	57	50	56	50	45	50	46	50	47	56	59	61	63
Neskemt	A	100	50	33	50	40	33	29	25	22	20	27	25	31	29	27	25	24	22	21
	N	0	50	33	25	40	50	57	63	67	60	64	50	46	50	67	63	59	56	53
	B	0	0	33	25	20	17	14	13	22	20	18	25	23	21	20	25	24	28	32
Giydamnan	A	0	0	0	0	20	33	43	38	33	30	27	25	31	29	33	31	29	28	26
	N	100	100	67	75	60	50	43	50	44	50	55	50	46	50	47	44	47	44	42
	B	0	0	33	25	20	17	14	13	22	20	18	25	23	21	20	25	24	28	32
Dedesa	A	0	0	0	0	20	33	29	38	33	40	36	33	31	29	27	25	24	22	21
	N	0	50	67	50	40	33	43	38	44	40	36	42	38	36	33	31	35	39	42
	B	100	50	33	50	40	33	29	25	22	20	27	25	31	36	40	44	41	39	37
Dengago	A	0	0	33	25	20	17	29	25	22	20	18	17	15	21	27	31	29	28	26
	N	100	50	33	25	40	50	43	50	44	50	55	50	54	50	47	44	47	44	42
	B	0	50	33	50	40	33	29	25	33	30	27	33	31	29	27	25	24	28	32
Nejo	A	0	0	0	25	20	17	14	13	11	10	18	17	23	21	20	19	18	17	21
	N	0	0	33	25	40	33	43	50	56	60	55	58	54	57	60	63	65	61	58
	B	100	100	67	50	40	50	43	38	33	30	27	25	23	21	20	19	18	22	21

Wgean Tena	A	100	50	33	25	20	17	14	25	22	20	27	25	23	21	20	19	18	22	26
	N	0	50	67	75	60	50	57	50	56	50	45	42	46	50	53	50	53	50	47
	B	0	0	0	0	20	33	29	25	22	30	27	33	31	29	27	31	29	28	26
Bahir Dar	A	100	50	33	50	40	33	43	50	56	50	55	58	62	64	60	56	53	50	47
	N	0	50	67	50	60	67	57	50	44	50	45	42	38	36	40	44	46	50	53
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
Angure Guliti	A	100	50	33	25	20	17	14	13	22	30	36	42	46	50	47	44	41	39	37
	N	0	0	33	50	60	67	71	75	67	60	55	50	46	43	40	38	41	39	37
	B	0	50	33	25	20	17	14	13	11	10	9	8	8	7	13	19	18	22	26
Addis Zemen	A	100	50	33	25	20	17	14	13	22	30	36	42	46	50	47	44	41	39	37
	N	0	0	33	50	60	67	71	75	67	60	55	50	46	43	40	38	41	39	37
	B	0	50	33	25	20	17	14	13	11	10	9	8	8	7	13	19	18	22	26
Alibo	A	0	0	33	50	40	50	43	50	56	50	45	42	38	36	33	31	29	28	26
	N	100	50	33	25	40	33	43	38	33	40	36	42	46	50	47	44	47	44	47
	B	0	50	33	25	20	17	14	13	11	10	18	16	15	14	20	25	24	28	26
Abedlla	A	0	0	0	25	20	17	14	13	11	20	18	17	15	14	13	13	12	11	11
	N	0	50	67	50	40	50	43	50	56	50	45	50	54	50	47	50	47	50	53
	B	100	50	33	25	40	33	43	38	33	30	36	33	31	36	40	38	41	39	37

Appendix4: Tercile categories for observed seasonal rainfall based on Gridded (CHIRPS) Datasets

Station Name	**Tercile Categories**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**
Dega istfa	A	0	0	0	25	20	17	29	25	33	30	27	25	31	29	27	25	24	28	26
	N	0	0	33	25	40	50	43	50	44	50	45	50	46	50	47	44	47	44	47
	B	100	100	67	50	40	33	29	25	22	20	27	25	23	21	27	31	29	28	26
Merawi	A	0	0	0	0	0	0	14	13	11	10	9	8	15	21	20	19	18	22	26
	N	100	50	67	75	80	83	71	63	67	60	55	58	54	50	53	50	53	50	47
	B	0	50	33	25	20	17	14	25	22	30	36	33	31	29	27	31	29	28	26
Sululta	A	0	0	0	0	0	0	14	13	22	20	18	25	31	29	27	25	24	28	26
	N	0	0	67	50	60	67	57	63	56	60	55	50	46	50	47	44	47	44	47
	B	100	100	67	50	40	33	29	25	22	20	27	25	23	21	27	31	29	28	26
melk turi	A	0	0	33	50	40	33	43	38	33	30	27	25	31	29	27	25	24	28	26
	N	100	50	33	25	40	33	29	38	44	50	45	50	46	50	47	44	47	44	47
	B	0	50	33	25	20	33	29	25	22	20	27	25	23	21	27	31	29	28	26
Kombolecha	A	0	0	0	25	20	17	29	25	33	30	27	33	38	36	33	31	29	28	26
	N	0	50	67	50	60	67	57	63	56	60	64	58	54	57	53	50	47	50	47
	B	100	50	33	25	20	17	14	13	11	10	9	8	8	7	13	19	24	22	26
Mendi	A	0	0	33	50	60	50	43	38	33	30	27	25	31	29	27	25	24	28	26
	N	0	0	0	0	0	17	29	25	33	40	36	42	38	43	40	44	47	44	47
	B	100	100	67	50	40	33	29	38	33	30	36	33	31	29	33	31	29	28	26
Yifga	A	0	0	33	25	20	17	29	25	22	20	18	17	23	29	27	25	24	28	26
	N	100	50	33	50	40	50	43	50	56	50	45	50	46	43	47	44	47	44	47
	B	0	50	33	25	40	33	29	25	22	30	36	33	31	29	27	31	29	28	26
sinrika	A	100	50	33	25	20	17	14	13	22	20	18	17	15	14	13	13	18	22	26
	N	0	0	33	50	60	67	71	75	67	60	55	50	54	57	60	56	53	50	47
	B	0	50	33	25	20	17	14	13	11	20	27	33	31	29	27	31	29	28	26
Gorgora	A	0	50	33	25	20	17	14	13	11	20	27	33	38	36	33	31	29	28	26

	N	0	0	0	25	40	50	57	50	56	50	45	42	38	43	40	38	41	44	47
	B	100	50	67	50	40	33	29	38	33	30	27	25	23	21	27	31	29	28	26
Gonder	A	100	50	33	25	20	17	14	13	22	20	18	17	23	29	27	25	24	28	26
	N	0	50	33	50	60	67	71	63	56	50	55	58	54	50	47	44	47	44	47
	B	0	0	33	25	20	17	14	25	22	40	27	25	23	21	27	31	29	28	26
Deber tabor	A	0	0	0	25	20	17	29	25	22	20	18	17	23	29	27	25	24	28	26
	N	0	0	33	25	40	50	43	50	56	50	45	50	46	43	47	44	47	44	47
	B	100	100	67	50	40	33	29	25	22	30	36	33	31	29	27	31	29	28	26
Tilitil	A	0	0	0	0	0	0	14	13	11	10	9	8	15	21	20	19	18	22	26
	N	0	0	33	50	60	67	57	50	56	60	55	58	54	50	53	50	53	50	47
	B	100	100	67	50	40	33	29	38	33	30	36	33	31	29	27	31	29	28	26
jiga	A	100	50	33	25	20	17	29	25	22	20	18	17	23	29	27	25	24	28	26
	N	0	0	33	50	60	67	57	50	56	50	45	50	46	43	47	44	47	44	47
	B	0	50	33	25	20	17	14	25	22	30	36	33	31	29	27	31	29	28	26
Finote Selam	A	0	0	0	0	0	0	14	13	11	10	9	8	15	21	20	19	18	22	26
	N	100	50	67	75	80	83	71	63	67	60	55	58	54	50	53	50	53	50	47
	B	0	50	33	25	20	17	14	25	22	30	36	33	31	29	27	31	29	28	26
Changi	A	0	0	0	0	0	0	14	13	22	20	18	17	23	21	20	25	24	28	26
	N	0	0	0	25	40	50	43	38	33	40	36	42	38	43	47	44	47	44	47
	B	100	100	100	75	60	50	43	50	44	40	45	42	38	36	33	31	29	28	26
Mota	A	0	0	0	25	20	17	29	25	22	20	18	17	15	21	20	19	18	22	26
	N	0	0	33	25	40	50	43	50	56	50	45	50	54	50	53	50	53	50	47
	B	100	100	67	50	40	33	29	25	22	30	36	33	31	29	27	31	29	28	26
Sheno	A	0	0	0	25	20	17	29	25	33	30	27	25	23	21	20	19	18	22	21
	N	100	50	33	25	40	50	43	50	44	50	45	50	54	57	53	50	53	50	53
	B	0	50	67	50	40	33	29	25	22	20	27	25	23	21	27	31	29	28	26
Gber Gura	A	0	0	0	25	20	17	29	25	22	20	18	25	31	36	33	31	29	28	26

	N	0	0	33	25	40	50	43	50	56	60	55	50	46	43	40	38	41	44	47
	B	100	100	67	50	40	33	29	25	22	20	36	33	31	29	27	31	29	28	26
Fiche	A	0.0	0.0	0.0	0.0	0.0	0.0	14.3	12.5	11.1	10.0	9.1	16.7	23.1	28.6	26.7	25.0	23.5	27.8	26.3
	N	100.0	50.0	33.3	50.0	60.0	66.7	57.1	62.5	66.7	70.0	63.6	58.3	53.8	50.0	46.7	43.8	47.1	44.4	47.4
	B	0.0	50.0	66.7	50.0	40.0	33.3	28.6	25.0	22.2	20.0	27.3	25.0	23.1	21.4	26.7	31.3	29.4	27.8	26.3
Tikure echet	A	0	0	0	0	0	0	14	13	22	20	18	25	23	29	27	25	24	28	26
	N	0	50	67	75	80	83	71	75	67	70	73	67	69	64	60	56	53	50	53
	B	100	50	33	25	20	17	14	13	11	10	9	8	8	7	13	19	24	22	21
Dangla	A	0	0	0	0	0	0	14	13	11	10	9	8	15	21	20	25	24	28	26
	N	0	0	0	25	40	50	43	38	44	50	45	50	46	43	47	44	47	44	47
	B	100	100	100	75	60	50	43	50	44	40	45	42	38	36	33	31	29	28	26
Shambo	A	0	0	33	50	60	67	71	63	56	50	45	42	38	36	33	31	29	28	26
	N	100	50	33	25	20	17	14	25	33	40	36	42	46	50	53	44	41	44	47
	B	0	50	33	25	20	17	14	13	11	10	18	17	15	14	13	25	29	28	26
Neshi	A	100	50	33	50	60	67	71	63	56	50	45	42	38	36	33	31	29	28	26
	N	0	0	33	25	20	17	14	25	33	40	36	42	46	50	53	50	47	50	47
	B	0	50	33	25	20	17	14	13	11	10	18	17	15	14	13	19	24	22	26
Finacha	A	100	50	33	50	40	33	43	38	44	40	36	42	38	36	33	31	29	28	26
	N	0	50	67	50	60	67	57	63	56	60	64	58	62	64	60	56	53	56	53
	B	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	13	18	17	21
Nakemte	A	0	0	0	25	20	33	29	25	33	30	27	25	31	29	27	25	24	28	26
	N	0	0	0	0	20	17	29	25	22	30	27	33	31	36	40	44	47	44	47
	B	100	100	100	75	60	50	43	50	44	40	45	42	38	36	33	31	29	28	26
Gidama	A	0	0	33	50	60	67	71	63	56	50	45	42	38	36	33	31	29	28	26
	N	100	50	33	25	20	17	14	25	33	40	36	42	46	43	47	44	41	44	47
	B	0	50	33	25	20	17	14	13	11	10	18	17	15	21	20	25	29	28	26
Dedesa	A	0	0	0	25	20	17	29	25	33	30	27	25	31	29	27	25	24	28	26
	N	100	50	33	25	40	50	43	38	33	40	36	42	38	43	40	44	47	44	47

	B	0	50	67	50	40	33	29	38	33	30	36	33	31	29	33	31	29	28	26
Dengago	A	0	0	0	25	20	33	43	38	33	30	27	25	31	29	27	25	24	28	26
	N	0	0	0	0	20	17	14	13	22	30	27	33	31	36	40	44	47	44	47
	B	100	100	100	75	60	50	43	50	44	40	45	42	38	36	33	31	29	28	26
Nejo	A	0	0	0	25	40	50	43	38	33	30	27	25	31	29	27	25	24	28	26
	N	100	50	67	50	40	33	43	38	56	50	45	50	46	43	40	44	47	44	47
	B	0	50	33	25	20	17	14	25	11	20	27	25	23	29	33	31	29	28	26
Wegan tena	A	100	50	33	25	20	17	14	13	11	10	9	8	15	14	13	13	18	22	26
	N	0	50	67	75	60	67	71	75	78	70	64	58	54	57	60	56	53	50	47
	B	0	0	0	0	20	17	14	13	11	20	27	33	31	29	27	31	29	28	26
Bahir Dar	A	0	0	0	0	0	0	14	13	22	20	18	17	23	29	27	25	24	28	26
	N	100	50	67	75	80	83	71	63	56	50	45	50	46	43	47	44	47	44	47
	B	0	50	33	25	20	17	14	25	22	30	36	33	31	29	27	31	29	28	26
Addis Zemen	A	0	0	0	0	0	0	14	13	11	10	9	17	15	21	20	19	18	22	21
	N	100	50	67	75	80	83	71	75	78	70	64	58	62	57	53	50	53	50	53
	B	0	50	33	25	20	17	14	13	11	20	27	25	23	21	27	31	29	28	26
Alibo	A	100	50	67	75	60	67	71	63	56	50	45	42	38	36	33	31	29	28	26
	N	0	50	33	25	40	33	29	25	33	40	45	50	54	50	53	50	47	50	47
	B	0	0	0	0	0	0	0	13	11	10	9	8	8	14	13	19	24	22	26
Abdella	A	0	0	0	0	20	17	29	25	22	20	18	25	31	29	27	25	24	28	26
	N	0	0	33	50	40	33	43	50	56	60	55	50	46	50	47	50	47	44	47
	B	100	100	67	50	40	50	29	25	22	20	27	25	23	21	27	25	29	28	26

Appendix 5: Name and Location of Meteorological Stations Selected For This Study

Station Name	Latitude	Longitude	No .Year Data observation	Years covers
Wegen Tena	11.6	39.2	36	1981 - 2018
Nejo	9.5	35.5	36	1981 - 2018
Dengoro	9.2	35.7	36	1981-2018
Dedesa	9.4	36.1	31	1985 - 2018
Gidayana	9.9	36.9	38	1981 - 2018
Gimbi	9.2	35.8	36	1981 - 2018
Nekemet	9.1	36.5	35	1981 - 2018
Finchaa	9.6	37.4	30	1989 - 2018
Neshi	9.7	37.2	39	1981 - 2019
Shambo	9.6	37.1	38	1981 - 2019
Dangla	11.1	36.4	32	1987 - 2018
Tikure Inchet	8.8	37.6	38	1981 - 2018
Fiche	9.8	38.7	38	1981 - 2018
Gebre Gura	9.8	38.4	39	1981 - 2019
Sheno	9.3	39.3	33	1986 - 2018
Mota	11.1	37.9	29	1900 - 2018
Chagni	11.0	36.5	33	1981 - 2018
Finote Selam	10.7	37.3	30	1981 - 2018
Tilitli	10.9	37.1	35	1981 -2018
Bahir Dar	11.6	37.4	27	1992 - 2018
Debro Tabor	11.9	38.0	30	1988 - 2018

Gondor	12.6	37.4	38	1981 - 2018
Gorgora	12.3	37.3	25	1994 - 2018
Sirinka	11.6	39.6	38	1981 - 2018
Alibo	9.9	37.1	39	1981 - 2019
Mendi	9.8	35.1	36	1981 - 2018
Kombolcha	9.6	37.5	38	1981 - 2018
Miker Turi	9.6	38.9	32	1986 - 2018
Sululta	9.2	38.7	38	1882 - 2018
Addis Zemen	12.1	37.9	38	1882 - 2018
Abdella	8.4	36.3	35	1982 - 2018
Dega Istifaos	11.9	37.3	36	1981 - 2018