JIMMA UNIVERSITY

COLLEGE OF SOCIAL SCIENCE AND HUMANITIES

DEPARTMENT OF GEOGRAPHY AND ENVIRONMENTAL STUDIES

EVALUATION OF SATELLITE-BASED RAINFALL ESTIMATES AND APPLICATION TO MONITOR METEOROLOGICAL DROUGHT IN GIBE BASIN, SOUTH WEST ETHIOPIA

BY:
INDALE NIGUSE

A THESIS SUBMITTED TO SCHOOL OF GRADUATE STUDIES OF JIMMA UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN GIS AND REMOTE SENSING

ADVISOR: KEFELEGN GETAHUN (PhD)
CO-ADVISOR: ASHENIF MELESE (MSc)

JULY, 2020
JIMMA, ETHIOPIA

JIMMA UNIVERSITY

SCHOOL OF GRADUATE STUDIES

This is to certify that the Thesis prepared by **Indale Niguse Dejene** entitled as ‘Evaluation of Satellite-Based Rainfall Estimates and Application to Monitor Meteorological Drought in Gibe Basin, South West Ethiopia’ submitted to Graduate Studies of Jimma University, for the award of Master of Science degree in GIS and Remote Sensing.

APPROVED BY BOARD OF EXAMINERS:

Chair Man	Signature	Date
Tesfaye Debala	____________	____________
Dr. Kefelegn Getahun Advisor	____________	____________
Mr. Ashenif Melese Co-Advisor	____________	___________
Internal Examiner		
Mr. Dessalegn Obsi	____________	___________
External Examiner		
Dr. Biadglign Demissie	____________	___________

DECLARATION

I hereby declare that the thesis entitled “Evaluation of Satellite-Based Rainfall Estimates and Application to Monitor Meteorological Drought in Gibe Basin, South West Ethiopia” has been carried out by me under the supervision of Dr. Kefelegn Getahun and Mr. Ashenif Melese, Department of Geography and environmental studies, Collage of Social Sciences and Humanity, Jimma University, during the year 2019-2020 as a part of Master of Science program in GIS and Remote Sensing. I declare that this thesis is originally prepared by me. It is based on my own work, with acknowledgments of other sources, and has not been submitted in whole or part for any other professional qualification.

Place: Jimma, Ethiopia
Date: July, 2020

(Indale Niguse)

ACKNOWLEDGMENT

First and foremost, I would like to Praise the Almighty, All-knowing and Ever-present Lord for his unlimited love, blessing and protection all the way in my life and during the study years: Thank you Jesus!

My heartiest appreciation and gratitude goes to my advisor Dr. Kefelegn Getahun (Associate Professor), Collage of Social Sciences and Humanity, Jimma University, for his academic guidance, critical comments, great help and timely response for all academic issues.

I would like to extend my deepest gratitude and appreciation to my co-advisor Mr. Ashenif Melese (MSc) Collage of Social Sciences and Humanity, Jimma University, for his consistent guidance, critical comments. Your suggestions was clue to get the necessary data input for my study.

My appreciation also goes to Wollega University, for providing a chance to study. I am thankful for National Meteorological Agency (NMA) of Ethiopia for all the meteorological, data you provided for free of charge.

My acknowledgment also goes to all staff members of Department of Geography and environmental studies, Collage of Social Sciences and Humanity, Jimma University for their contribution in timely schedule arrangement for my study.

I would like to extend my sincere gratitude and appreciation to Mr. Gizachew Kabite and Dr.Yared Bayissa for their consistent guidance, critical comments, and suggestions. Mr. Gizachew, Your guidance and critical comments on the first concept note was memorable and plentiful. You were constructing my capacity starting from my under graduate courses: thank you a lot!!
Dr.Yared I would not forget your commitment, clarifications, and respect. You were showing me the same behavior and respect all the way: thank you!!

My special thanks also to my friends Mr. Firdissa, Mitiku, Biratu, Daniel, Bayisa, Fayera and Bekan for their valuable moral support and encouragement. Their suggestion guided me to become self-reliant and efficient during the work.

Last but not least, words cannot express my grateful and appreciation to my parents for their unlimited love, care and support. They paid inestimable sacrifices as I reach here today. Special thanks for my sister Gabaye Niguse and her families. “Gabo” you pay a lot to lead me to the place where I am today.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

ACRONOMYS/ABBREVIATIONS

ARC	Africa Rainfall Estimate Climatology
CHIRPS	Climate Hazards Group InfraRed Precipitation with Station data
CHRS	Center for hydrometeorology and Remote sensing
CMORPH	Climate Prediction Center morphing technique product
CSA	Central Statistical authority
CZI	China-Z index
DM	Drought monitor
DSI	Drought Severity Index
FEWS NET	Famine Early Warning Systems Network
GPCP	Global Precipitation Climatology Project
ITCZ	Inter-Tropical Convergence Zone
ME	mean error
MoWR	Ministry of Water Resources
NDVI	Normalized Difference Vegetation Index
NMA	National Meteorological Agency
PDSI	Palmer drought severity index
PERSIANN-CDR	Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks-Climate Data Record
RAI	rainfall anomaly index
RFE	African Rainfall Estimation
RMSE	root mean square error
SPI	Standardized Precipitation Index
SREs	satellite rainfall estimates
TAMSAT	Tropical Applications of Meteorology using Satellite
TARCAT	African Rainfall Climatology and Time-series
TMPA	Tropical Multi-satellite Precipitation Analysis
TRMM	Tropical Rainfall Measuring Mission
USGS	United States Geologic Survey
VCI	Vegetation Condition Index
WMO	World Meteorological Organization

ABSTRACT

Drought is a natural hazard and a serious problem which is being revealed in most parts of Ethiopia. Meteorological stations in Ethiopia are not as much adequate to monitor drought mainly because of unevenly distributed. However, it could be able to fill this gap through applying satellite rainfall estimation products. Therefore, this study was attempt to evaluate the performance of satellite rainfall product and monitoring meteorological drought in Omo-Gibe basin, South Western Ethiopia. The major data used for the study were Satellite Rainfall Product (CHRIPS, PERSIANN and TMPA), Earth Observation Satellite (eMODIS) and Weather station data from 2000 to 2019. To evaluate the performance of satellite rainfall products statistical analysis (i.e., Pearson correlation coefficient (r), mean error (ME), root mean square error (RMSE), and Bias) were used to evaluate the satellite rainfall products with the corresponding ground observation data at ten independent weather stations. CHRIPS satellite rainfall product was selected as best performance as compared to other satellite rainfall products with r>0.96 at monthly, seasonally and yearly time-scales. TMPA did well next to CHIRPS whereas PERSIANN presented a poor performance under all the criteria. Consequently, the CHIRPS rainfall product was selected and used to assess the spatial and temporal variability of meteorological drought in this study. The 3 month and 12 months SPI values were measured for each grid and used to evaluate the spatial and temporal patterns of drought. The results from SPI values clearly shows that the occurrence of drought was observed during historic drought years (1987-1988, 1991-1992, 2000, 2002-2003, 2009-2010, and 2015-2016); particularly severe drought occurred in the year of 2002, 2009 and 2016 in the study area. Spatially, southern and central parts of the basin experiences severe drought than north parts. The validity of the result was computed by Vegetation Condition Index (VCI) and Drought Severity Index (DSI) with R^2 value of 0.45 and 0.31 respectively. The expected drought occurrences for 3-month timescales in the next 100 years shows that more drought events are expected at Jimma by about 42 times with 15(moderate), 15 (severe) and 12 (extreme) severity classes. Henceforth, the CHIRPS rainfall product can be used as an alternative source of information in developing the grid-based drought monitoring tools for the basin that could help in developing early warning systems.

Key Words: *Satellite rainfall; CHIRPS; Evaluation; Drought Assessment; Omo-Gibe basin*

CHAPTER ONE

1. INTRODUCTION

1.1. Background of the study

Drought is a natural hazard described by a significant decrease in water availability during anelongated period of time over a large area. It happens in different parts of the world and may cause considerable effect on economic activities, human lives, and numerous elements of the environment (Barua, 2011). Although drought is a naturally occurring recurrent extreme event (Shatanawi *et al*., 2013), various empirical and modeling studies proved that climate change is very likely to increase the magnitude, occurrence and duration of droughts over some portions of the world in the coming decades (Degefu and Bewket, 2015; IPCCII, 2014). Scientific literature has commonly classified droughts into four main categories as meteorological, agricultural, hydrological and socio-economic (Mishra and Singh, 2010).

In East African countries the effects of droughts are severe particularly due to high rainfall variability in space and time (Bayissa *et al*., 2017). Ethiopia encounters frequent droughts among these countries (occurring once in every 2-3 years). Some of the notable droughts (such as those in 2014–2015, 2016, 2009–2010, 1994–1995 and 1983–1984) covered the majority of the country (Bayissa *et al*., 2015). In addition, the high variability of rainfall in both space and time leads to high variability of the available water at the root zone (Manatsa *et al.*, 2008).

Omo-Gibe basin is a pastoral and agro-pastoral area, were the functioning and operation of existing water infrastructures including hydropower, structural, drainage and irrigation systems as well as water management practices affected by drought. The rapid growth of population, deforestation, surface erosion, and sediment transport and climate change affects adversely existing land and water resource system of the area. Hince quantifying such impacts in order to identify the variation in decisions and thereby minimize the potential damage magnitude of drought on a local and regional scale very important (Chaulagain, 2006).

Drought monitoring and early warning systems are vital to mitigate drought's adverse impacts (Bayissa *et al*., 2015). In every drought monitoring practice more emphasis is given to meteorological drought (simply absence/deficit of rainfall from the normal) as it is the first to occur and other droughts are consequent to it. According to (Hao *et al*., 2017) the other droughts happen one after the other if the precipitation deficit continuous for a longer period. The availability of rainfall data at adequate spatial and temporal scales highly influence meteorological drought monitoring system. Because drought is a recurring phenomenon and common for all climate zones, it is difficult to predict and monitor meteorological drought using conventional approaches over large areas. A number of indices have been developed through time to calculate the magnitude of drought. Most of these indices are based on direct measurement of climatic variables such as rainfall, evapotranspiration and temperature (Steinemann *et al*., 2005). The SPI was proposed by McKee *et al*., (1993) and has been used frequently during the past decades (Vicente-Serrano *et al*., 2015). The robustness of SPI over the other drought indices has been reported in many studies (Vicente-Serrano *et al*., 2015). In addition to its simplicity and ease of calculation, in countries like Ethiopia, where access to data is limited, there are good reasons for choosing a rainfall based drought measures (SPI) (Viste *et al*., 2012; Degefu and Bewket, 2015).

However, one of the main challenges, particularly in developing countries such as Ethiopia is getting a reliable record of rainfall at weather stations that are evenly distributed over the area Beyene and Meissner, 2010). Satellite-based rainfall estimates/products are becoming increasingly available for use at global and regional scales to overcome these challenges.

Many studies have made an effort to compare and evaluate satellite based rainfall products with in-situ observations across many countries in Africa. Evaluation of satellite rainfall products such as the Climate Prediction Center's morphing technique (CMORPH), Tropical Rainfall Measuring Mission (TRMM), Multi-satellite Precipitation Analysis (TMPA) near-real-time product (3B42RT), and the TMPA method post-real-time research version product(3B42) in the UBN basin in a case of Ethiopia (Dinku *et al*., 2008; Hirpa *et al*., 2010; Romilly and Gebremichael, 2011) has been conducted.

The studies that have been conducted to compare satellite rainfall products with rainguage measurements over the Ethiopia are mainly conducted at the country scale considering many basins with different physical and climatic conditions (Dinku *et al*., 2007; Hirpa *et al.*, 2010). According to, Toté *et al* (2015), results from such studies show large differences in algorithm performance depending on location, topography, local climate, and season (Maidment *et al*.,2013). Moreover, it is relevant to assess several high spatial resolution products at multi-temporal scales for a specific region in order to determine which products are promising for which specific uses.

However, particularly for Omo-Gibe basin in Ethiopia on evaluation of the performance of the satellite rainfall for meteorological drought monitoring, limited studies have been conducted. The Spatio-temporal assessment of meteorological drought on the bases of satellite rainfall using SPI has not yet been assessed in Omo-Gibe basin. This studies focus on the spatial and temporal assessment of meteorological drought in the Omo-Gibe basin using best performing satellite rainfall products, in regard to comparing with ground station rainfall. For this purpose, three satellite rainfall products (CHIRPS, PERSIANN and TMPA) were first evaluated with respect to rainguage station data to identify and recommended the best satellite-derived rainfall product for drought monitoring in the basin. In this study the long-term record of the best performing satellite rainfall product was used to study the temporal extent and pattern of meteorological drought using SPI in the Omo-Gibe basin.

The aim of this study was to analyze and assess the Spatio-temporal variation of drought in the Omo-Gibe basin, this study compared rainguage data and satellite rainfall products to evaluate the application of satellite rainfall data for drought monitoring in Omo-Gibe basin.

1.2. Statements of the problem

According (IPCC, 2014) there is an alarming rate of increase in extreme weather events as well as change in the precipitation and atmospheric circulation patterns. Shift in precipitation and temperature patterns affects the hydrological process and availability of water resources. Groundwater recharge have directly affected by changes in precipitation and evaporation. The expected impacts of climate changes for most of the land areas of the world, could be cause to reduce groundwater recharge; which more intense precipitation and longer drought periods (IPCC, 2001a). Due to their economic, climatic and geographic settings of developing countries will be more vulnerable to climate change (IPCC,2007). Due to these reseasons, the agricultural production from rainfed agriculture could be reduced in some countries that mainly depended on rain. Similar to the rest of the world, Ethiopia is not an exception to these effects of climate change which causes drought. Ethiopia susceptibility to climate change can be attributed to the regions higher frequencies of droughts and floods, lower access to technology, fewer institutions, and lack of infrastructure (Chaemiso, *et al.*, 2016).

Omo-Gibe basin, specially southern parts were severely affected by frequent droughts and erratic rainfall conditions that resulted in chronic shortage of water and pasture, mass livestock deaths, food insecurity, disease outbreaks and cross-border and inter-community conflicts due to increasing competition for water and pasture resources over the past few decades (Gebresenbet and Kefale 2012). In the recent years, there is a crisis in the power supply that reached critical point in the country. The water volume in the currently operating hydropower reservoirs was going down causing power failure. Hydro power reservoirs are not holding water in their full capacity to serve though (Mokonnen, 2007).

However rainfall is the meteorological parameter affecting societies in the most direct way. Estimating the spatial and temporal distribution of rain is hence one of the main challenges for the meteorological services in study area. Accordingly, scarcity of rainfall data for ungauged places and remote area within the basin is one of the major problem and gap for rainfall information users for drought monitoring. The distribution of station in the basin is not even central, extreme lowlands and the border areas have consist few amount of the entire stations found within the basin. The distribution of rainguage network of stations for point measurements can be made but to derive continuous aerial amounts would still remained inadequate because of an unfeasibly dense network. Also it takes months to collect data from the other stations, which are not equipped with radios and telephone service. Because, in study area only about 4.6 percent of existing stations are equipped with radios and report on real time basis (WMO, 1995).

Despite these, satellite based rainfall estimation is an adequate/primary means/ to meteorological drought monitoring. The investigation made by Degefu and Bewket (2015) in the Omo-Gibe basin used rainguage data alone, regardless of the distribution of station data in the basin is sparse. Another study under taken by Mokonnen, (2007) used TAMSAT to estimate rainfall in the basin. The study considers TAMSAT as best satellite without considering the performance of other rainfall estimation satellite in the basin, also the study does not contemplate an application of satellite-based estimation rainfall for drought monitoring.

The current study intend to fill this gap by using satellite rainfall product for drought monitoring through evaluating the performance of TMPA, CHIRPS and PERSIANN rainfall satellite products with rainguage station data in study area.

1.3. Objectives of the study

1.3.1. General objective

The general objective of the study is to evaluate satellite-based rainfall estimation and monitoring meteorological drought in Omo-Gibe basin, south west Ethiopia

1.3.2. Specific objectives

The specific objectives of the study are:

- To evaluate the performance of satellite rainfall estimations in the study area
- To assess metreological drought (spatial and temporal scales) in the study area,
- To compare the finding of this study with other remote sensing based drought indices in the study area; and
- To estimate the probability of drought events to be occurred in the next 100 years in the study area

1.4. Research questions

1. Which satellite rainfall product is relatively closer to the observed rainfall in the study area?
2. What is the spatio-temporal extent of the severity of meteorological drought during the study period in Omo Omo-Gibe basin?
3. Does meteorological drought assessment matches with Remote Sensing Indices?
4. What is the probability of drought events to be occurred in the next 100 years in study area?

1.5. Scope of the study

This study is delimited geographically to Omo-Gibe basin, and evaluated the performance of satellites for rainfall estimation and monitoring meteorological drought. Methodologically, it is limited to pairwise statistical comparison of satellite products rainfall (CHIRPS, PERSIANN and TMPA) estimation performance and SPI index, DSI, VCI based drought monitoring. In order to validate the meteorological drought spatio-temporal that assessed by SPI index the correlation between DSI and VCI of respective time were analyzed. The time horizon of the study was from Oct. 2019 to July of 2020.

1.6. Significance of the study

Rainfall is often associated with extreme weather events, such as droughts which can have tremendous socio-economic impacts on the local scale and quite frequently on the regional scale. Ethiopia is primarily based on rainfed agriculture; particularly Omo-Gibe basin and hence adequate drought monitoring depends on the appropriate satellite rainfall is required. Satellite based rainfall estimation could help to solve the problem of rainguage scarcity as long as the technology and methods of rainfall estimation is accurate and practical. Drought indices based on satellite remote sensing data are therefore capable capturing spatial details and have become the most promising tools for drought monitoring in the study area. This study is significant to understand the situation of the drought and performance of satellite for rainfall estimation in the study area. Also it helps to develop management strategies for future drought condition. The result of the study assumed to be significant for the meteorologist, policy and decision makers at different levels; agriculture and rural development officers and agents at the basin and/or other levels, environmental analysts, researchers and other concerned bodies to use as an input for further drought monitoring.

CHAPTER TWO

2. LITERATURE REVIEW

2.1. Concepts of Drought and Types

FAO (2004) defined a drought as a departure from the average or normal situations, adequately prolonged (1-2 years) as to affect the hydrological balance and adversely affect ecosystem functioning and the resident populations. Since drought disturbs so many economic and social sectors, scores of definitions have been developed by a variety of disciplines. In addition, because drought happens with erratic occurrence in almost all sections of the globe, in all types of economic systems, and in developed and developing countries alike, the attitudes taken to define it also reflect regional differences as well as dissimilarities in conceptual perspectives. Impacts also diverge spatially and temporally, subject on the societal context of drought. A worldwide definition of drought would therefore be an unrealistic expectation (Wilhite, 2007).

The impact of drought is governed by the magnitude, duration, frequency and spatial extent of the rainfall deficit (Zargar *et al*., 2011; Degefu and Bewket, 2013). Magnitude denotes to the amount of rainfall or water storage deficit at a particular place and specific time. Drought magnitude is categorized, in most commonly used indices, into mild, moderate, severe and extreme. Frequency/return period/is the average time between drought events and duration refers to the length of time that a given drought event stays. The spatial coverage refers to the areal extent of a specific area affected by a given drought incidence. Regularly severe and extreme drought episodes cover wider areas, while mild and moderate drought episodes tend to affect localized areas (Degefu and Bewket, 2013).

There are four types of drought including meteorological, hydrological, agricultural and socio-economic. However, other classifications have also includes ecological droughts (Mishra and Singh, 2010; Sheffield and Wood, 2011).

2.1.1. Meteorological drought

Meteorological drought is a type of drought event that can be considered as an early warning of drought before it affects the agricultural and hydrological water components (Vogt *et al.*, 2012). Meteorological drought typically results from the existence of continuously high atmospheric pressure over a region, representing a significant negative deviation from mean precipitation. Meteorological droughts tend to happen over relatively short time scales, usually days/weeks but possibly extending into months/seasons and the associated precipitation deficit is the propagation trigger for hydrological and agricultural drought. (Sheffield and Wood, 2011)

Meteorological drought is defined based on the degree of dryness or deviation from normal or average amount of rainfall for a prolonged period (Wilhite, 2007).Meteorological drought happens when there is a deficit in the actual volume of precipitation received and the amount that may normally be expected for an extended duration (precipitation received is far below the expected normal). It is dependent in its determination on rainfall falling below threshold levels that are determined from long-term rainfall records. Smakhtin and Hughes (2004) simply consider that meteorological drought is brought about when there is a prolonged period with less than average or expected precipitation. It usually precedes the other kinds of drought.

Definitions of meteorological drought must be considered as region specific since the atmospheric conditions that result in deficiencies of precipitation are extremely flexible from region to region. For example, some definitions differentiate meteorological drought on the basis of the number of days with precipitation less than some specified threshold (Sheffield and Wood, 2011). Extended periods without rainfall are common for many regions; such a definition is unrealistic in these instances. Other definitions may include actual precipitation departures to average amounts on monthly, seasonal, year, or annual time-scales. Definitions derived for application to one region usually are not transferable to another since meteorological characteristics differ. Human perceptions of these conditions are so variable. Both of these facts must be taken into account in order to identify the characteristics of drought and make comparisons between regions (Zargar *et al*., 2011). This study considered Omo-Gibe basin as one region and assessed meteorological drought rather than any other type of drought because it is the initial type of drought. Hence its assessment is crucial for better examine the other types of drought.

2.1.2. Hydrological drought

Hydrological drought is a period during which stream flows are inadequate to supply established uses under a given water management system (Mishra and Singh, 2010). This occurs when the amount of precipitation in a region is insufficient to maintain normally expected flows in stream/river systems or normally expected levels or volumes in lakes/reservoirs systems like the lowering of Lake Levels and inadequate filling of reservoirs and tanks. Definition of hydrological drought revolves around the effects of dry spells on surface or subsurface waters (Fleig *et al.,* 2006).

If the actual flow for a selected period of time falls below a certain threshold, then hydrological drought is considered will be in progress. Such a threshold level can be defined based on the flow characteristics or the water demand scenario of the place and/or basin under consideration. It is brought about when the water available in sources such as aquifers, lakes and reservoirs fall below the average. It is the deficit of runoff into rivers and other surface water resources and in groundwater resources. It involves the description of availability of water, in the form of precipitation runoff, evaporation, infiltration, river systems, and other surface/groundwater inflow/outflow systems, which may be included in the hydrological water balance equation. Thus hydrological droughts are related more with the effects of periods of precipitation shortfall on surface or subsurface water supply (i.e. stream flow, reservoir and lake levels) rather than precipitation shortfalls.

2.1.3. Agricultural/ Soil moisture drought

Agricultural drought is typically defined as a period when soil moisture is inadequate to meet evapo-transpirative demands so as to initiate and sustain crop growth (Van *et al.,* 2011). This is related to physiological drought, which is determined from conditions of natural vegetation, crops, livestock, pastures and other agricultural systems. It is a measure of the availability of soil water to plants or animals. It is usually measured by the effects of water deficit in terms of economic losses to agriculturalists. The economic loss terms can include factors like drop in crop production, livestock deaths, industrial losses; plants not planted or replanted changes in land use, emergency relief expenses, as well as losses incurred after the agricultural drought (e.g. losses through wind and water erosion) (Corti *et al.,* 2009).

2.1.4. Socio economic drought

This kind of drought associates the supply and demand of some economic good or service with elements of meteorological, hydrological, and agricultural drought. Some scientists suggest that the time and space processes of supply and demand are the two basic processes that should be included in an objective definition of drought. For example, the supply of some economic goods (e.g. use of water, hay, and electric power in a region) is weather dependent (Laaha *et al.,* 2013). In most instances, the demand for such goods increases as a result of increasing population and/or per capita consumption. Therefore, drought could be defined as occurring when the demand for an economic good exceeds supply as a result of a weather-related shortfall in water supply (Smakhtin and Hughes, 2004).

2.2. Drought in Ethiopia

Drought is a frequently recurring phenomenon often accompanied by very serious and diversified impacts on human lives and environment inn Ethiopia (Tagel *et al.,* 2011). A million people lose their lives, destroyed crops and livestock, and forced millions of people into displacement and destitution due to drought in the year of 1984/85 (Tagel *et al.,* 2011). Additional specific figures from recent drought episodes in Ethiopia illustrate the magnitude of drought associated impacts. For instance, the worst famine since the mid-1980s, which affected 13.5 million people were caused by drought of 2003 (Wagaw *et al*., 2005) and triggered large devastation in terms of lives and economical losses. About 20 million people were estimated suffering from food insecurity in East Africa in 2009 (Sheffield and Wood, 2012). The year 2009 is likewise recorded as one of the severe drought years in Ethiopia; 6 million people were affected and needed food aid from the international emergency services (Sheffield and Wood, 2012). Another severe drought that covered major parts of the country occurred recently, in 2015. The estimate showed that more than 4.5 million people needed food aid and emergency services (http://www.the guardian.com/global-development /2015/aug/25 /unethiopia-need-food-aidafter-poor-rains). The historic drought events in Ethiopia were highly related with the incidence of El Niño weather phenomenon and the 2015 drought was a recent example. The probability of the increase of drought frequency and severity in Ethiopia as a result of the changing environment and population growth reinforces the essential for the development of drought monitoring and forecasting (Edossa *et al.*, 2010, Araya *et al.*, 2010, Tagel *et al.*, 2011).

Table 1: Major drought years in Ethiopia as of 1950.

Year	Region affected	Effect
1957–1958	Tigray	100,000 people died
1964–1966	Tigray and Wallo	About 1.5million people were affected and about 300,000 livestock died
1972–1973	Tigray and Wallo	Death of about 200,000 people and 30% of livestock population in the area
1978–1979	Southern Ethiopia	1.4 million people were affected
1983–1984	All regions	8 million people were affected, 1 million people died
1982	Northern Ethiopia	2 million people were affected
1987–1988	All regions	7 million people were affected
1991–1992 affected	North, east and south Ethiopia affected	4 million people were affected
1993–1994 affected	Tigray and Wallo million people were affected	7.6 million people were affected
2000	All regions	About 10.5 million people were affected
2002–2003	All regions	About 13 million people were affected
2006	Southern-Ethiopia (Borena)	About 247,000 livestock died
2008	Southern-Ethiopia (Borena)	About 26,000 livestock died
2008–2009	All regions	About 5 million people were affected
2015-2016	Major parts of the country	4.5 million people affected

Sources: (Bayissa, *et al.*, 2017; Suryabhagavan, (2017); Bayissa, 2018).

2.2.1. Drought in Omo-Gibe basin

According to empirical evidence (Gebresenbet and Kefale, 2012) that the southern part of the basin was severely affected by frequent droughts and erratic rainfall conditions that resulted in chronic shortages of water and pasture, mass livestock deaths, food insecurity, disease outbreaks and cross-border and inter-community conflicts due to increasing competition for water and pasture resources over the past few decades.

2.3. Drought Monitoring (DM)

Drought monitoring includes the wide application of drought indices that measure the deficit of hydrologic cycle components, as compared to the long-term mean (Bayissa *et al.*, 2017). The deficit in meteorological parameters (mainly rainfall) can be considered as a precursor for the deficit of other hydrological water cycle components (river flow, ground water flow, reservoir storage, etc.), known as hydrological drought. NOAA, USDA and national drought mitigation derived a weekly drought monitor (DM) product that incorporates climatic data and professional input from all levels (Svoboda, 2000). The key parameters are objectively scaled to five DM drought categories. The categories D0 (abnormally dry area) to D4 (exceptional drought event, likened to a drought of record) and labels indicating the sectors being impacted by droughts (A for agricultural impacts, F to indicate the high risk of wildfires and W for hydrological impacts,). McKee *et al.*, (1993) developed the Standardized Precipitation Index (SPI) to quantify the precipitation deficit for multiple time scales, reflecting the impact of precipitation deficiency on the availability of various water supplies. Singh (2006) reported that a drought prone area was one in which the probability of a drought year was greater than 20 percent. A long-lasting drought prone area was one in which the probability of a drought year was greater than 40 per cent. A drought year occurred when less than 75 percent of the “Normal” rainfall was received.

2.4. Station based rainfall estimation

Traditionally, precipitation data are collected through ground-based observations using rain gauges and/or weather radars. Catchment-representative rainfall is typically acquired by interpolation of point precipitation measured at rain gauges (e.g. Rogelis and Werner, 2013). However, even in densely monitored areas, precipitation data are highly uncertain (Woldemeskel *et al*., 2013). In developing countries and regions which are difficult to access–such as high elevation areas there is usually only a sparse network of meteorological stations available, and therefore the obtained spatial rainfall fields are subject to even larger uncertainties (Woldemeskel *et al*., 2013). Station-based drought indices can effective way to estimate drought conditions around meteorological station. Lack of continuous spatial coverage of station is great problem to characterizing and monitoring complete spatial pattern of drought in area which with sparse meteorological stations and high degree of spatial variability.

2.5. Satellite-based Rainfall Estimation (SRFE)

Satellite-rainfall estimation (RFE) has been used by the FEWS NET since 1995 with the development of the RFE algorithm (Xie and Arkin, 1997). Even though the absolute precision of satellite rainfall varies by geographic location and algorithm/sensor used (Huffman *et al*., 1997), the combination of synoptic coverage of large areas and consistency in estimates (Xie and Arkin, 1997) has allowed the effective application of RFE for various agro hydrologic applications including drought monitoring (Verdin and Klaver, 2002; Senay and Verdin, 2003; Senay *et al*., 2012). Satellite estimates of precipitation have received different names and acronyms in the literature: satellite precipitation estimates (SPEs) (Scofield and Kuligowski, 2007), satellite based rainfall estimates (SRFEs) (Thiemig *et al.*, 2012), satellite quantitative precipitation estimates (SQPEs) (Lee *et al*., 2015), satellite rainfall estimates (SREs) (Abera *et al*., 2016), and satellite precipitation products (SPPs) (Maggioni *et al*., 2016). The emergence of the aforementioned near-global and high-resolution SREs opens up new opportunities for applications in data-scarce or ungauged districts.

To overcome some of the limitations of ground-based rainfall measurements, space-based estimates of precipitation provide a promising alternative source. A number of near-global high-resolution satellite-based rainfall estimates (SREs) have recently become effective, including the Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks (PERSIANN) (Sorooshian *et al*., 2000), the PERSIANN Cloud Classification System estimation (PERSIANN-CCS) (Hong *et al*., 2004), the National Oceanic and Atmospheric Administration (NOAA) Climate Prediction Center morphing technique product (CMORPH) (Joyce *et al*., 2004; Janowiak *et al*., 2005), and the Tropical Rainfall Measuring Mission (TRMM) Multi-satellite Precipitation Analysis products (TMPA) (Huffman *et al*., 2007), among others. The main advantage of the remote sensing based rainfall products is that they are reasonably good in terms of spatial and temporal coverage and have proved their applicability to climate and hydrological studies (Hirpa, *et al.*, 2010; Tadesse, *et al.*, 2015).

However, their accuracy evaluated and compared with ground truth rainfall measurement before using it for further application in drought and other natural hazards studies (Romilly and Gebremichael, 2011; Bitew *et al*., 2012). SRE products need evaluation and often calibration before use for any applications. Recently, Maggioni *et al*., (2016) published a review on SRE accuracy during the TRMM-Era, evaluating TMPA 3B42 (research and real-time products), CMORPH, GSMAP, PERSIANN, and PERSIANN-CCS. They found that topography, seasonality, and climate impacted on the SRE's performance, especially in probability of detection and bias. Tian and Peters-Lidard (2010) studied uncertainties in SRE, by computing the variance from an ensemble of six different TRMM datasets. They found that SREs are more reliable over areas with strong convective precipitation and flat surfaces, such as the tropical oceans and South America. Dinku *et al*

(2010) evaluated CMORPH and two TMPA products (3B42and3B42RT) for mountainous regions of Africa and South America. Both products underestimated the occurrence and amount of rainfall which they attributed to the complex terrain and orographic rain process. Scheel *et al* (2011) compared TMPA 3B42v6 estimates with rain gauges in the regions of Cuzco (Peru) and LaPaz (Bolivia). They detected large biases in the estimation of daily precipitation amounts. The occurrence of strong precipitation events was well represented but their intensities were underestimated.

In addition, TMPA estimates for La Paz showed high false alarm ratios. Mantas *et al*., (2015) validated the research 3B42v7 and the near real-time 3B42RT for the Peruvian and of similar complex topography against in-situ data. Results also showed a strong regional variability due to different climatic and topographic features. Thiemig *et al.*, (2012) compared six SREs against rain gauge data over four African river basins. They found that SREs showed higher performance over the tropical wet and dry zone compared to semiarid mountainous regions, low accuracy in detecting heavy rainfall events over semiarid areas, general underestimation of heavy rainfall events, and overestimation of the number of rainy days in the tropics. Demaria *et al.,* (2011) used an object-based verification method to explore the existence of systematic errors for three SREs in South America (La Plata River basin): TRMM, CMORPH, and PERSIANN. They found that PERSIANN underestimated the observed average rainfall rate and maximum rainfall, CMORPH overestimated the average rainfall rate while the maximum rainfall was slightly underestimated, and the average rainfall rate and volume provided by TRMM correlated well with ground observations, whereas the maximum rainfall was systematically overestimated. In general, there does not seem to exist a single SRE product that performs best always and everywhere.

Table 2**:** Summary of studies on satellite based rainfall estimation and application to drought monitor.

Study area	Remote sensing products	Results	Reference
Western Highlands, Ethiopia	CMORPH, TMPA 3B42RT, TMPA 3B42	Occurrence of rain under estimated by all products Total amount under estimated by TMPA 3B42 (14%); over estimated by TMPA 3B42RT (13%) and CMORPH (11%)	Dinku *et al.*, 2010
Highlands, Columbia	CMORPH, TMPA 3B42RT, TMPA 3B42	Occurrence of rain under estimated by all products Total amount under estimated by all products; TMPA 3B42RT (17%), TMPA 3B42 (16%) and CMORPH (9%)	Dinku *et al.*, 2010
Great-Rift Valley, Ethiopia	CMORPH, PERSIANN, TMPA 3B42RT	TMPA 3B42RT and CMORPH show elevation-dependent trends, with under estimation at higher elevations PERSIANN significantly under estimates at higher elevations. Does not exhibit elevation-dependent trends	Hirpa *et al*., 2010
Berressa Watershed, Ethiopia	CMORPH PERSIANN-CCS	Both underestimate heavy rainfall by 50% Both under estimate total rainfall; CMORPH (32%), PERSIANN-CCS (49%)	Bitew and Gebremichael, (2009)
Mainland China	TMPA 3B42 V.6 ,CMORPH	Over estimate rainfall less than 1mmday^{-1} Under estimate rainfall greater than 1mmday^{-1}.	Yu *et al*., 2009
Northwest Mexico	PERSIANN-CCS	Over estimates precipitation at low elevations, under estimates light precipitation at higher elevations; exhibits elevation-dependant bias	Hong *et al*., 2007
Northwest Mexico	CMORPH ,PERSIANN, TRMM 3B42	CMORPH and PERSIANN overestimate the precipitation rate and frequency. TRMM 3B42 closely agrees with the rain gauge network.	Nesbitt *et al*., 2008
UBN,Ethiopia	CHIRPS v2.0, TARCAT, PERSSIAN, TRMM, ARC 2.0	CHIRPS showed a greater correlation with weather stations at a monthly time scale. An excellent score of Bias (close to one) and mean error was observed in CHIRPS at dekadal, monthly and seasonal time scales in a majority of the stations. TARCAT performed well next to CHIRPS whereas PERSSIAN presented a weak performance under all the criteria. Thus, the CHIRPS rainfall product was selected and used to assess the spatial and temporal variability of meteorological drought in a study.	Bayissa *et al*., 2017
UBN,Ethiopia	CHIRPS	SPI, Z-score, EDI, and VCI, identified the historic drought events well. The three indices indicated different drought frequency, severity and duration for the historic events.	Bayissa, 2018

2.6. Application of statistical indicators in satellite-based rainfall evaluation

The satellite rainfall validation performed applying the descriptive statistical measures (Li *et al*., 2013; Hu *et al*., 2014): mean error (ME), root mean square error (RMSE). The performances of the four daily satellite rainfall products, i.e., CMORPH, TRMM, and PERSIANN, were evaluated using daily rainfall records of 34 rain gauges dispersed over the island. The root mean square error (RMSE) also measures the average error magnitude, but gives greater weight to larger errors. The range of RMSE is zero to infinity and the perfect score is zero (Vila and Lima 2009).

Continuous verification statistics measure the accuracy of a continuous variable such as rain amount or intensity. These are the most frequently used statistics in validating satellite-based estimates; many people are familiar with them and find them easy to estimate. The mean error (bias) measures the average difference between the estimated and observed values averaged over the data set. The range of mean error is minus infinity to infinity and the perfect score is zero. The correlation coefficient (r) is measures the strength and the direction of a linear relationship between satellite RFE and observed gauge data. Statistical Analysis metrics were used to assess the quality of TMPA products: Mean Absolute Error (MAE), refined index of agreement, (systematic and unsystematic components of the Mean Squared Error. Because we assume that GBGR is not error free, MAE is used here to compute the average magnitude of deviations between TMPA estimates and GBGR rather than as an error measurement statistic. According to Willmott and Johnson (2005), when evaluating model performance it is usually preferable to compute measures based on absolute values, such as MAE, rather than those based on squared differences, such as RMSE. However, RMSE(orMSE) can provide information on the type of error (random or systematic). By computing these metrics, it is possible to assess the extent to which the TMPA data deviate from GBGR (MAE), quantify the degree of agreement between such datasets and assess the type of "error" present in TMPA rainfall estimates.

2.7. Drought indices

Different indices used to characterized droughts over a region, which all use rainfall either alone or in combination with other meteorological elements (Edossa *et al*., 2010; Zargar *et al*., 2011). in recent decades several drought indices have been derived. Commonly, a drought index is a major variable for assessing the effect of a drought and defining different drought parameters. Drought parameters include intensity, duration, severity and spatial extent. Year, followed by a month is the most commonly used time scale for drought analysis. Although the yearly time scale is long, it can also be used to abstract information on the regional behavior of droughts. The monthly time scale seems more suitable for monitoring the effects of a drought in conditions related to agriculture, water supply and ground water abstractions (Panu and Sharma, 2002). A time series of drought indices provides a framework for evaluating drought parameters of interest.

Generally drought indices categorized as Rainfall and temperature based, and Remote Sensing based drought indices.

2.7.1. Rainfall and temperature based drought indices

I. Standard Precipitation Index (SPI)

SPI was projected by McKee *et al*., (1993) and it is a probability index that uses monthly rainfall data as input. The SPI also gives better spatial standardization than other drought indices such as the Palmer drought severity index (PDSI) in analyzing extreme drought events (Sönmez *et al*., 2005). Based on the long-term precipitation record for a desired period the standardized precipitation index (SPI) for any location is calculated. SPI has been used for studying different characteristics of droughts, for example, approximating (Mishra and Desai, 2005a; Mishra *et al*., 2010), frequency analysis (Mishra *et al*.,2009), spatio temporal analysis (Mishra and Desai, 2005b; Mishra and Singh, 2009).

II. Palmer drought severity index (PDSI)

Using precipitation and temperature for estimating moisture supply and demand within a two-layer soil model, Palmer (1965) formulated what is now referred to as the Palmer drought index (PDI). The palmer Index varies between -6.0 and +6.0. PDSI is possibly the most broadly used regional drought index for monitoring droughts. The index has been used to show the areal extent and severity of various drought episodes (and to investigate the spatial and temporal drought characteristics as well as to explore the periodic behavior of droughts monitoring hydrologic trends, crop forecasts, and assessing potential fire severity), droughts over large geographic areas and drought forecasting (Özger *et al*., 2009).

III. Rainfall Anomalies

Rainfall Anomalies is to indicate the meteorological drought for the growing seasons of regions. The negative rainfall anomalies signified that precipitation was less than the average seasonal rainfall for a particular place (Shaheen and Biag, 2011).

IV. Z-score index

The Z-index is reflects the departure of moisture conditions in a particular month from normal and measure of the monthly moisture anomaly moisture conditions (Heim, 2002). Occasionally, the Z-Score is confused with the SPI by the user (Hayes, 2000). The Z-Score does not require adjusting the data by fitting the data to the Gamma or Pearson Type III distributions. Because of this, it is speculated that Z-Score might not represent the shorter time scales (Edwards and Mckee, 1997).

2.7.2. Remote sensing based drought indices

I. Normalized Difference Vegetation Index (NDVI).

NDVI was first suggested by Tucker (1979) as an index of vegetation health and density. NDVI reflects vegetation vigor, percent green cover, Leaf Area Index (LAI) and biomass. It varies in a range of -1 to + 1 (Thenkabail *et al*., 2004). Previous studies have shown that NDVI lags behind precursor precipitation by up to 3 months. The lag time is dependent on whether the region is purely rainfed, fully irrigated, or partially irrigated. The greater the dependence on rainfall is the shorter the lag time. NDVI itself does not reflect drought or non-drought conditions. (Wang *et al*., 2016).

II. Drought Severity Index

The severity of a drought (or the degree of wetness, on the other end of the range) may be defined as NDVI deviation from its long-term mean (DEVNDVI). The Drought Severity Index (DSI) is one of the most checked for detecting drought conditions in a quick and reliable manner. The DSI algorithm uses satellite derived evapotranspiration (EP), potential evapotranspiration (PET) and NDVI products to detect and monitor droughts on a global basis (Mu *et al*., 2013). DSI is a dimensionless index ranging theoretically from unlimited negative values (drier than normal) to unlimited positive values (wetter than normal). Different studies conducted based on the DSI. For example, Berhanu *et al*., (2014) in drought risk assessment using remote sensing and GIS in Tigray region, Ethiopia. Other studies also used this indices derived from the NDVI in different parts of countries (Melese *et al., 2018*) in multi-model vegetation indices for drought velnerability assessment in a of Afar regional state.

III. Vegetation Condition Index (VCI): VCI was first recommended by Kogan (1997). It shows how close the NDVI of the current month is to the minimum NDVI calculated from the long-term record. Vegetation condition index (VCI) is retrieved from the Normalized Difference Vegetation Index (NDVI), and provides a normalized relative index in which the current observed value of NDVI is compared against the extreme limits (minimum and maximum values) observed during a reference period. VCI offers a good surrogate of the vegetation stress due to wetness situations; the TCI is more closely related to the thermal stress of vegetation (Bokusheva *et al*., 2016).

The condition/health of the ground vegetation presented by VCI is measured in percent. The VCI values around 50% reflect fair vegetation conditions. The VCI values between 50 and 100% indicate optimal or above normal conditions. At the VCI value of 100%, the NDVI value for this month (or week) is equivalent to NDVImax. Different degrees of a drought severity are indicated by VCI values below 50%. Kogan (1997) illustrated that the VCI threshold of 35% may be used to identify extreme drought conditions and suggested that further research is necessary to categorize the VCI by its severity in the range between 0 and 35%. The

VCI value close to zero percent reflects an extremely dry month, when the NDVI value is close to its long term minimum. Low VCI values over several consecutive time intervals point to drought development.

IV. Temperature Condition Index (TCI): TCI was also suggested by Kogan (1997) and its algorithm is calculated similar to VCI but its formulation was modified to reflect vegetation's response to temperature (the higher the temperature the more extreme the drought). TCI is based on brightness temperature and represents the deviation of the current month's (week's) value from the recorded maximum. TCI is computed, from the Normalized Difference Vegetation Index (NDVI), but using instead Land Surface Temperature (LST) as input (Bokusheva *et al*., 2016).

V. Vegetation Health Index (VHI): The VHI, computed as the average of both indices, provides a combined (VCI and TCI) effect of both stressors and thus represents a good overall indicator of the health status of vegetation (WMO and GWP, 2016; Bokusheva *et al*., 2016).

VCI, TCI and VHI values range between 0 (highest level of drought severity) and 100 (lowest level of severity). These indices are widely employed in drought impact assessments on agriculture (Bokusheva *et al*., 2016).

2.8. Application of drought indices for drought monitoring

2.8.1. Application of Standard Precipitation Index in Drought Monitoring

SPI has been confirmed to perform well in comparing drought crossways different areas (Guttman, 1998). In many watersheds the SPI has been widely applied and tested. Edossa *et al.,* (2010) reported the temporal and spatial analysis of meteorological and hydrological droughts for the Awash basin of Ethiopia, applying SPI for the assessment of meteorological drought using monthly rainfall data from 1963 to 2003. The study showed the potential benefits of SPI for drought assessment and examined the lag time between the hydrological and meteorological droughts. Tagel *et al.,* (2011) evaluated the spatial and temporal variability of drought using SPI and the vegetation condition index (VCI). Cancelliere *et al.,* (2007) used stochastic techniques for seasonal forecasting of SPI and showed the importance of SPI for drought assessment and forecasting. Generally, many studies have been conducted using SPI in different parts of the world for drought assessment and forecasting (e.g. Cancelliere *et al*., 2007, Wu *et al.*, 2007 and Li *et al*., 2008).

CHAPTER THREE

3. METHODS AND MATERIALS

3.1. Description of the study area

3.1.1. Geographic location

Omo-Gibe basin is the third largest river basin in Ethiopia interms of volume of water discharge and drains the southwestern highlands and ends at Lake Turkana at the Ethiopia-Kenya boarder (MoWR 1996). The basin has an area almost about sqkm.79,000, covering parts of two National Regional States, Oromia and the Southern Nations and Nationality Peoples Region (SNNPR). It is river basin that flows in to the Lake Turkana in Kenya which forms its southern boundary. The Western watershed is the range of hills and mountains that separate the Omo-Gibe basin from the Baro-Akobo Basin. To the Northwest and North of the basin is bounded by the Blue Nile Basin with small area in the northeast bordering the Awash Basin. The whole of the eastern parts of the basin bordered by rift valley basin. It lies between $4^{0}41'0''$ to $9^{0}17'0''$N Lat and $34^{0}20'0''$ to $39^{0}0'0''$E Long (Figure:1). The Basin has Annual flow 16.60 (billion m^3) and Irrigation potential of 383,000 (ha).

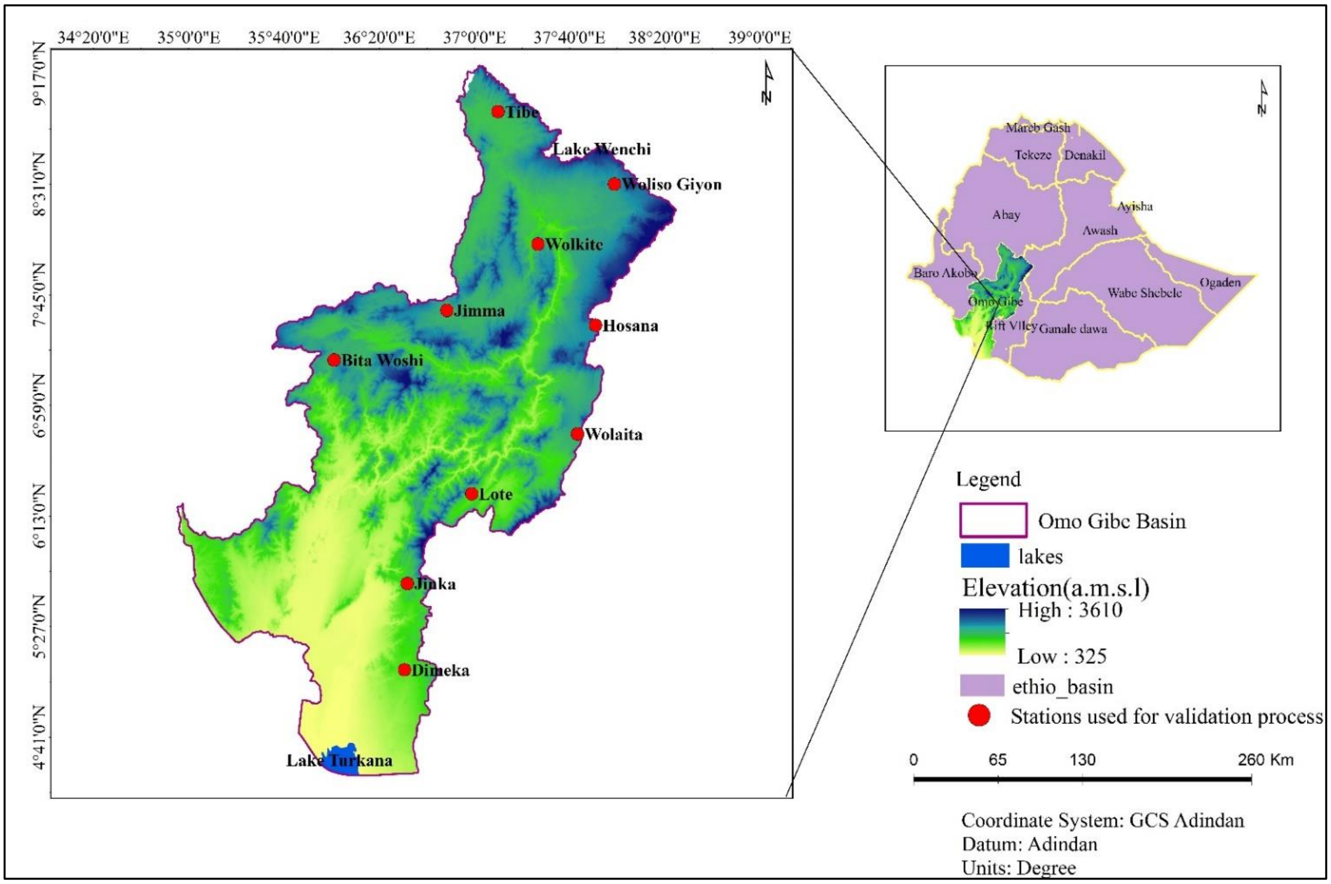


Figure 1: Location Map of Omo-Gibe basin

(Source: computed from ASTER DEM 30m resolution, 2020)

3.1.2. Climate

The climate of Omo-Gibe basin ranges from semi–arid in the lowest Omo-valley to humid in the north and northeasterly highlands on bases of elevation above mean sea level of the areas (MoWR, 1996). Climatic variations are a function largely of land surface altitude.

Rainfall

Rainfall is the major element that shows the spatio-temporal variability in Omo-Gibe basin. Rainfall within in the basin has strong seasonal and elevation variability (Mokonnen, 2007). The primary wet season extends from April to October, July and September is the wettest months particularly in the upper north part of the basin. The water volume of the basin is produce from rainfall governed by the seasonal migration of ITCZ (Inter-Tropical Convergence Zone) and the associated atmospheric circulation (Mokonnen, 2007). Over the highland area the mean annual rainfall between successive contour lines is 1719 mm and over the lowland regions it reaches as low as 433 mm. The amount and distribution of the rainfall decrease from north and east to the south of the Omo river valley floor.

The annual mean rainfall for some selected areas located in the north and western highlands in the basin are high near Baco, Abelti, Maji, Algae, Shishinda, Whish Wish, Tibe, Assendabo, Dedo and Dimtu. In the North eastern highlands the rainfall is below the long year average but some places like Areka, sawla, Jinka and bulki have more than annual rainfall. The central lowlands Chida, Hamer, Sila, Mago and the southern extreme lowland areas Bume, Ginimonere and Fejel have get less annual rainfall. Annual rainfall varies from 433 mm in the extreme south low land to 1719mm in the high land with the average being 1076 mm. Isohyetal maps and rainfall patterns for the basin were prepared based on annual mean rainfall data processed from CHIRPS rainfall satellite for the period of 2013-2018 (Figure 2).

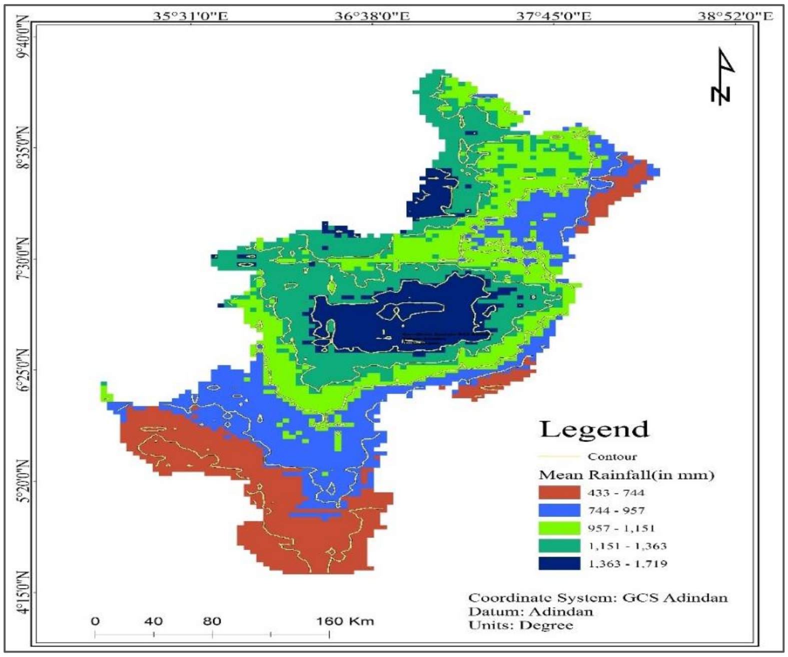


Figure 2: Annual Isohyetal map of Omo-Gibe basin

(Source: computed from, CHIRPS-2.0 data ~5Km resolution, 2020)

Temperature

The mean annual temperature of the basin varies from less than 17.5^{0}C in the highland to the west, to over 29^{0}C to the south with respect of the altitudinal variations. The average monthly minimum temperature during dry (Winter) season ranges from 10^{0}C at the north and northeastern highlands to 14.2^{0}C at the central and southern lowlands. The average monthly maximum temperature during the rainy (Summer) months ranges from about 22^{0}C in the highland and more than 30^{0}C near and at the valley of Omo-river. For most of the year, maximum temperature is occurring around April and a minimum in July and August (MoWR, 1996).

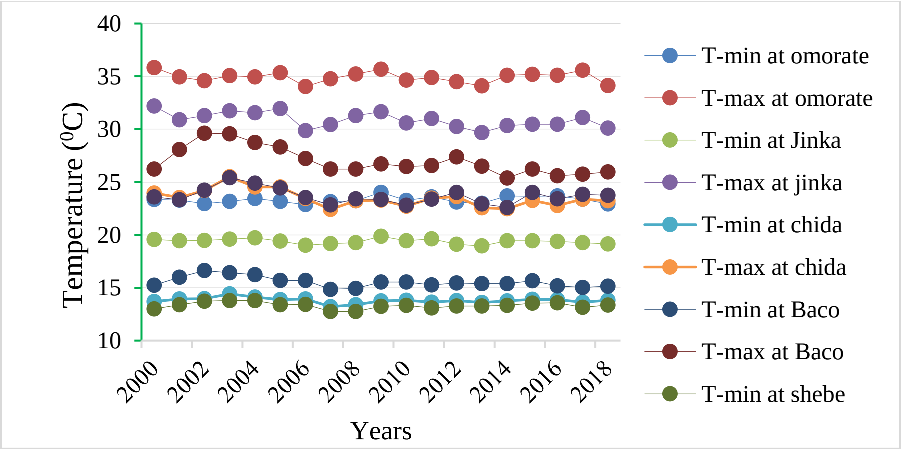
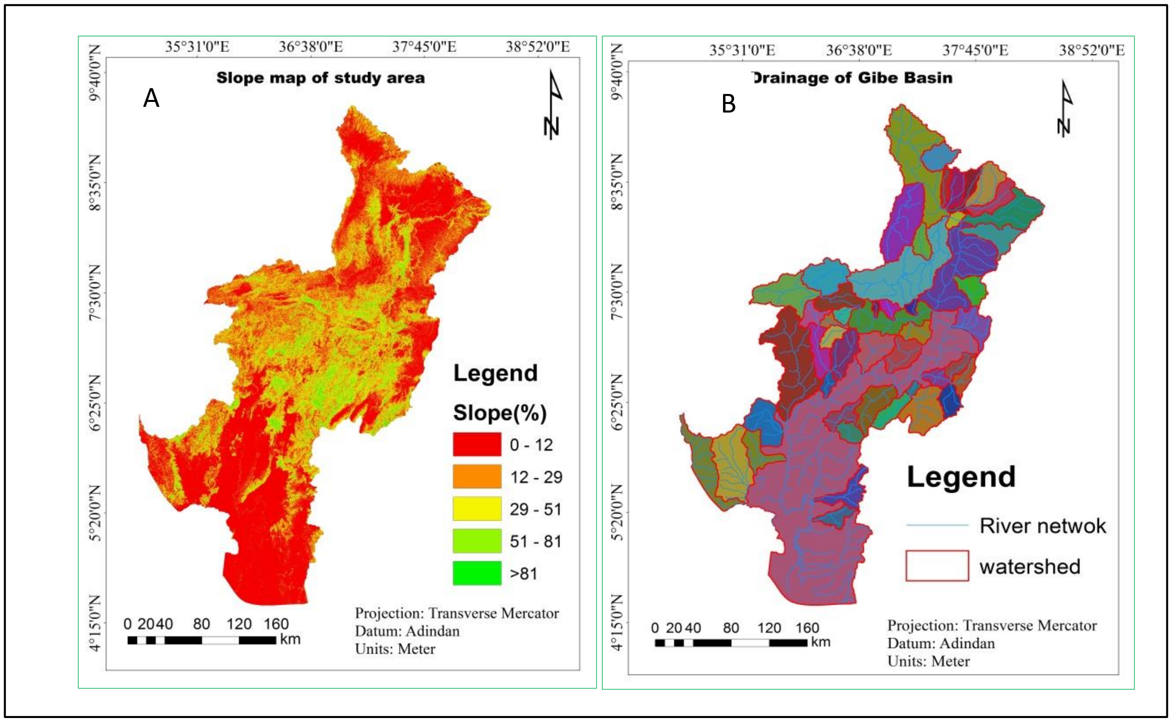


Figure 3: Maximum and minimum temperature of Omo-Gibe basin recorded for five seleted stations (NMA, 2020)

3.1.3. Physiography and Drainage

The elevation of the study area is lying between 325 to 3610m above the mean sea level (m.a.s.l). Steep slopes with dissected hills characterize the highlands while the low lands are characterized by relatively gentle and undulating slopes. (Chemiso *et al*., 2016).

The total mean annual flow from the river basin is estimated at about 16.6 Billion Cubic Meter (BMC). Gibe River is known as the Omo River in its lower touches, south westwards from the confluence with the Gojeb River. The main tributaries of Omo-Gibe River Basin are from Northeast Walga, Wabe, Wariness and Derghe and Southwest Tunjo (called Gilgel Gibe as station) and Gilgel Gibe Rivers and the West Gojeb River. From the eastern side of the middle and lower Omo-Gibe catchment the Sana, Soke, Wabe, Deme and Zage rivers are the main tributaries. It is an bounded river basin that flows into the Lake Turkana in Kenya, which forms its southern boundary (Chemiso *et al*., 2016).

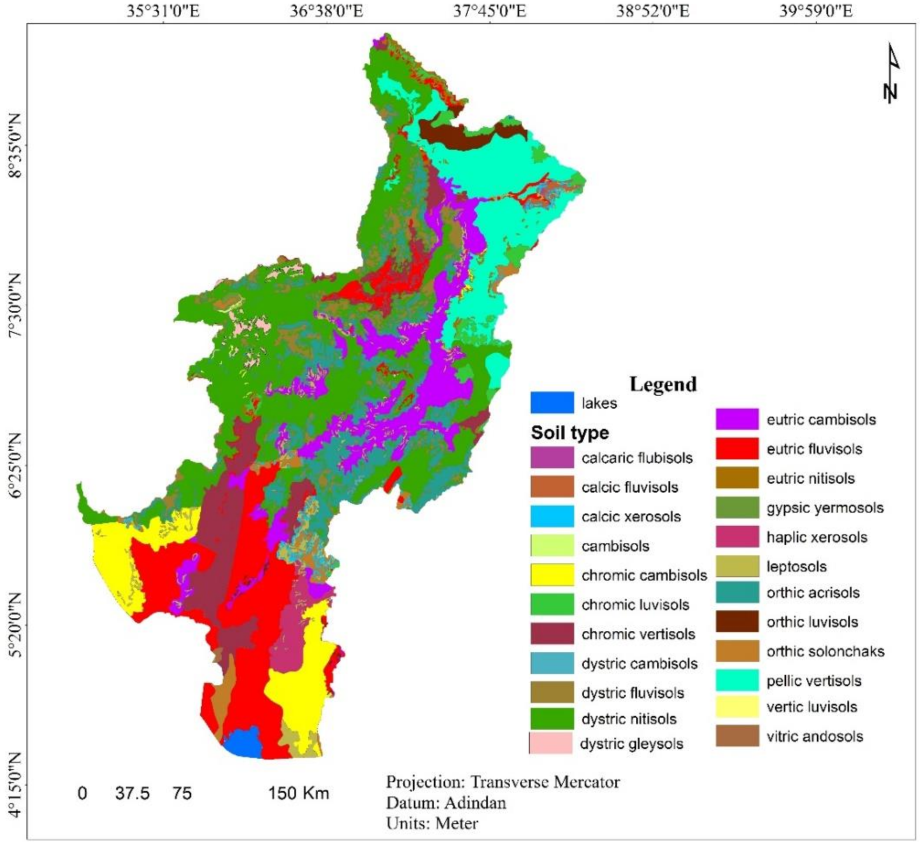


Source: Computed from ASTER DEM 30m resolution, 2020

Figure 4: A: Slope Map of study area and B: Drainage of study area

Soil

Majority of the basin is covered with ignous rock type. Of the total soil types, pellic vertisols, dystric netosols and orthic luvisols dominate North and Northeastern of the basin; whereas centeral parts are covered with dystric nitisols and eutric cambisols. Chromic cambisols, eutric fluvisols and orthic luvisols dominately covers the Southern parts of the basin(Figure 5). Other alluvial soils can have moderate to high fertility. However in the low lands, cultivation is generally excluded by climate (MoWR, 1996).



Source: computed from Ministry of Water and Energy, 2020

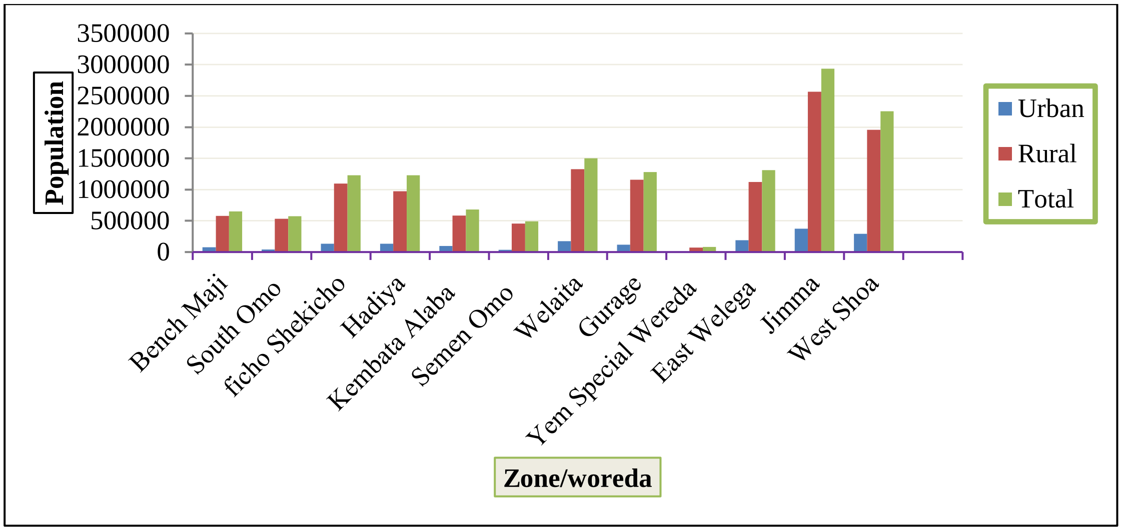
Figure 5: soil type map of study area

3.1.4. Socio-economic characteristics

The administrative structure of the basin is divided by regional states, zonal and Woreda level. Most of zones of SNNP's are found within the basin with poor range of service and infrastructure development. The social service (health, school, market, tourism, energy, etc.) are a product of under development of infrastructures (transport service) and lack of local administrative centers. In general, all the agricultural production of the basin is dependent on rain, occupying over 3.1 million hectare of land from the total 38.9 percent of cultivable land (Mokonnen, 2007).

The basin also contains major resource for irrigation (100km^2), livestock (all types 16.7 million), fishing (69 fish species of which 21 considered commercially important), and Truism in the Omo and Mago National parks is the dominant activity in the lower Omo sub basin. The local heritages also have historic attractions as well as importance for the study of earlier hominids. Except the lower Omo where the dominant mode of agriculture is pastoralist, mixing farming in the highlands and dominantly livestock production in the lowlands is common feature in the basin. General trend of the settlement is very dense in the high lands and sparse in lowland (Mokonnen, 2007).

The population of the basin was 6.4 million in 1994 and about 50.3% of it was female and about 5% and 2.9% of the total population live in the lowlands and in urban areas respectively (MWIE, 2014). According to the report of Central Statistical Agency (2002), the population of the basin was estimated over 7 million. This population is not uniformly distributed. The lower basin represents approximately 51 percent of the basin area but only 5 percent of population exist. The vast majority of people live in the highlands where North Omo and Jimma zone are the most populated, with 26.7 percent and 23 percent of the population, respectively. The least population zones in the basin are southern Omo and Maji with 4.1 percent and 1.3 percent, respectively. In 2007 the population of the basin is more than 14 million (CSA, 2007). The basins labor force of the economically active population is about 2.8 million, representing 43.6% of the total population (MWIE, 2014).



Source: CSA, 2007

Figure 6: Population of Omo-Gibe basin

3.1.5. Land use

In a very broad term, most of the northern catchments of the Omo-Gibe basin are under extensive cultivation with increased land pressure, meaning the expansion of cultivated areas into increasingly marginal lands at the expense of wood lands. Deforested areas are now confined to areas too steep and inaccessible to farm. The flatter poorer drained bottom lands of the northern catchments are usually not cultivated but are used for dry season grazing and eucalyptus tree plantations (Mokonnen, 2007). The main gorges of the basin are relatively unpopulated and support a cover of open wood land and bush land with grasses, the eastern part of the basin has some of the most densely populated and intensively farmed areas in the basin. The south of the basin is more sparsely populated with a greater population of natural vegetation, through even here the forest is reduced at an alarmingly rate (Richard, 1996). Most of the reminder central lowlands and the Omo valley are occupied by a mix of grassland, bush lands and shrub lands. The majority of the highland area is covered by forest (Mokonnen, 2007).

3.2. Research Design

The study employed quantitative research methods. The reason for using quantitative method is to evaluate satellite-based rainfall evaluation and present the fidings statistically.

3.3. Data Collection

3.3.1. Satellite data

For this study three satellite-derived rainfall products were used to evaluate their performance in satellite based rainfall estimation.Terra expedited Moderate Resolution Imaging Spectoradiometer (eMODIS) was used for eMODIS-NDVI generating eMODIS-NDVI which was used for deriving DSI and VCI in study area. The selection of those products was based on the availability of long time series of data in near-real time, relatively high spatial and temporal resolutions and free access of the data.

CHIRPS: CHIRPS was created in association with scientists at the USGS, EROS center in order to provide complete, reliable, up-to-date data sets for a number of early warning objectives, like trend analysis and seasonal drought monitoring. It is a 35+ year quasi-global rainfall data set. Spanning 50^0S-50^0N (and all longitudes) and ranging from 1981 to present, CHIRPS incorporates our in-house climatology, CHPclim, 0.05^0 resolution satellite imagery, and in-situ station data to create gridded rainfall time series (Springs *et al*., 2010). CHIRPS data product used in this study was downloaded from USCB-CHG from 2000 to 2019 and compared with respective monthly, seasonally and yearly ground station data to evaluate the performance for rainfall estimation.

PERSIANN: PERSIANN (Precipitation Estimation from Remotely Sensed Information using Artificial Neural Networks) developed by the Center for Hydrometeorology and Remote Sensing (CHRS) at the University of California, Irvine (UCI) (Juan *et al*., 2014), uses neural network function classification/ approximation procedures to compute an estimate of rainfall rate at each $0.25^0 \times 0.25^0$ pixel of the infrared brightness temperature image provided by geostationary satellites. The PERSIANN system was based on geostationary infrared imagery and later extended to include the use of both infrared and daytime visible imagery (Hsu *et al.*, 1999). The CHRS data product proposed used in this study was PERSIANN CDR from 2000 to 2019. PERSIANN CDR monthly and yearly were downloaded from CHRS data portal. The monthly data were accumulated to get seasonal PERSIANN CDR Data. Like CHIRPS and TMPA (TRMM3B43) above PERSIANN CDR data product were compared with respective monthly, seasonally and yearly ground rainguage station data to evaluate the performance for rainfall estimation.

TRMM: The Tropical Rainfall Measuring Mission (TRMM) is a joint space mission between NASA and the Japan Aerospace Exploration Agency (JAXA) designed to monitor and study tropical and subtropical precipitation and the associated release of energy (Maidment *et al*., 2014). The product used in this study was TRMM Multi-satellite Precipitation Analysis (TMPA) monthly, (TRMM 3B43 V7) product from 2000 to 2019. TRMM3B43 was downloaded from Earth data and compare with ground station data by statistical comparison to evaluate performance for rainfall estimation. Monthly TRMM data were added to get seasonal and yearly accumulated data for evaluation purpose in this study.

eMODIS: eMODIS is a process for creating a community-specific suite of vegetation monitoring products based on the National Aeronautics and Space Administration's (NASA), Earth Observing System (EOS), Moderate Resolution Imaging Spectroradiometer (MODIS) and produced in the U.S. Geological Survey's (USGS), Earth Resources Observation and Science (EROS) Center (Jenkerson and Schmidt, 2008). Jenkerson *et al*., (2010) reported that the eMODIS NDVI data are well suited for vegetation studies because the data were acquired with a frequent and repeated cycle. In addition, the spatial resolutions of the data were better than the Advanced Very High Resolution Spectroradiometer (AVHRR) and SPOT-Vegetation products. A multi-temporal smoothed 10 days Terra expedited Moderate Resolution Imaging Spectoradiometer Normalized Difference Vegetation Index (eMODIS-NDVI) data from the period of 2015 to 2019 at 250m spatial resolution were acquired from the Famine Early Warning Systems Network (FEWS NET) East-Africa region for this study. In this study, the row eMODIS data were processed, rescaled and analyzed in ArcGIS 10.3 package to find out the real NDVI value of the study area. The composite of different seasons eMODIS-NDVI images were used for derivation of corresponding seasonal DSI and VCI of different seasons.

3.3.2. Rainguage Station Data

The observed monthly rainfall data from 2000 to 2019 for all independent weather stations located in the Omo-Gibe basin was obtained from the Ethiopian National Meteorological Agency (NMA). The quality of the data were checked and stations having more missed data were omitted from use. Accordingly, the stations with good data and located in different agro-climatic zone was selected and used in this study: seasonal and yearly data was accumulated from the monthly fall records for each Rainguage station. The historical record of the rainfall data were observed from selected stations for comparison and validation of satellite rainfall products. All the data used in the study are summarized in the table below.

Table 3: Summary of data used in the study

S/n	Type	Description	Temporal Coverage	Spatial Resolution	Temporal Resolution	Source
1	Satellite Rainfall Product	CHIRPS Version 2.0	1981–present	0.05° (~5 km)	Monthly	USCB-CHG
		TMPA 3B43 V7.0	1998–present	25◦ (~27 km)	Monthly	Earth data
		PERSIANN-CDR	1983–present	25◦ (~27 km)	monthly	CHRS data portal
2	EOS	eMODIS	1999-present	250m*250m	1-2 days	FEWS NET
3	Weather station data	Rainguage data			Monthly	NMA

3.4. Data analysis

To evaluate performance of satellite for rainfall estimation, assessment of spatio-temporal drought variability and estimation of probability of the drought the following key steps were considered.

3.4.1. Evaluation of Satellite Derived Rainfall

In this study, the evaluation of satellite rainfall estimation products was carried out for the period from 2000 to 2019 using measured rainfall data from selected independent rainguage stations in the Omo-Gibe basin. Evaluation with independent data set is crucial in the study region to identify the satellite product that reproduces the measured data relatively well. There are about 98 operational rainguage stations in the study area; however, among these stations ten (10) of them were purposely selected in the comparison of satellite rainfall products. The selections of the independent rainguage stations based on the relative location of each station in different agro-climatic zone and availability of good records during the study period.The grid values of the satellite rainfall estimates data was extracted to the station for validation process in ArcGIS environment. Excel software was also used for comparison of the ground-based observations with satellite rainfall estimation. This means, point-to-grid comparison has taken place in this study irrespective of the different grid size of each satellite product. The evaluations of the satellite rainfall products were conducted at monthly, seasonal and yearly time scales.

Evaluation Statistics

The techniques used in this study centered on the results of the 3rd Algorithm Inter comparison Project of the Global Precipitation Climatology Project (GPCP) (Ebert, 1996). This techniques includes pairwise comparison statistics to evaluate the performance of the satellite products in estimating the amount of rainfall.

Four statistical indictors (Bias, Mean error, Root mean square erro and correlation coefficient), were summarized in (Table 5), were used to compute the pairwise comparison statistics. In this study attention was given to some statistics over others depending on the application of satellite products. For flood forecasting and hydrological purposes, it is important to avoid underestimations of rainfall events and rainfall amounts, and then avoid ME < 0. In contrast, for drought monitoring, overestimations must be avoided, and then avoid ME > 0. Products with high r and low RMSE have considered for general purposes (Toté *et al*., 2015). Hence, more emphasis was given to the products with ME < 0 and low RMSE in this study.

The Bias is defined as the average difference between rain gauge observations and satellite data, and can be either positive or negative. A negative Bias indicates underestimation of rainfall while a positive Bias indicates overestimation. Bias reflects how well the mean of the satellite rainfall corresponds with the mean of the observed rainfall; Equation (1). A Bias value closer to one indicates the cumulative satellite rainfall estimate is closer to the cumulative observed rainfall. Bias value of 1 is the perfect score. Underestimation leads to values less than one, and overestimating leads to values greater than one (Duan *et al*., 2012)

$$\text{Bias} = \frac{\sum \boldsymbol{S}}{\sum \mathbf{O}} - - - - - - - - - - - - - - - \text{Eq (1)}$$

Where: O = gauge rainfall measurement, and S = satellite rainfall estimate.

The root mean square error (RMSE), which gives a greater weight to larger errors compared to the mean average error (Toté *et al*., 2015), were used to measure the overall error magnitude. A lower RMSE value means greater central tendencies and small extreme error. RMSE value of zero is the perfect score (Equation 2).

$$\text{RMSE} = \sqrt{\frac{1}{\text{n}} \sum (\text{S} - \text{O})^2} - - - - - - - - - - - \text{Eq (2)}$$

Where: RMSE is the root mean square error, O= gauge rainfall measurement, S = satellite rainfall estimate and n= number of data pairs.

Mean error (ME) is used to estimate the average error; a positive value indicates an overestimate of the satellite rainfall whereas a negative value indicates an underestimate as compared to the observed rainfall. ME values of zero is the perfect score (Equation 3)

$$\text{ME} = \frac{1}{\text{n}} \sum (\text{S} - \text{O}) - - - - - - - - - - - - - - \text{Eq (3)}$$

Where: ME is the mean error, O = gauge rainfall measurement, and S = satellite rainfall estimate and n= number of data pairs.

The correlation coefficient (r) were used to assess the degree of agreement between satellite-based rainfall and rain gauge observations. Equation (4). The value of r is such that −1 <r<+1. An r value of +1 indicates a perfect positive fit, while value of –1 indicates a perfect negative fit. If there is no linear correlation or a weak linear correlation, r is close to 0 (Moazami *et al*., 2013; Sharifi *et al*., 2016):

$$\mathrm{r} = \frac{\sum(\mathrm{O}-\tilde{\mathrm{O}})\left(\mathrm{S}-\check{\mathrm{S}}\right)}{\sqrt{(\mathrm{O}-\tilde{\mathrm{O}})^2}\sqrt{\left(\mathrm{S}-\check{\mathrm{S}}\right)^2}} ------------ \mathrm{Eq}(4)$$

Where: r is the correlation coefficient, O = gauge rainfall measurement, $\tilde{\mathrm{O}}$ = average gauge rainfall measurement, S = satellite rainfall estimate, Š = average satellite rainfall estimate.

Table 4: Summary of pairwise statistical formula used in this study

Statistical indicator	Formula	Value range	Perfect score	Eq
Bias	$\mathrm{Bias} = \frac{\sum S}{\sum \mathrm{O}}$	0 to ∞	1	(1)
Root mean square error	$RMSE = \sqrt{\frac{1}{n}\sum(S-O)^2}$	0 to ∞	0	(2)
Mean error	$ME = \frac{1}{n}\sum(\mathrm{S}-\mathrm{O})$	-∞ to ∞	0	(3)
Pearson correlation coefficient	$r = \frac{\sum(\mathrm{O}-\tilde{\mathrm{O}})\left(\mathrm{S}-\check{\mathrm{S}}\right)}{\sqrt{(\mathrm{O}-\tilde{\mathrm{O}})^2}\sqrt{(\mathrm{S}-\check{\mathrm{S}})^2}}$	–1 to 1	1	(4)

3.4.2. Spatio-Temporal Assessment of Meteorological Drought

In this study, to identify the best performing satellite product for further application in dealing with meteorological drought monitoring three satellite precipitation products were evaluated. The long term record of the best performing satellite rainfall product was used to study the spatio-temporal range and pattern of meteorological drought in the basin. The Standardized Precipitation Index (SPI) is a frequently used meteorological drought index (Guttman, 1999).

SPI was considered to measure the rainfall deficit for multiple time scales in the studied location. The SPI is a z-score and represents the drought event departure from the mean, expressed in standard deviation units. SPI is a standardized index in time and space. This feature allows contrasts of SPI values among diverse locations. Although SPI can be calculated from 1 month up to 72 months, 1 to 24 months is the best useful range of application (WMO, 2012). In this study the SPI values were computed at two time scales, i.e. 3-months (SPI-3) and 12 months or annual (SPI-12). The monthly time series data were the base to calculate the 3 –month SPI and 12-SPI values for each time scales.

The 3-month SPI is often used to characterize the shortfall of rainfall during the rainy season and its consequence for the reduction of crop yield (Trambauer *et al*., 2014). The SPI-3 were used to assess droughts during summer seasons which represent the longer rain seasons and SPI-12 were used to assess the annual drought in study area. The SPI value provides a comparison of the rainfall over a specific period with the rainfall totals from the same period for all the years included in the historical record (Shahid, 2008). SPI was used in this study because of its wide application in meteorological drought studies. Unlike other widely used meteorological drought indices (e.g., Palmer Drought Severity Index (PDSI), and Standardized Precipitation Evapotranspiration Index (SPEI)), SPI only uses rainfall data to characterize drought.

In this study SPI values were generated for each 3-month and 12-month of the year using the exel package for temporal druought assessment. To assess the spatial extent of meteorological drought in study periods the raster data of most performing satellite rainfall product data were analyzed in ArcGIS. The computation was based on long-term precipitation data for the desired time step, where the difference of the precipitation from the mean for a particular time step is taken and then divided by the standard deviation of the time series (Sonmez *et al*., 2005). The drought events generated in four intensity classes based on McKee *et al*., (1993) definition; i.e. mild drought (SPI between 0.99 and −0.99), moderate drought (SPI between −1.00 and −1.49), severe drought (SPI between −1.50 and −1.99), and extreme drought (SPI −2.00 or less) as shown in Table 5. The time series values of the 3-month SPI at the corresponding locations of the representative independent stations were extracted and analyzed to study the frequency and severity of the meteorological drought during rainy season. The performance of the SPI was evaluated/validated on how well it characterize the known historic drought years, DSI (drought severity index) and VCI (vegetation condition index) values of corresponding years (Equation 5).

Conceptually, SPI is equivalent to the Z-score used in statistics, and it is calculated as:

$$\mathrm{SPIij} = \frac{\mathrm{Xij}-\mu\mathrm{ij}}{\alpha\mathrm{ij}}, ------------\mathrm{Eq}\ (5)$$

Where: SPI_{ij} = the SPI of the ith month at the jth times scale,

X_{ij} = rainfall total for the ith month at the jth time scale,

μ_{ij} and α_{ij} = the long-term mean and standard deviation associated with the ith month at the jth time scale, respectively.

Table 5: Classification of SPI Values in Terms of Drought Condition

SPI value	Drought categories
2.0 to more	Extremely Wetter
1.5 to 1.99	Very wet
1.0 to 1.49	Moderately moist
0.99 to -0.99	mild drought
−1.0 to -1.49	moderate drought
−1.5 to -1.99	Severe drought
−2 to less	extreme drought

Source: (McKee, 1993).

3.4.3. Calculation of Remote sensing indices for comparison

To compare drought intensity assessed by SPI value in study area the vegetation indices (i.e; vegetation condition index and drought severity index) were computed in this study from respective year of eMODIS NDVI from 2005-2019.

Calculation of MODIS (eMODIS) NDVI

Rhee *et al*., (2010) reported that the NDVI has been most broadly used for drought monitoring. The value of NDVI ranges from -1.0 to +1.0. The negative NDVI ratio shows less vigorous vegetation cover mainly occurred in a barren rock (rock outcrop), and sand, while the positive NDVI value depicts the vegetation cover. NDVI values are much higher in dense vegetation than less vegetated areas (Kogan, 2013). Similarly, sparse vegetation cover such as grasslands, bushes/shrubs may result in moderate NDVI values range from 0.2 to 0.5. The High NDVI values (0.6 - 0.9) correspond with dense vegetation in the temperate and tropical forests or crops at their peak growth stage. NDVI is thus a very good parameter for studying vegetation greenness, and mapping vegetation health or cover dynamics status in each satellite image pixel. However, NDVI data alone cannot completely show the severity and magnitude of droughts (Kogan *et al*., 2013; Kogan and Guo 2016). Therefore, the multitemporal analysis of eMODIS NDVI data supported by VCI and DSI can suggestively improve the drought monitoring and early warning systems. In this study, the eMODIS NDVI data were used as input to compute the VCI and DSI. The NDVI was mathematically computed as follows (Eq 6).

$$\mathrm{NDVI} = \frac{\mathrm{NIR} - \mathrm{RED}}{\mathrm{NIR} + \mathrm{RED}} - - - - - - - - - - Eq(6)$$

In this study, the row eMODIS data were processed, rescaled and analyzed in ArcGIS 10.3 package to find out the real NDVI value of the study area as follows (Eq. 7):

$$\mathrm{eMODIS\ NDVI} = \mathrm{Float}\frac{(\mathrm{Smoothed\ eMODIS\ NDVI}\ -\ 100)}{100} - - - - - - - - \mathrm{Eq}(7)$$

3.4.4. Calculation of Vegetation Condition Index (VCI)

NDVI has also been used for detecting drought impacts on vegetation and used as a base index for a number of remote sensing indices that similarly quantify vegetation conditions. Among these the most popular ones are the Vegetation Condition Index (Kogan, 1990). The best method to compare the respective NDVI with historical values is the Vegetation Condition Index of respective time. The VCI has been extensively used to monitor vegetation conditions. It normalizes NDVI on a pixel-by-pixel basis, scaling between the minimum and maximum values of NDVI: For this particulat study the Vegetation Condition Index maps was produced for the corresponding seasonal eMODIS-NDVI images for 2005-2019 (Eq 8).

$$\mathrm{VCI} = 100 *\ \mathrm{NDVI} - \mathrm{NDVImin}\ /\ \mathrm{NDVImax} - \mathrm{NDVImin}\ \ - - - - \mathrm{Eq}(8)$$

Where: NDVI, NDVImin, and NDVImax are the mean month/seasonal NDVI, and its absolute long-term minimum and maximum NDVI values, respectively for each pixel.

VCI varies in the range of 0 to 100 percent, reflecting relative changes in the vegetation condition from extremely low (bad) to high (finest) VCI (Taylor *et al*., 2007). As proposed by (Taylor *et al*., 2007) and recently applied by (Measho *et al.*, 2019), a threshold value of below 35% is used to indicate drought conditions. In this study, the VCI were derivated from NDVI for each seasonal (June, July and Augest) NDVI image of drought assessed by SPI to compare it. Vegetation condition index (VCI) were processed for years of drought assessed by SPI from 2005 to 2019 using the ArcGIS raster calculator.

Table 6: Drought categories based on Vegetation Condition Index (VCI).

VCI Percentage	Drought Severity Level
0 to <20%	Extreme drought
20 to <35%	Severe drought
35 to <50%	Moderate drought
>50%	No drought

Source: Kogan, (2013)

3.4.4. Calculation of Deviation of NDVI (Drought Severity Index)

The Drought Severity Index (DSI) was developed to infer rooting zone soil moisture from surface energy balance consideration; relative soil water deficit in the rooting zone (Su *et al*., 2003a). For this particulat study Drought Severity Index (DSI) were computed based on the seasonal level using ArcGIS raster calculator. To derive the DEVNDVI (DSI) eMODIS NDVI mean images composed together and monthly long term mean was calculated. The DSI were computed for the rainy season basis to validate the drought years and its severity class that assessed by SPI in study area. It is computed using the following formula (Eq 9).

$$DSI\ (DEVNDVI) = NDVIi - NDVIm, mean --------- Eq(9)$$

Where: NDVI*i* is the NDVI value for season and NDVI*m*, mean, is the long-term mean NDVI for the same season.

Table 7: Drought Severity Index classes.

Drought severity index	Drought Severity Level
< -0.25	Extreme drought
-0.25 to -0.1	Severe drought
-0.1 to 0.1	Moderate drought
0.1 to 0.25	Mild drought
>0.25	No drought

Source: Kogan, (2004)

3.4.5. Estimation of probability of droughts in the next 100 years

To estimate the probability of drought events for time-scale (3-month) and intensity class per 100 years in Omo-Gibe basin the following method was adopted as used by Labedzki, (2007), and Sternberg *et al*., (2010). In this sudy the probability of drought events were estimated for drought classes (moderate drought, severe drought and exteremly drought drought classes. Probability for mild drought class didn’t considered in this study due to mild drought expected at every times (Labedzki, 2007). The probability of drought for next 100 year is calculated as (Eq 10):

$$\mathrm{Ni},100 \ = \frac{\mathrm{Ni}}{\mathrm{i} * \mathrm{n}} * 100, - - - - - - - - - - - Eq(10)$$

where:

Ni,100 = the number of droughts for a timescale i in 100 years;

Ni = the number of months with droughts for a timescale i in the n-year set;

i = the timescale (3 and 12 months) and

n =the number of years in the data set (34 years in this study)

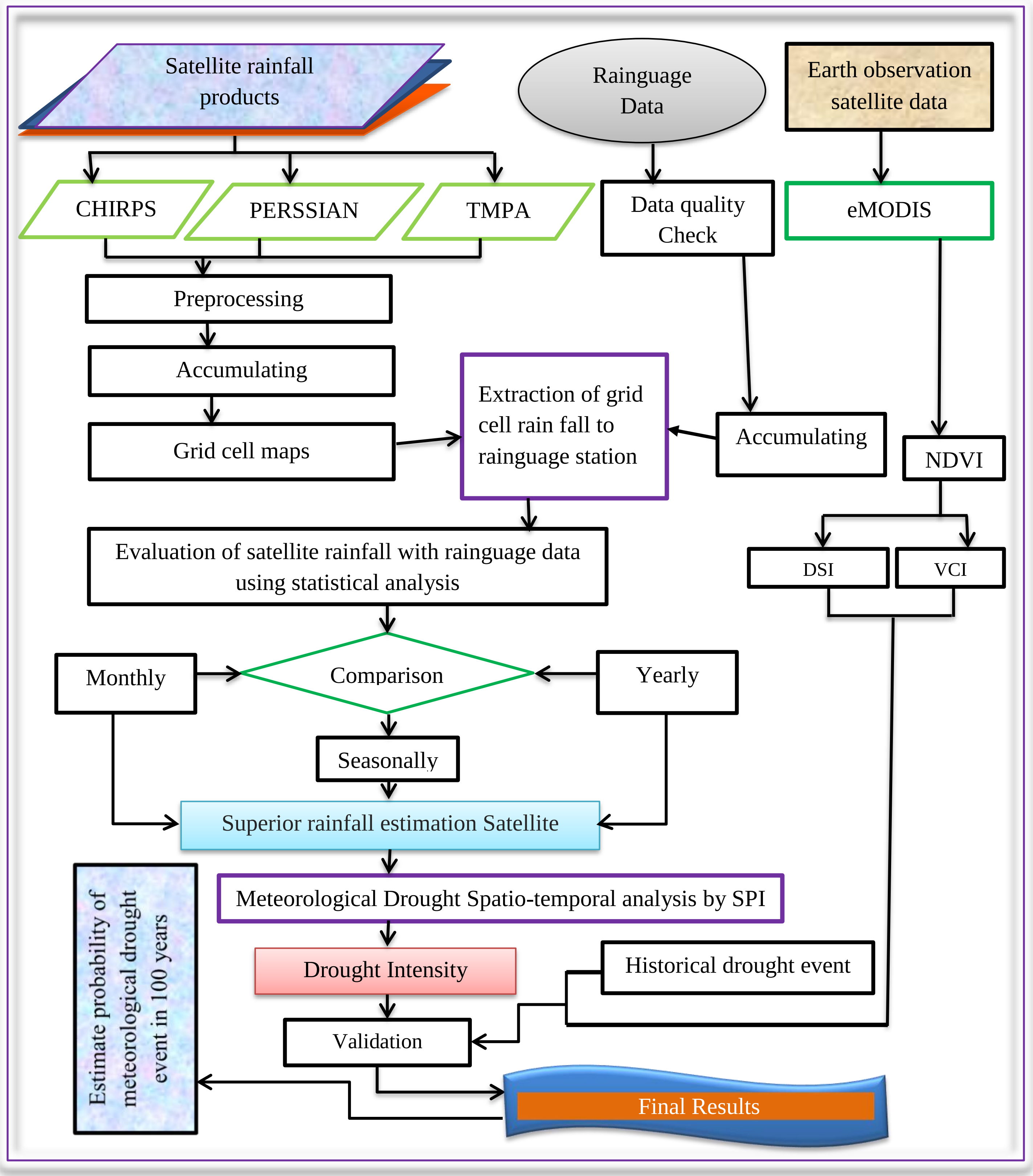


Figure 7: General Methodology flow chart

CHAPTER FOUR

4. RESULTS AND DISCUSSION

4.1. Evaluation of Satellite Rainfall Estimation

4.1.1. Monthly Comparison

In this study the result of the comparison between satellite rainfall products and weather station reveals that CHIRPS scored the maximum correlation coefficeint (r = 0.99) at Woliso Giyon station; the minimum was scored by PERSIANN-CDR (r = 0.02) at Jinka and Bita woshi stations (Figure 8a). Overall, CHIRPS correlated very well, with correlation coefficient (r) values ranging from 0.73 to 0.99 compared to PERSIANN and TMPA satellite rainfall products in all weather stations. Following to CHIRPS, TMPA scored the next highest correlation coefficient values (ranging from 0.50 to 0.79). In addition, CHIRPS and TMPA showed mean Bias scores of 0.99, which are close to the perfect score of 1.00 (Figure 8b). PERSIANN scored the weakest mean Bias of 0.75. In general, good agreement between the three satellite-based rainfall estimates and the weather station-based rainfall observations was found using Pearson's correlation coefficient (r), ranging from 0.02 to 0.99. In other words, cumulative estimates of CHIRPS and TMPA were close to the observed rainfall in 80% of the total validation weather stations whereas PERSIANN underestimated in most gauging stations whereas, PERSIANN showed less closer cumulative results in all of the weather stations. TMPA scored the best ME (-1.06mmmonth^{-1}) and RMSE (58.74mm month^{-1}) values at Dimeka and Hosana stations, respectively. Accordingly, CHIRPS scored the best ME and RMSE in 70% and 80% of the total validation weather stations, respectively (Figure 8c and d). The result agrees with previous studies conducted in Ethiopia: for instance, in Upper Blue Nile (Bayissa *et al*., 2017); in Rift Valley Lakes Basin (Tesfamariam *et al.*, 2019) that they stated as CHRIPS was best performed satellite rainfall product at monthly time-scale.

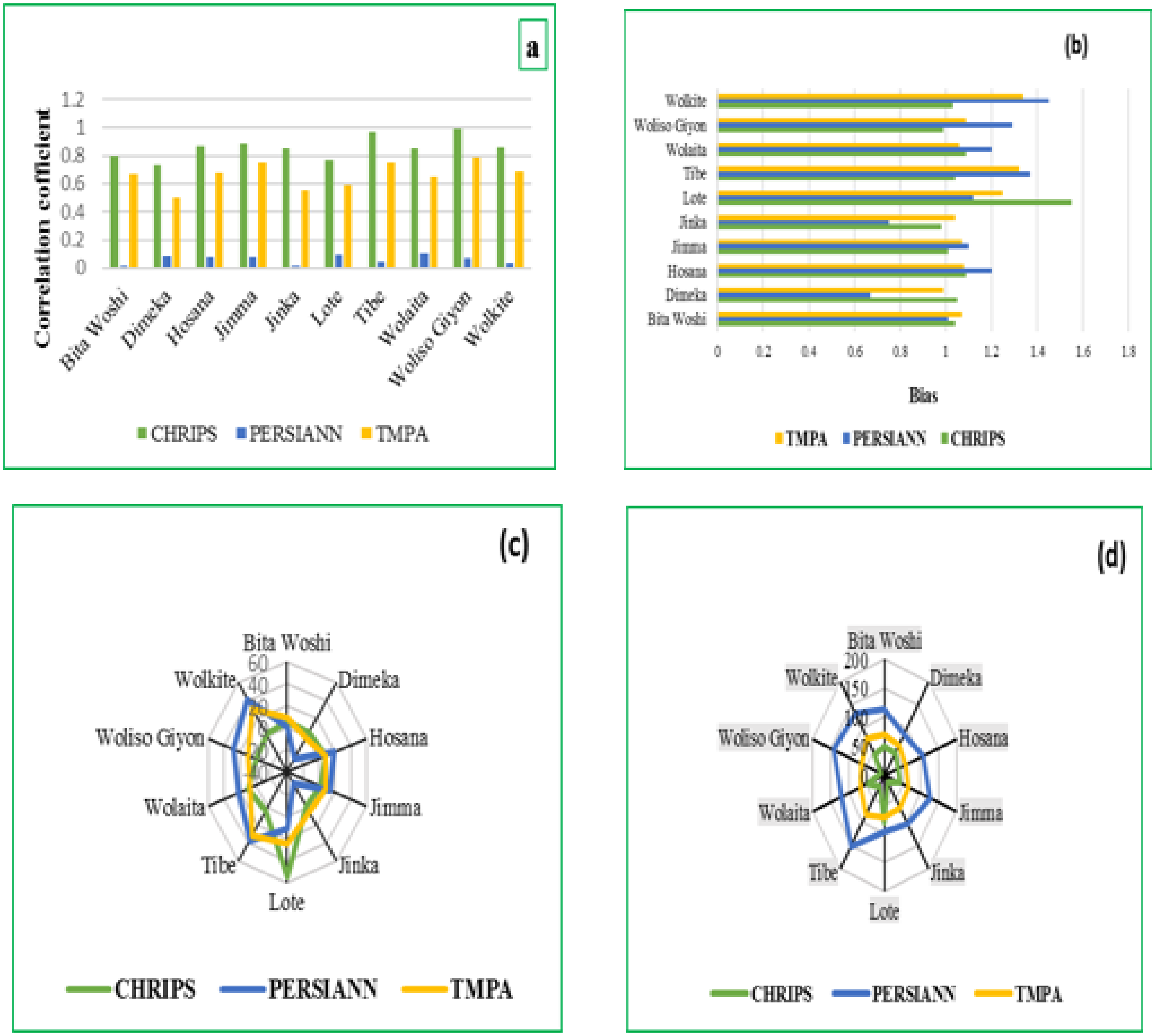


Figure 8. The statistical indicators correlation coefficient (a), Bias (b), mean error (c) and root mean square error (d) for each station at a monthly time scale

Figure 9 below shows the scatter plots produced using the monthly time series data of all the stations against the satellite-based rainfall products that were extracted at the corresponding locations of the weather stations. The highest coefficient (R^2 = 0.99) was scored by CHIRPS at Woliso station. TMPA scores the next highest (R^2 = 0.62), whereas, PERSIANN scores the lowest (R^2 = 0.013). However, the trend lines of CHIRPS and TMPA follow the 45^0 line that showed similarity in variability with the gauged rainfall.

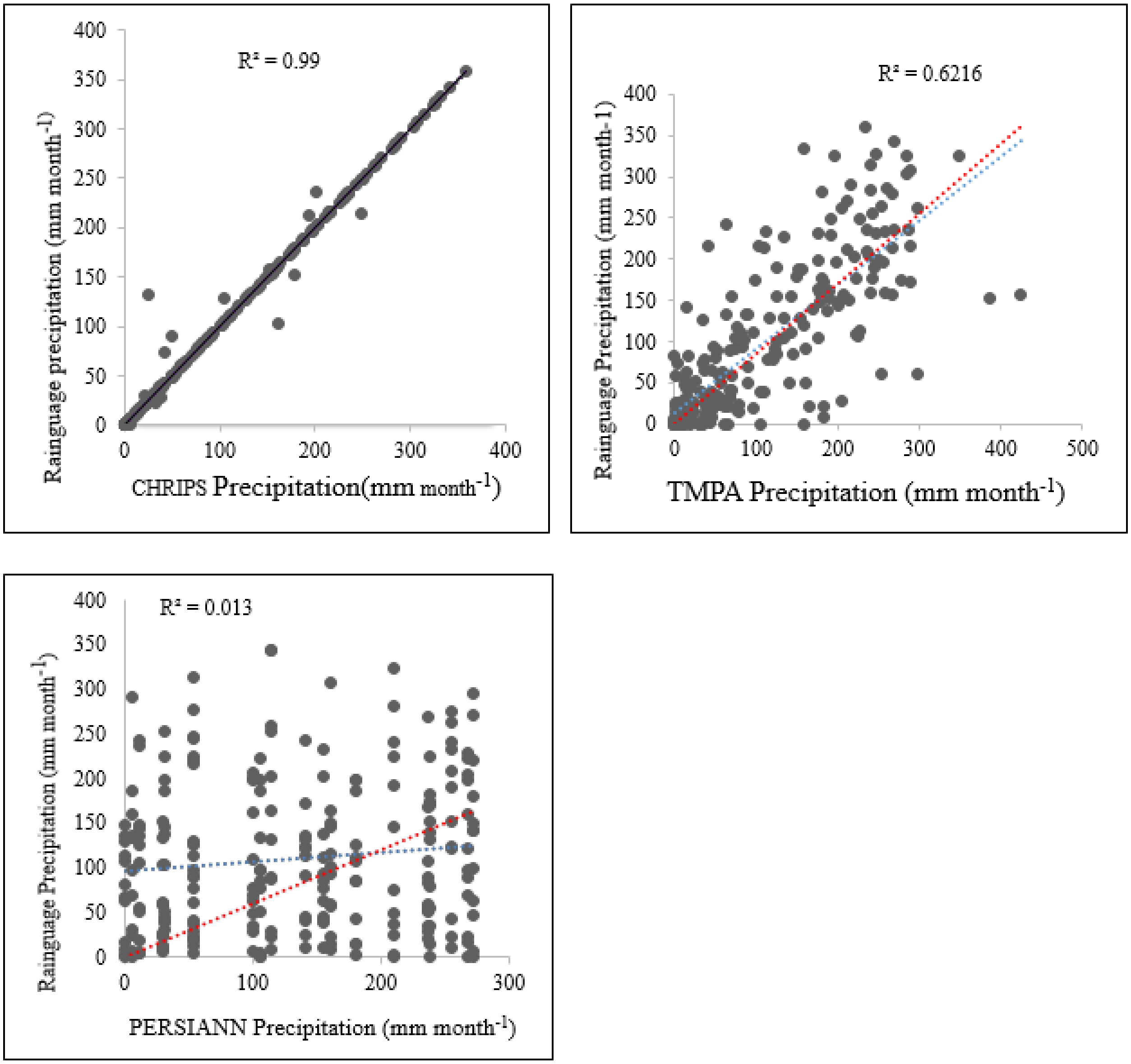


Figure 9. Correlation between the weather stations versus the three satellite-based rainfall estimates at a monthly time scale

4.1.2. Seasonal Comparison

The main rainy season in the Omo-Gibe basin is from June to September. The scarce of the main seasonal rainfall most often causes damage in the basin since agricultural practices are entirely reliant on on the seasonal rainfall. The satellite rainfall estimates were examined at a seasonal time scale. The monthly data precipitation from June to September were added to get the seasonal total precipitation for each weather station and each satellite derived rainfall product (at grid points respective to the ten stations). This resulted in 200 seasonal time series data (pairs) over the ten weather stations for CHIRPS, PERSIANN and TMPA satellite product. Figure 10 below summarizes the statistical indicators derived using the seasonal time series data. The study demonstrates, there is good agreement between the satellite products and gauging stations, with correlation coefficients (r) ranging from -0.26 to 0.98. As a result shows maximum correlation coefficient (r = 0.98) was obtained by CHIRPS, whereas PERSIANN Showed the minimum correlation coefficient having (r = -0.26). All the satellite rainfall products overestimated seasonal rainfall amounts as compared to the observed rainfall (Bias >1). The performance of CHIRPS is relatively good, because minimum mean error (ME = −1.83 mm season$^{−1)}$ and root mean square error (RMSE = 18.83 mm season$^{−1}$) were scored at the seasonal scale. In addition, the Bias scored by CHIRPS is equal to the perfect score of one (Bias = 1) as compared to the other satellite-derived products. Yet again, PERSIANN performed the least (Bias = 0.60) at the seasonal scale.The result of this study inline with (Bayissa *et al*., 2017; Tesfamariam *et al*., 2019).

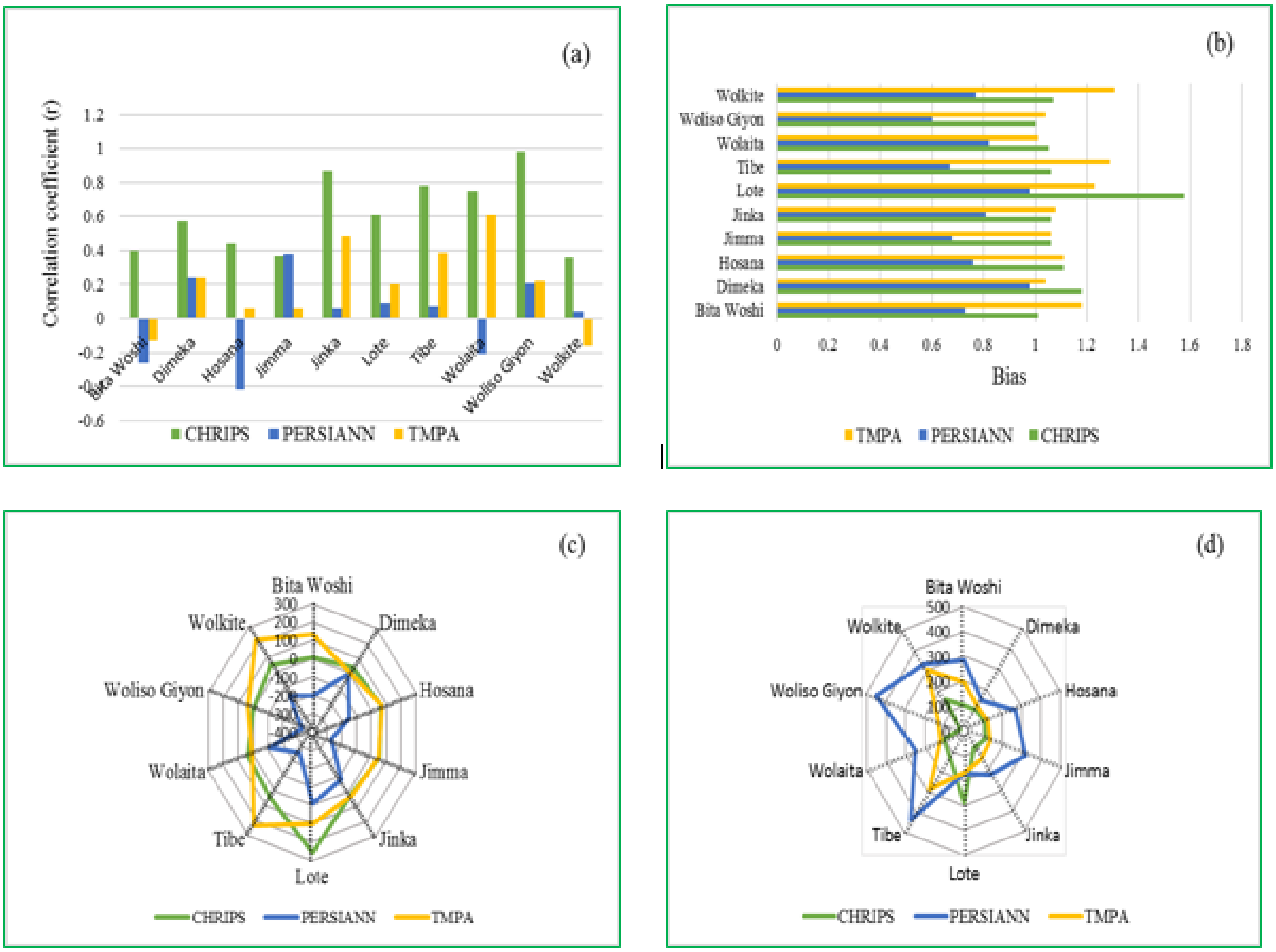


Figure 10. The statistical indicators: correlation coefficient (a) Bias (b),mean error (c) and root mean square error (d) for each station at a seasonal time scale

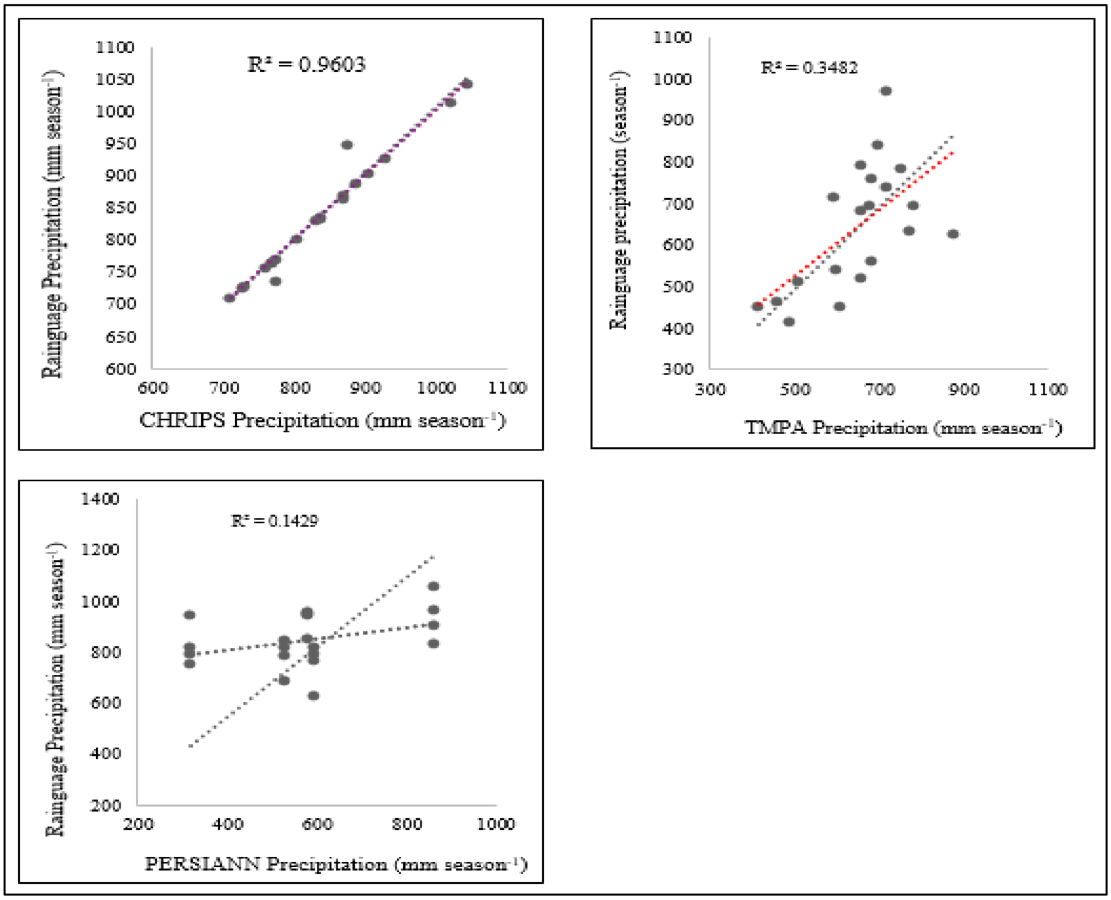


Figure 11. Relationship between the raingauge versus the three satellite-based rainfall estimates at seasonal time scales

4.1.3. Annual Comparison

The monthly accumulated rainfall data were further accumulated to get annual total precipitation for rain-gauge data, CHIRPS, PERSIANN and TMPA/TRMM 3B43. The comparison of ten rainguage station for point-based evaluation for each of the satellite products data sets indicates strong agreement with the rain-gauge data for all of the satellite products. The best correlation was indicated by CHRIPS (r = 0.96), whereas TMPA has the weakest correlation (r = -0.08). Both CHRIPS and TMPA satellite products presented Bias scores approximately equal to 1, while PERSIANN had the weakest Bias (0.73). In addition, CHRIPS and TMPA satellite products over estimated rainfall with positive ME values in 80% of station used for validation. CHRIPS showed the lowest ME (-6.47mm year^{-1}) and the lowest RMSE score (38 mm year^{-1}). From results of the study CHRIPS was the best among all of the compared satellite products, whereas PERSIANN had the worst performance. The annual precipitation from rainguage data with each of the satellite-based rainfall estimates at the point-based station locations scale summarized as Table 8 below.

Table 8. Summary of the yearly/annual statistical indicators.

Dataset	Bias	ME	R	RMSE
CHRIPS	0.99	-6.47	0.96	38.00
PERSIANN	1.0	11.26	0.59	160.49
TMPA	0.99	-12.74	0.65	170.74

As summarized the satellite rainfall products (CHIRPS, TMPA and PERSIANN) at three time scales (i.e., monthly, seasonal and annual) on the basis of satellite-derived rainfall data that could potentially be used for meteorological drought assessment in the Omo-Gibe basin. The result of comparative evaluation of these three satellite products shows that CHIRPS is the best satellite-derived rainfall data at monthly, seasonal and yearly time scales. Thus, CHIRPS was carefully chosen in this study for further analysis in the spatial and temporal assessment of meteorological drought in the study area. This result is in agreement with (Dinku *et al*., 2008; Hirpa *et al*., 2010; Bayissa *et al*., 2017; Dandridge, 2019; Owusu *et al*., 2019).

Table 9: Overall statistical indicators of CHRIPS satelliranfall product with rainguage station

Satellite Products	Station	SUM(S)	SUM(O)	SUM(S-O)	Number of sample	SUM(S-O)^2	Bias	RMSE	Mean Error	Correlation coefficient
CHRIPS (Monthly)	Bita Woshi	33713	32365.1	1347.9	240	583617.45	1.04	49.31	5.62	0.80
	Dimeka	19207	18262	945	240	558514.84	1.05	48.24	3.94	0.73
	Hosana	25366	23243.6	2122.37	240	340226.87	1.09	37.65	8.84	0.87
	Jimma	31749	31294.2	454.8	240	424611.8	1.01	42.06	1.90	0.89
	Jinka	26206	26613.1	-407.1	240	381739.25	0.98	15.49	-1.70	0.85
	Lote	36792	23636.5	13155.5	240	1603640.77	1.55	81.74	54.81	0.77
	Tibe	24486	23601.3	884.7	240	128361.53	1.04	23.13	3.69	0.97
	Wolaita	28623	26344.7	2278.3	240	510101.07	1.09	46.10	9.49	0.85
	Woliso	23419	23548.4	-129.4	240	22017.66	0.99	9.58	-0.54	0.99
	Wolkite	22925.	22225.5	699.5	240	446544.49	1.03	43.13	2.91	0.86
CHRIPS (Seasonally)	Bita Woshi	14976	14870.5	105.5	20	206589.71	1.01	101.63	5.27	0.40
	Dimeka	4947	4195.4	751.6	20	211003.92	1.18	102.71	37.58	0.57
	Hosana	13615	12288.5	1326.5	20	228709.09	1.11	106.94	66.33	0.44
	Jimma	18028	16942.2	1085.8	20	254175.8	1.06	112.73	54.29	0.37
	Jinka	8707	8201.5	505.5	20	142239.37	1.06	84.33	25.28	0.87

	Lote	14111	8942.8	5168.2	20	1643946.26	1.58	286.70	258.4	0.61
	Tibe	16984	16042.8	941.2	20	286756.18	1.06	119.74	47.06	0.78
	Wolaita	13537	12861.5	675.5	20	213645.27	1.05	103.36	33.78	0.75
	Woliso	16686	16722.5	-36.5	20	7093.71	1.00	18.83	-1.83	0.98
	Wolkite	14970	13925.6	1044.4	20	489915.92	1.07	156.51	52.22	0.36
CHRIPS (Yearly)	Bita Woshi	33713	32365.10	1347.90	20	1571460.81	1.04	280.31	67.40	-0.13
	Dimeka	19207	18262	945	20	477850.08	1.05	154.57	47.25	0.63
	Hosana	25366	23243.63	2122.37	20	524007.5289	1.09	161.87	106.1	0.53
	Jimma	31749	31294.2	454.8	20	455433.66	1.01	150.90	22.74	0.61
	Jinka	26206	26613.1	-407.1	20	580198.33	0.98	170.32	-20.3	0.60
	Lote	36792	23636.5	13155.5	20	9744859.53	1.56	698.03	657.7	-0.08
	Tibe	24419	23548.8	870.2	20	251929.7	1.04	112.23	43.5	0.88
	Wolaita	28623	26344.7	2278.3	20	1001414.13	1.09	223.76	113.9	0.51
	Woliso	23419	23548.4	-129.4	20	28884.72	0.99	38.00	-6.47	0.96
	Wolkite	22925	22225.5	699.5	20	779044.5	1.03	197.36	34.98	0.01

Table 10: Overall statistical indicators of PERSIANN satellite rainfall product with rainguage station

Satellite Products	Station	SUM(S)	SUM(O)	SUM(S-O)	Number of sample	SUM(S-O)^2	Bias	RMSE	Mean Error	Correlation coefficient
PERSIANN (Monthly)	Bita Woshi	32452.56	32365.1	87.46	240	3082815	1.01	113.34	0.36	0.02
	Dimeka	12303.24	18262	-5958.76	240	1853290	0.67	87.88	-24.83	0.09
	Hosana	27912.48	23243.63	4668.85	240	2731516	1.20	106.68	19.45	0.08
	Jimma	34464	31294.2	3169.8	240	3862553	1.10	126.86	13.21	0.08
	Jinka	19857.72	26613.1	-6755.38	240	2578955	0.75	103.66	-28.15	0.02
	Lote	26396.28	23636.5	2759.78	240	2330544	1.12	98.54	11.50	0.10
	Tibe	32389.56	23601.3	8788.26	240	5481146	1.37	151.12	36.62	0.04
	Wolaita	31499.52	26344.7	5154.82	240	3393608	1.20	118.91	21.48	0.11
	Woliso	30324.96	23548.4	6776.56	240	4858392	1.29	142.28	28.24	0.07
	Wolkite	32305.68	22225.5	10080.18	240	4208325.11	1.45	132.42	42.00	0.03
PERSIANN (Seasonally)	Bita Woshi	10817.52	14870.5	-4052.98	20	1609034	0.73	283.64	-202.65	-0.26
	Dimeka	4101.08	4195.40	-94.32	20	454177.32	0.98	150.69	-4.72	0.24
	Hosana	9304.16	12288.50	-2984.34	20	1412337.01	0.76	265.74	-149.22	-0.42
	Jimma	11488	16942.2	-5454.2	20	2028255.07	0.68	318.45	-272.71	0.38
	Jinka	6619.24	8201.50	-1582.26	20	964342.68	0.81	219.58	-79.11	0.06
	Lote	8798.76	8942.8	-144.04	20	589164.3	0.98	171.63	-7.20	0.09
	Tibe	10796.52	16042.8	-5246.28	20	3938295	0.67	443.75	-262.31	0.07

	Wolaita	10499.8	12861.5	-2361.7	20	1244925	0.82	249.49	-118.08	-0.21
	Woliso	10108.32	16722.5	-6614.18	20	4136177	0.60	454.76	-330.71	0.21
	Wolkite	10768.6	13925.6	-3157.0	20	2232686	0.77	334.12	-157.85	0.04
PERSIANN (Yearly)	Bita Woshi	28737.87	32365.1	-3627.23	20	2018332	0.89	317.67	-181.36	-0.31
	Dimeka	14740.31	18262	-3521.69	20	1145163	0.81	239.29	-176.08	0.54
	Hosana	23468.84	23243.63	225.21	20	523610.5	1.01	161.80	11.26	0.41
	Jimma	30628.32	31294.2	-665.88	20	1449699	1.0	269.2	-33.3	-0.25
	Jinka	19417.95	26613.1	-7195.15	20	3264791	0.73	404.03	-359.76	0.50
	Lote	24942.76	23636.5	1306.26	20	999456.3	1.06	223.55	65.31	-0.20
	Tibe	27881.52	23548.8	4332.72	20	2127916	1.18	326.18	216.64	0.04
	Wolaita	26845.32	26344.7	500.62	20	879568.7	1.02	209.71	25.03	0.41
	Woliso	25616.08	23548.4	2067.68	20	515163	1.09	160.49	103.38	0.56
	Wolkite	27574.44	22225.5	5348.94	20	1817321	1.24	301.44	267.45	0.59

Table 11: Overall Statistical indicators of TMPA satellite rainfall product with rainguage station

Satellite Products	Station	SUM(S)	SUM(O)	SUM(S-O)	Number of sample	SUM(S-O)^2	Bias	RMSE	Mean Error	Correlation coefficient
TMPA (Monthly)	Bita Woshi	34607.2	32365.1	2242.1	240	1196363	1.07	70.60	9.34	0.67
	Dimeka	18007.30	18262.00	-254.70	240	1019466.60	0.99	65.17	-1.06	0.50
	Hosana	25132.7	23243.63	1889.1	240	828017.6	1.08	58.74	7.87	0.68
	Jimma	33473.4	31294.2	2179.2	240	1073050	1.07	66.87	9.08	0.75
	Jinka	27803.93	26613.10	1190.83	240	1189914.12	1.04	70.41	4.96	0.55
	Lote	29499.2	23636.5	5862.7	240	1271432.66	1.25	72.78	24.43	0.59
	Tibe	31173.6	23601.3	7572.3	240	1659264.7	1.32	83.15	31.55	0.75
	Wolaita	27986.7	26344.7	1642.0	240	1091480	1.06	67.44	6.84	0.65
	Woliso	25777.7	23548.4	2229.3	240	947888.8	1.09	62.85	9.29	0.79
	Wolkite	29710.7	22225.5	7485.2	240	1457673.54	1.34	77.93	31.19	0.69
TMPA (Seasonally)	Bita Woshi	17514.1	14870.5	2643.6	20	774681.3	1.18	196.81	132.18	-0.13
	Dimeka	4377.8	4195.4	182.4	20	275311.9	1.04	117.33	9.12	0.24
	Hosana	13678.5	12288.5	1390.0	20	316314	1.11	125.76	69.50	0.06
	Jimma	17936.1	16942.2	993.9	20	369342	1.06	135.89	49.70	0.06
	Jinka	8822.7	8201.5	621.2	20	399352.5	1.08	141.31	31.06	0.48
	Lote	11000.2	8942.8	2057.4	20	565718.3	1.23	168.18	102.87	0.20

	Tibe	20731.1	16042.8	4688.3	20	1657049	1.29	287.84	234.41	0.39
	Wolaita	12955.1	12861.5	93.6	20	282935.1	1.01	118.94	4.68	0.61
	Woliso	17344.9	16722.5	622.4	20	345656.7	1.04	131.46	31.12	0.22
	Wolkite	18303.5	13925.6	4377.9	20	1847192	1.31	303.91	218.90	-0.16
TMPA (Yearly)	Bita Woshi	34607.2	32365.1	2242.1	20	1505206	1.07	274.34	112.10	0.02
	Dimeka	18007.3	18262	-254.7	20	805314.4	0.99	200.66	-12.74	0.29
	Hosana	25132.7	23243.63	1889.1	20	583057.5	1.08	170.74	94.46	0.33
	Jimma	33473.4	31294.2	2179.2	20	1142444	1.07	239.00	108.96	0.23
	Jinka	27803.9	26613.1	1190.8	20	816524.9	1.04	202.06	59.54	0.42
	Lote	29499.16	23636.50	5862.66	20	2180682.13	1.25	330.20	293.13	0.19
	Tibe	31173.58	23548.80	7624.78	20	3597754.69	1.3	424.1	381.2	0.50
	Wolaita	27986.7	26344.7	1642.0	20	680612.5	1.06	184.47	82.10	0.65
	Woliso	25777.7	23548.4	2229.3	20	632349.3	1.1	177.8	111.5	0.51
	Wolkite	29710.7	22225.5	7485.2	20	3855896	1.34	439.08	374.26	-0.08

4.2. Spatio-Temporal Assessment of Meteorological Drought

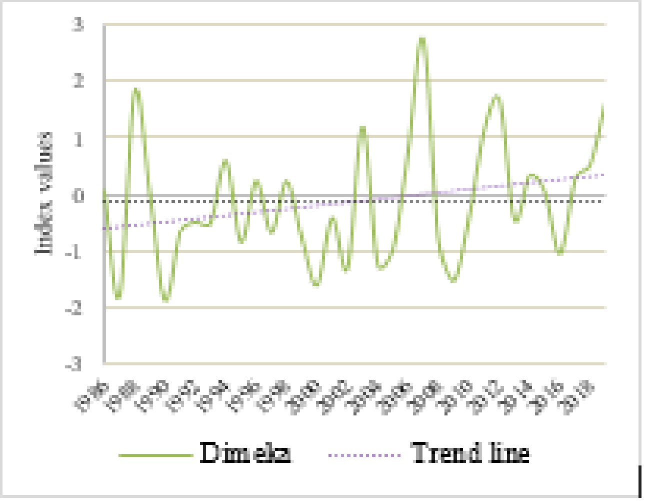
The distribution of station in the basin is not even; central, extreme lowlands and the border areas have consist few amount of the entire stations found within the basin. This might affect the quality of the spatial drought assessment.

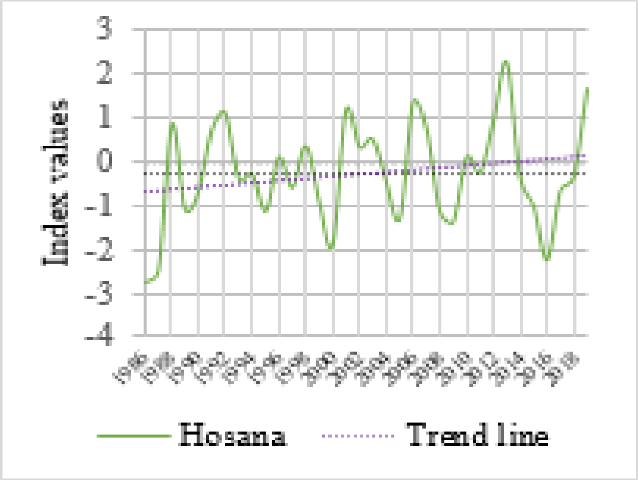
4.2.1. Temporal Drought Assessment

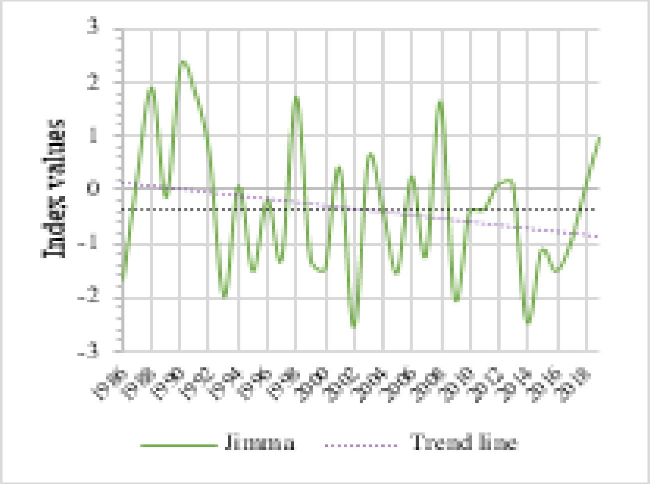
The index values of 3-months (June, July and August) SPI at the representative rainguage stations show time series plot for the period 1986 to 2019 during summer seasons (Figure 12).The result of temporal assessment of meteorological drought shows the presence of drought years with different intensities. It clearly reveals the occurrence of mild to extreme drought events in the study area. Extreme to mild drought conditions were observed in the year 2000 in all stations with drought intensity ranging from 0.52 to −2.15. The minimum intensity was observed at Bita woshi station with severity values of −2.15.

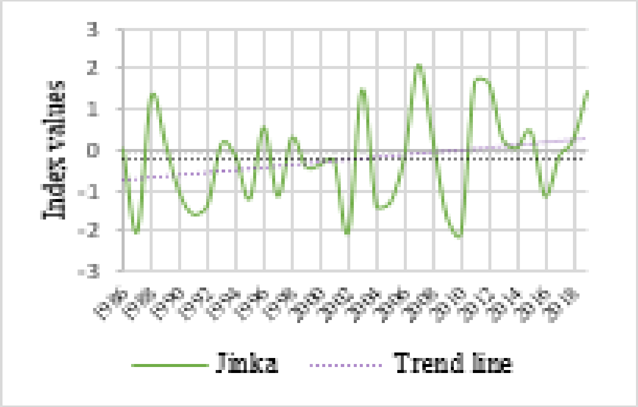
Additionally, in the years 2014 to 2015 mild to extreme drought were observed in all stations with drought intensity 0.46 to -2.58. The stations located in the southern (Dimeka and Jinka) and centeral (Bita worshi and Jimma) parts of the basin indicated more extensive drought than the stations located in the north part. Relatively persistent droughts have been detected in the years 2000, 2002, 2009, 2014 to 2015 and 2016. Although the trends were statistically significant, a relatively strong trend of increasing frequency was detected in the most stations during the seasons under investigation. The 3-month SPI is often used to illustrate the shortfall of rainfall during the rainy season and its consequence for the reduction of crop yield (Trambauer *et al.*, 2014). For instance, 1987-1988, 1991-1992, 2000, 2002-2003, 2009-2010, and 2015-2016, were some of the historic drought years in the country. As trends of drought increasing consistent monitoring is therefore suggested since Summer is the foremost rainy season in the basin on which farming production is highly dependent. Hence, CHIRPS rainfall can be used as an alternative source of information in developing drought monitoring and early warning systems for the basin. Figure 12 shows the trend of the frequency of occurrence of rainy season drought in the Omo-Gibe basin. The result is obtained in this study confirms with the previous findings (Bayissa *et al*., 2017).

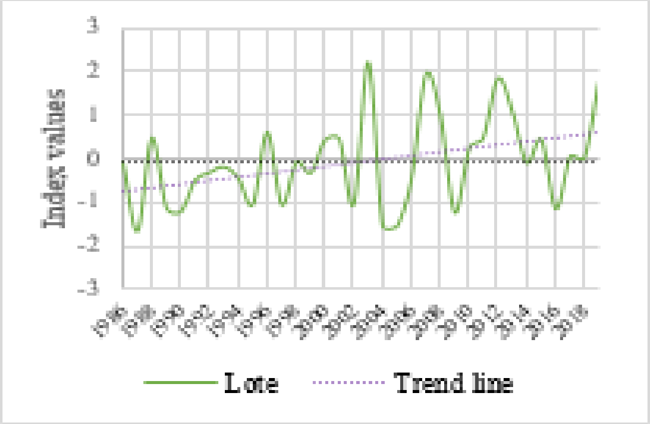

3
2
1
0
-1
-2
-3
Index values
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Bita Woshi
Trend line


3
2
1
0
-1
-2
-3
Index values
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Dimeka
Trend line


3
2
1
0
-1
-2
-3
-4
Index values
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Hosana
Trend line


3
2
1
0
-1
-2
-3
Index values
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Jimma
Trend line


3
2
1
0
-1
-2
-3
Index values
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Jinka
Trend line


3
2
1
0
-1
-2
-3
Index values
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
2018
Lote
Trend line

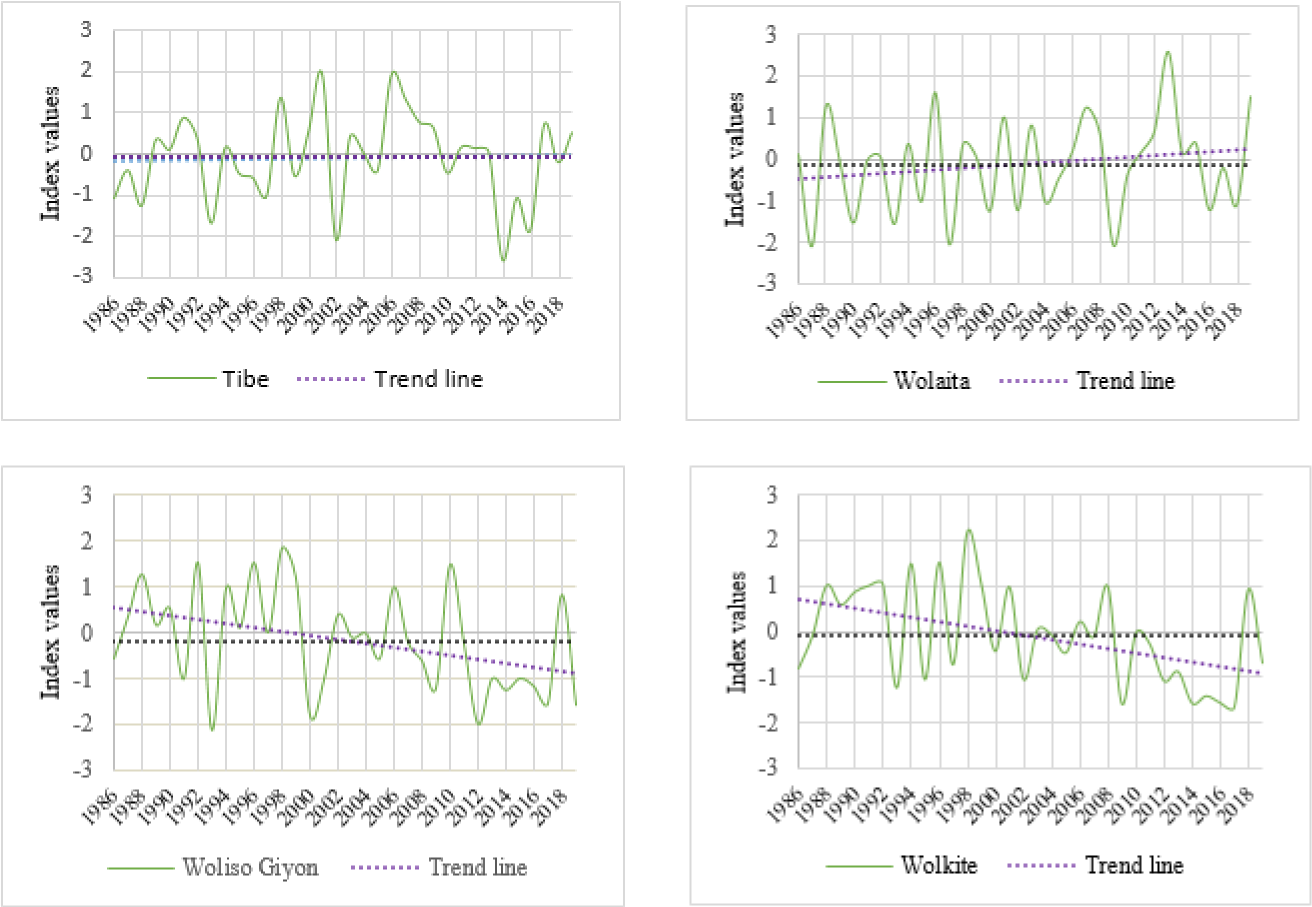


Figure 12. Time series plots of 3-month Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) SPI at rainguage stations used for validation for 1986–2019

In this study SPI-12 value index were used to assess the annual drought in study area. The index values of 12-month SPI at the representative rainguage stations shows time series plot for the period 2000 to 2019 in study area (Figure 13). The SPI value provides a comparison of the rainfall over a specific period with the rainfall totals from the same period for all the years included in the historical record (Shahid, 2008). The result of this study shows the occurrence of mild to severe drought events in the study region. For example, 2000, 2002-2003, 2009–2010,and 2016 were some of the historic drought years in the country. The temporal assessment of the meteorological drought indicated the occurrence of those drought years with different severity levels. Relatively persistent droughts have been observed in the years 2000 and 2009-2010.

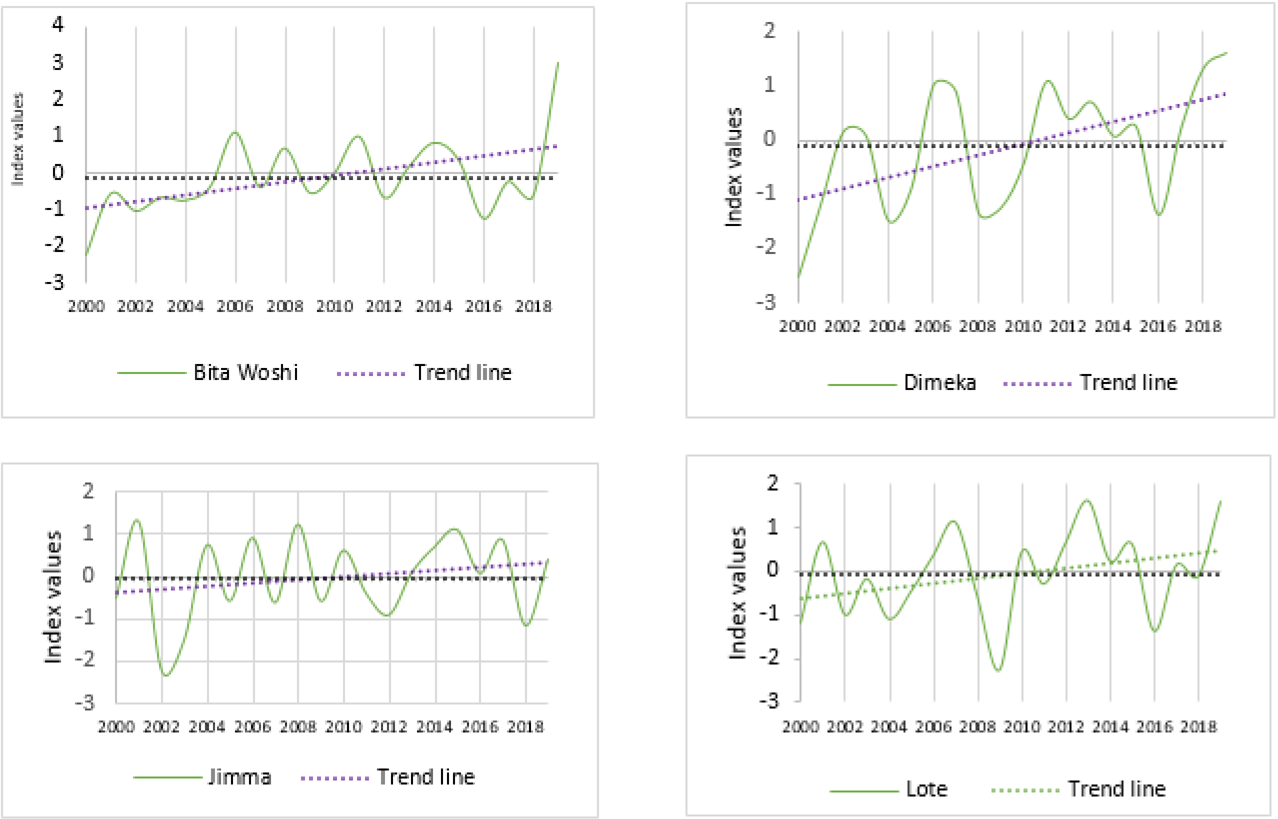


Figure 13. Time series plots of 12-month Climate Hazards Group InfraRed Precipitation with Stations (CHIRPS) SPI at four selected weather stations for 2000-2019

4.2.2. Spatial Drought Assessment

The spatial extents of meteorological drought over the basin were considered within the study period. Three recent drought years (2002, 2009 and 2016) were carefully selected for detecting spatial distribution of drought in this study area after the spatial patterns of all the historic drought years were assessed by the index. The SPI values of the study periods clealy reveal that extreme drought have been perceived during the year 2002, 2009 and 2016 in most portions of basin. Different evidences also confim that these three identified years were recalled as years of drought. For instance, Degefu and Bewket., (2015) stated 2000 and 2009 droughts was most severe droughts in entire areas of Ethiopia and about 10.5 million peoples and 5 million peoples were affected respectively. According to Bayissa *et al*., (2017) the 2015 drought was informed as one of the most severe recent droughts in the country, and it prolonged into 2016 in some portions of the Country and about 8.2 million people needed emergency food aid. Figure 14 shows the spatial extents of drought during the main rainy season (June, July, August and September) in the basin. The severity of the 2002, 2009 and 2016 droughts are indicated by their spatial extent. Extreme drought was observed in the majority of the basin during these years. For example, in the year of 2002 north and northwesten parts received mild to extreme drought at all summer months. Southern, parts were affected by extreme to severe drought in 2009 whereas central and northern parts faced severe drought in 2009. In general, the index evidently showed the drought and rainy years in the basin. Hence, the CHIRPS precipitation product can be used to study the spatial assessment of drought and to develop the drought monitoring and early warning system in the basin.

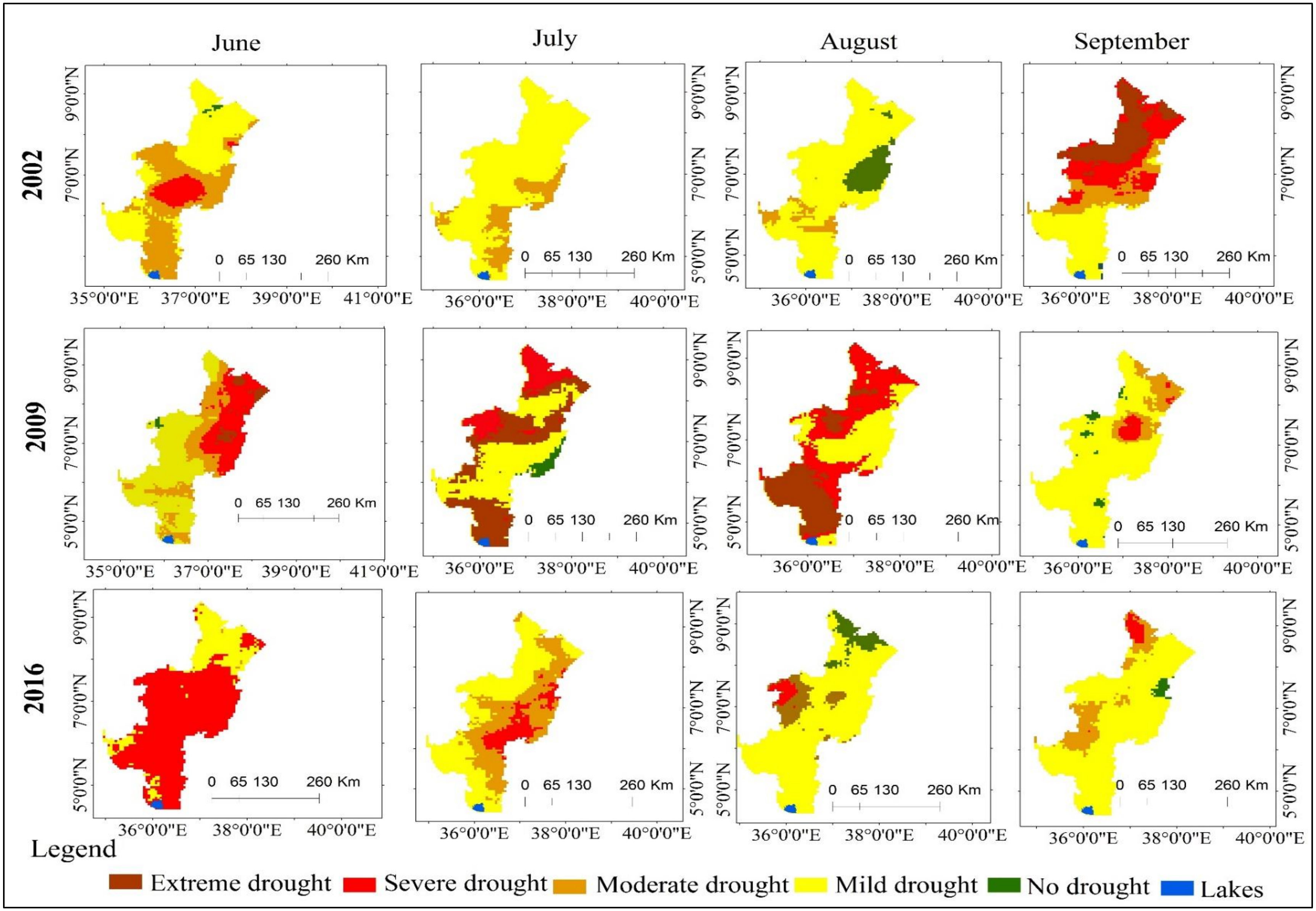


Figure 14. The spatial extents of summer season meteorological drought throughout recent drought years (2002, 2009 and 2016)

4.3. Comparison of Assessed Meteorological Drougt with Remote sensing Indices

4.3.1. Vegetation Condition Index (VCI) based drought assessment

The summer rainfall is associated with the main rainy season, in which rain-based farming is the dominant practice and its failure most often relates with roots water stress in the study area. Failure of the rainy season rainfall is a predecessor for drought to occur. The VCI values, reveal that the southern part is drought prone and most often affect by drought during the years of recorded historic drought events in the study area. The long-term average rainy season (2005-2019) VCI maps were processed to analyse the vegetation signals to the rainfall pattern. The marked vegetation signals were detected in the North and Northwest part that parallels to the high volume of rainy season rainfall. The VCI values for the South and Northeast part are smaller, which gives clear indication of poor vegetation condition that relates with the occurrence of drought during study periods. The VCI maps from the year 2005 to 2019 were used to evaluate the spatial and temporal extents of drought in the study area.

In general, VCI values less than 35% were observed in the Northeast, southern and towards the center, with different levels of severity (Figure 15,16 and 17). The maps indicate that in the rainy season years 2009 and 2016, more of the area suffered fair to extremely poor vegetation condition (VCI values less than 35 percent. Results obtained through the SPI and VCI are nearly similar which is inline with a number of studies. For instace, Bokusheva *et al*.,(2016); Measho *et al*., (2019) also pointed out that both SPI and VCI are best indicator drought occurance.

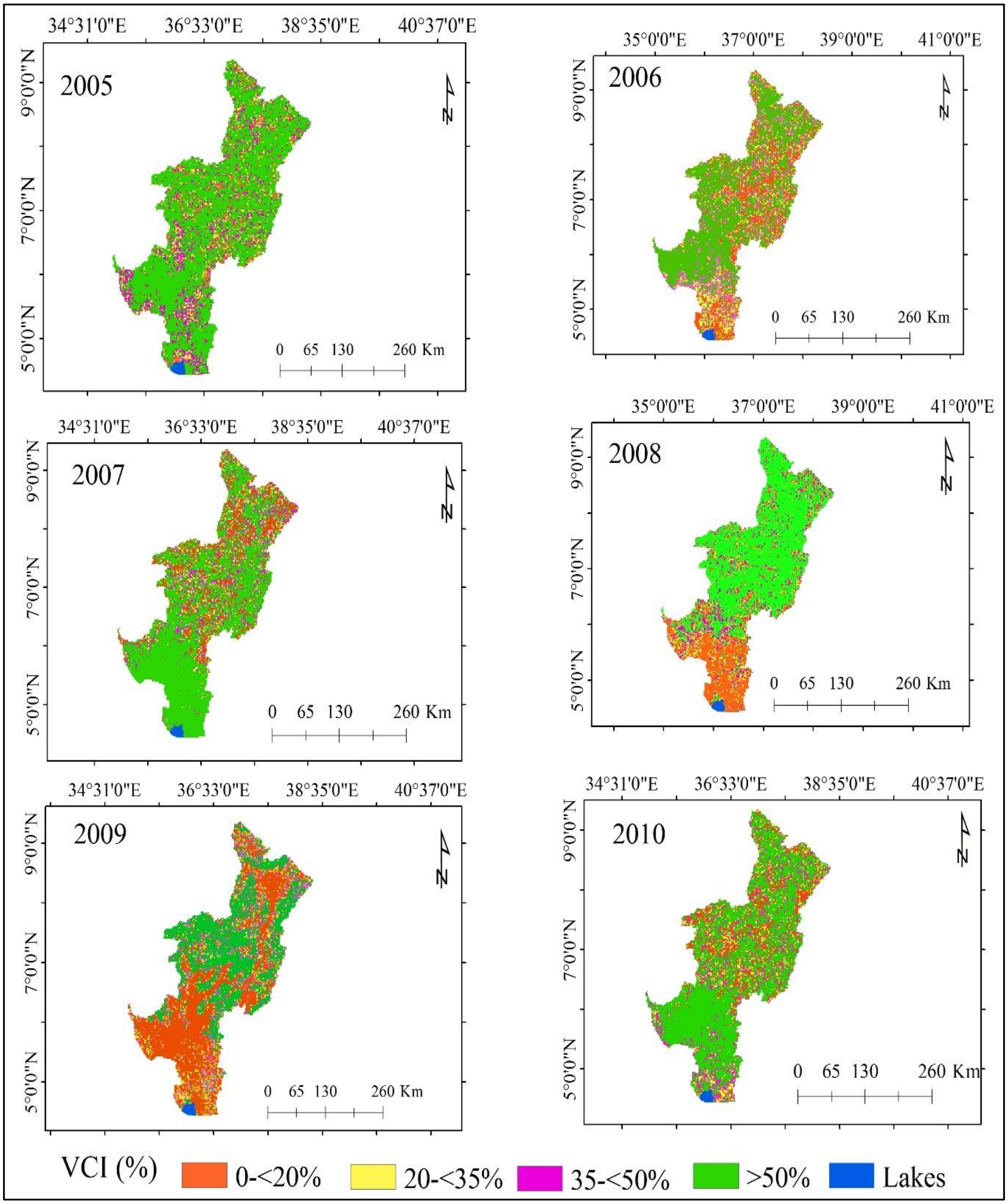


Figure 15: The spatial pattern of the VCI for Summer season from 2005 to 2010

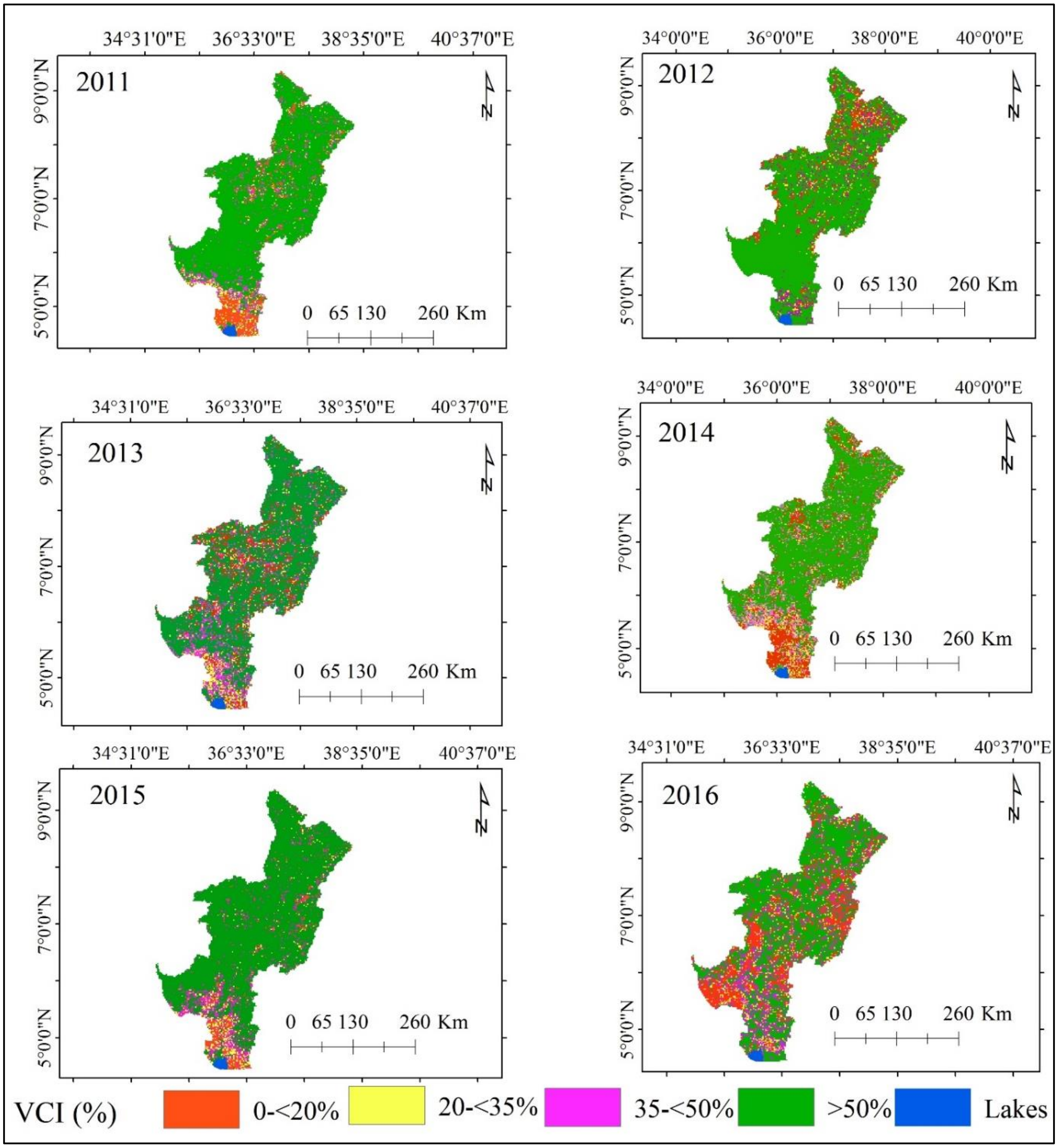


Figure 16: The spatial pattern of the VCI for Summer season from 2011 to 2016

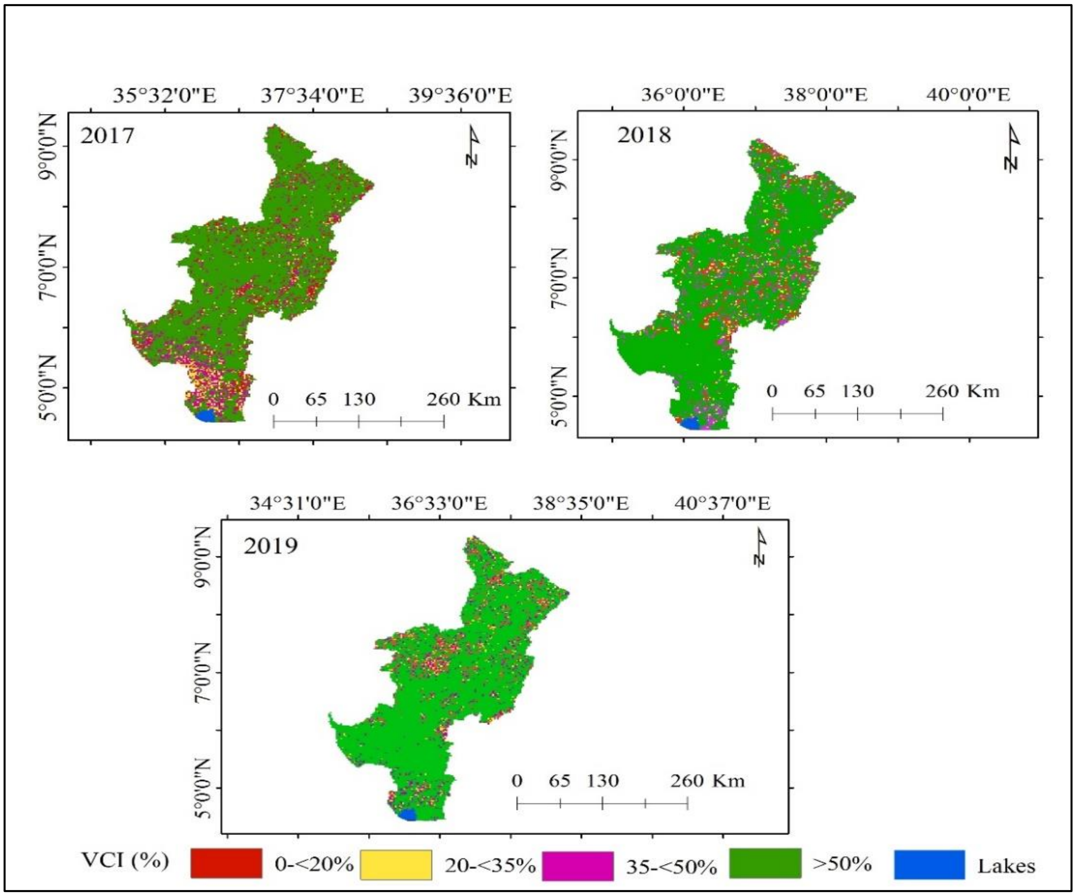


Figure 17: The spatial pattern of the VCI for Summer season from 2017 to 2019

4.3.2. Relationship between SPI and VCI

Findings from this study confirmed that as SPI suited for the rainfall based drought indices which show deviation of ranfall from long term mean; whereas, VCI is the remote sensing indices which show vegetation stress. The temporal trend of VCI and SPI was indicated (Figure 19). The relationship between mean SPI and VCI was positive and confirmed good correlation with (r = 0.67) and they are good indicator of drought in the Omo-Gibe basin (Figure 20). This finding is in line with other previous studies (Zhang and Jia, 2013; Bayissa, 2018)

The years 2009 and 2016 were identified as a drought years mainly because of a large area with fair to extreme vegetation condition damage; whereas the year 2013 was observed as wet year. This shows that VCI is also a good indicator of drought like SPI to capture the historic drought events in study area. The patterns of the Mean SPI during the rainy season (left) and VCI (right) are shown in figure 18 below.

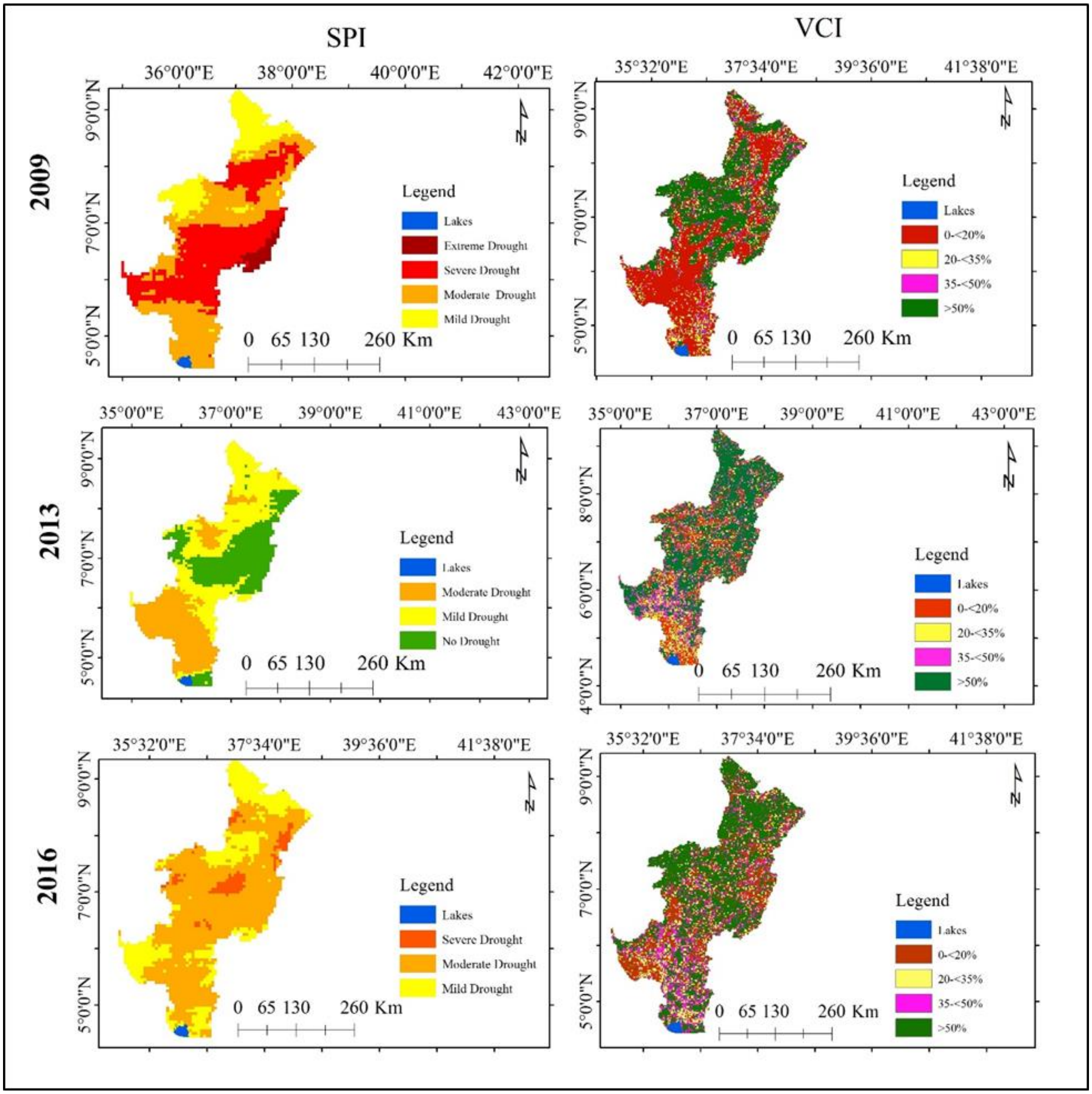


Figure 18: The spatial extents of meteorological drought during recent drought years (2009 and 2016) and one wet year (2013) revealed by SPI (left) and VCI (right)

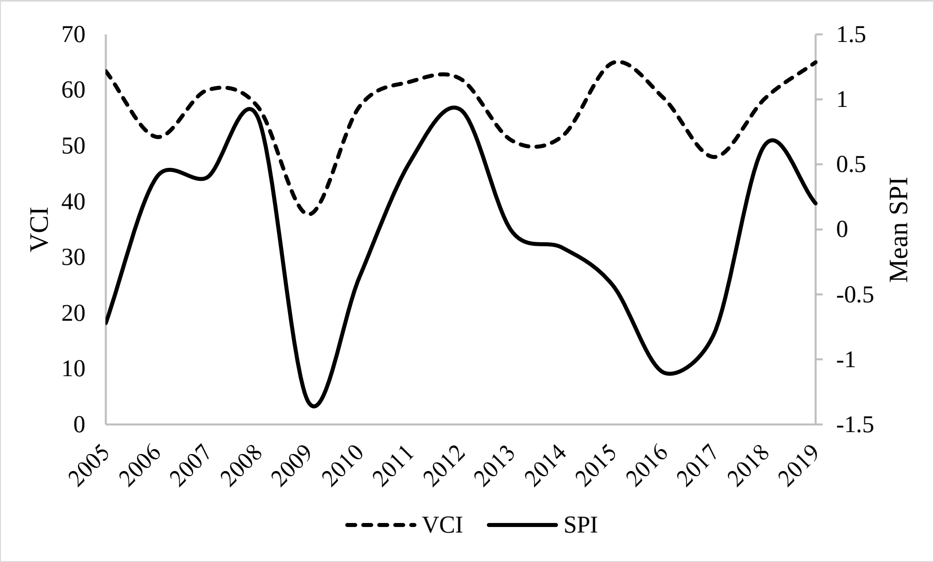


Figure 19: Temporal trends of VCI and SPI during 2015-2019

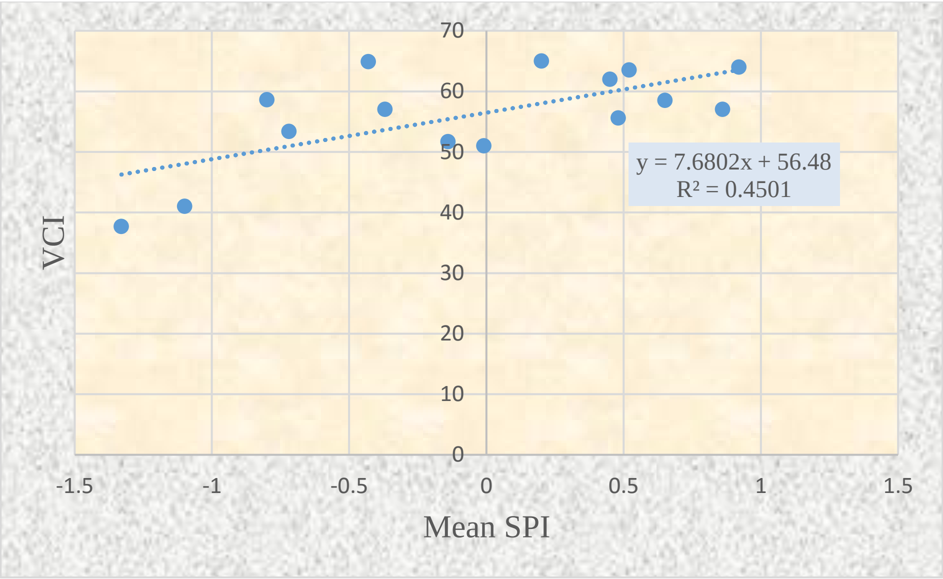


Figure 20: Correlation between VCI and SPI.from 2005-2019

4.3.3. Assessment of Drought Based on Drought Severity Index (DSI)

The Drought severity index (DSI) was calculated from the corresponding NDVI to identify and characterize the drought prone area; and to compare with the drought assessed by SPI values. The DSI maps from the year 2005 to 2019 were produced to assess the spatial and temporal extents of drought in the study area. The result indicates that DSI values less than 0.25 were observed in the Northeast, Southern and central parts, with different levels of severity which confirms the drought assessed by SPI and VCI in the study area (Figure 21, 22 and 23). In this study DSI value < 0.25 which is a good indicator of drought presence. The maps indicate that in the rainy season years, 2009 and 2016, large portion of the study area faced fair to extremely drought

(DSI values less than 0.25). The year 2009 was evidently identified as a drought year, because of a large area with DSI values less than 0.25. This shows that DSI is also a good pointer to capture the historic drought events.

In addition to SPI and VCI, DSI values also shows that the presence of drought was identified. For the period of 2005-2019, the mean seasonal DSI values were 0.002 -0.013, 0.007, 0.053,-0.034, 0.001, 0.013, 0.018, -0.02, -0.018, 0.024, -0.009, -0.027, 0.007, 0.019, respectively. Whereas the dry years were also recognized as 2009, 2014, and 2016 with mean seasonal DSI values of -0.034, -0.018, and -0.009, respectively.The results of this study confim with previous findigs (Measho *et al*., 2019).

The temporal trend of DSI shows, there was occurrence of drought in different years. However, its severity varied spatially and temporally across the basin during the study period. For instance, the DSI value was less than 0 throughout the summer season of the drought year assessed by SPI and VCI (2009, 2014 and 2016) indicating drought.

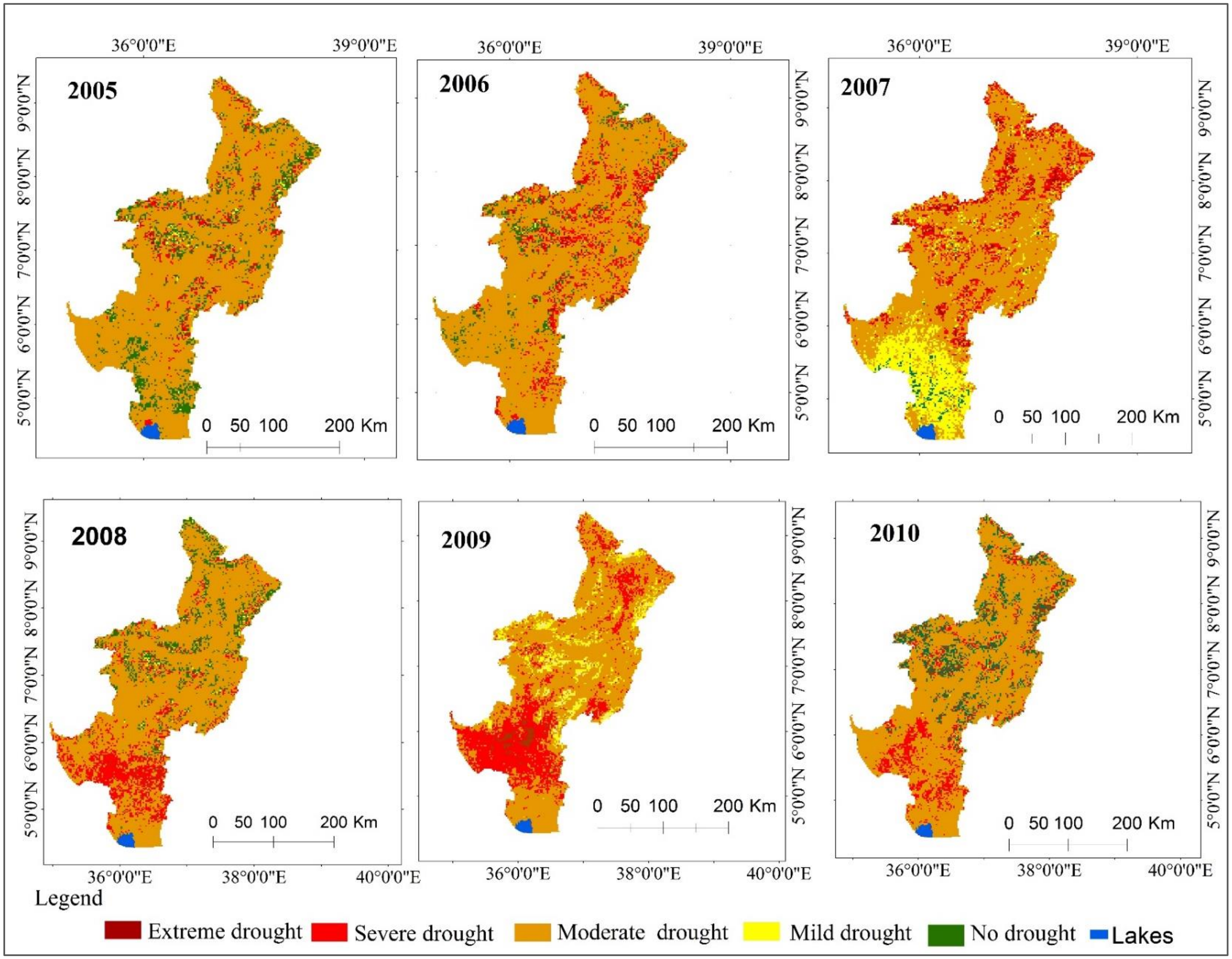


Figure 21: The spatial pattern of the DSI for Summer season from 2005 to 2010

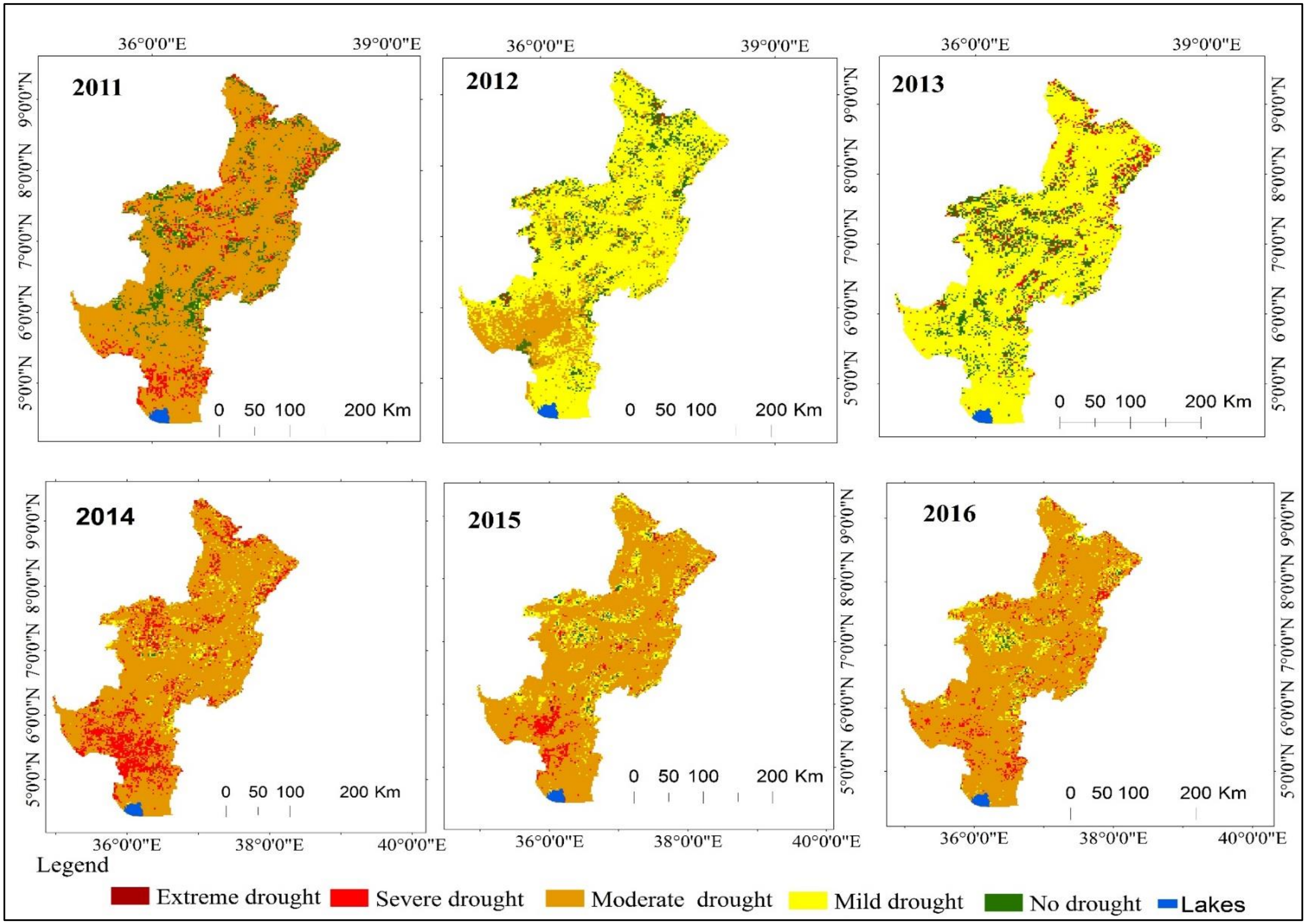


Figure 22: The spatial pattern of the DSI for Summer season from 2011 to 2016

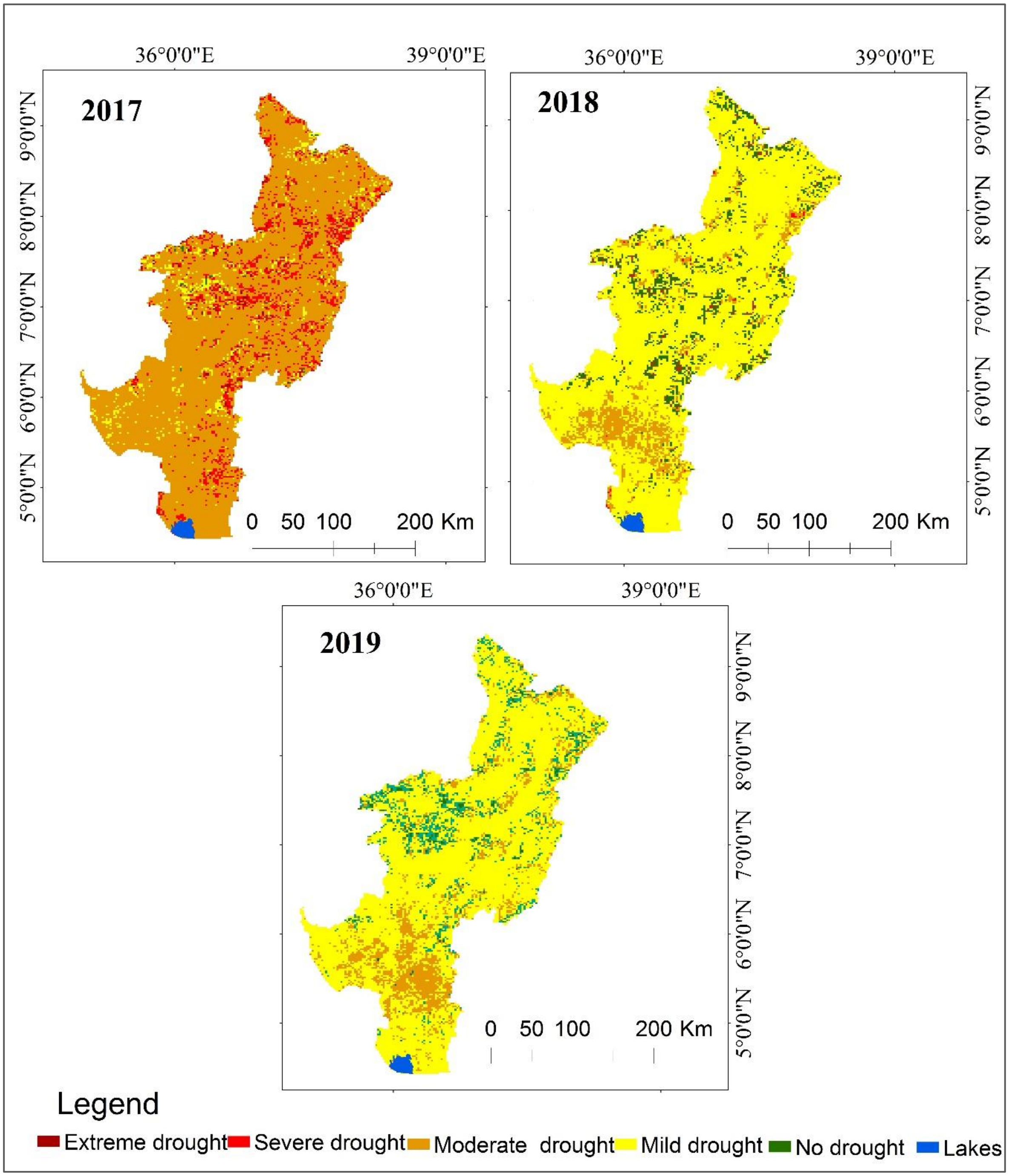


Figure 23: The spatial pattern of the DSI for Summer season 2017 to 2019

4.3.4. Relationship Between DSI and SPI

After relationship of both indices were evaluated, there was positive correlation between the values mean SPI and DSI of drought indices corresponding either increased or decreased. The statistical indicators showed that as good agreement between both indices with (r=0.63). DSI values indicated historic drought years like SPI. DSI values were too small in 2009, 2014, 20015, and 2016, with the values less than 0 (Figure 24). The SPI value was also low during those years with values less than 0. Hence, both of these drought indices showed the occurrence of drought in study area during the study periods.The results of this study confirms the previous findings (Bayissa, 2018)

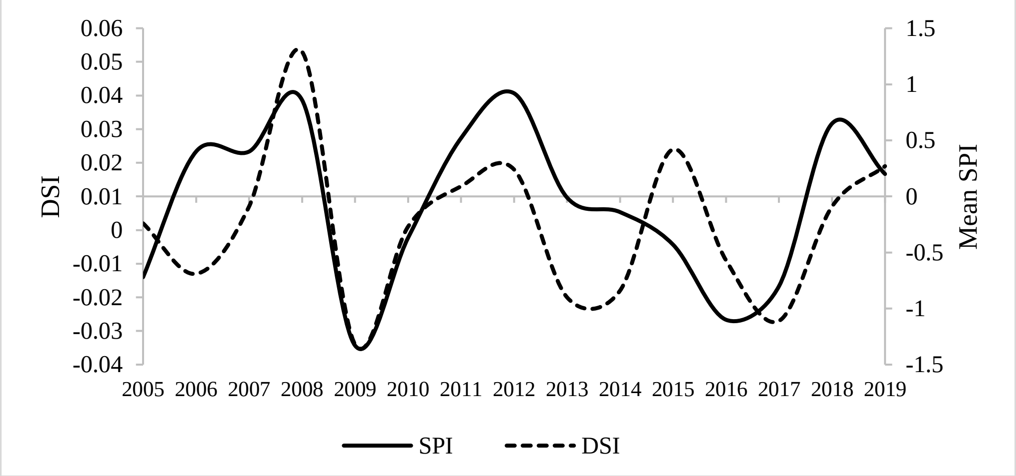


Figure 24: Temporal trends of DSI and SPI during 2005-2019

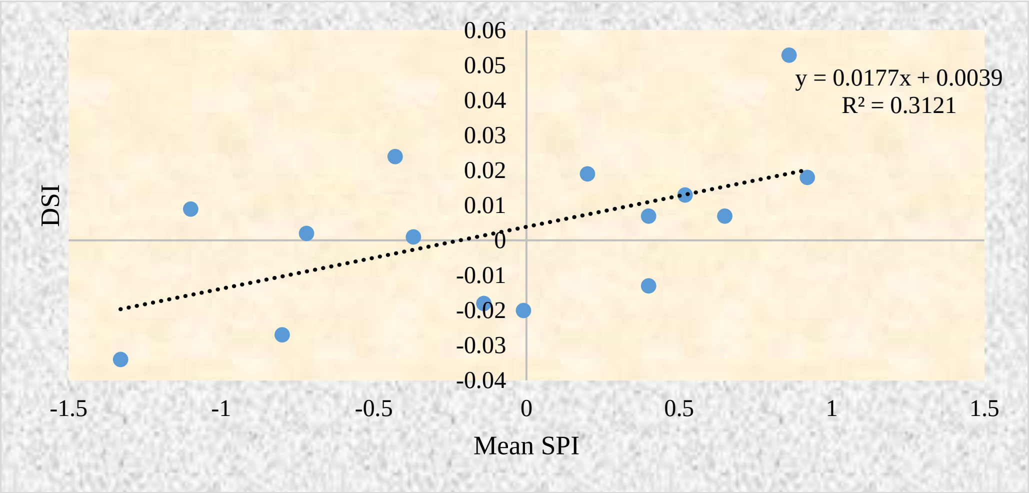


Figure 25: Relationship between DSI and DSI from 2005-2019

4.4. Estimation Probability of droughts in 100 years in Omo-Gibe basin

The expected drought occurrences for 3-month timescales in 100 years presented in table 12. The highest occurrences are expected for moderate drought intensity droughts followed by severe drought for shorter timescales (3-month). According to Labedzki, (2007), droughts of shorter timescales are circulated and change rapidly, while the longer timescale droughts are concentrated in the series of consecutive months within one year or succeeding several years. Accordingly, in this study for the 3-month timescale one can expect a total number of drought events of 42 (Jimma), 39 (Jinka), 36 (Woliso), 33 (Bita woshi, Hosana and wolaita), 30 (Dimeka and Lote), 27 (Wolkite), 24 (Tibe) at each in 100 years.

Among these,between 15, 15 ,12 events at jimma, 15, 6, 12 at Bita woshi and 18, 12, 9 events at Jinka are expected to occur with moderate, severe and extreme intensity respectively. In contrast twelve (12) extreme intensity droughts events are expected at Jimma and Bita woshi, 9 events at Jinka, Wolaita and Hosana. The estimated drought incidents for the shorter (3-month) time scales contribute vital implications for the management and preparation of agricultural activities as well as for disaster preparedness (Labedzki, 2007; Ellis *et al*., 2010). The prediction did not show any extreme intensity drought event at Dimeka,Lote and Wolkite in 100 years' time. However, Tibe and Woliso can be expected to experience extreme intensity droughts on six (6) times. Severe and moderate drought event can be expected in all station while Extreme drought event can be expcted in most of the station for next 100 years with different number of occasions. The results of this study also in line the findings of previous studies (Edossa *et al*., 2010; Viste *et al*., 2013).

Table 12: Probability of drought events per 100 years calculated at 3-month time scales

Station	Locatio(Lat,Long)	Elevation(a.m. s.l)	Intensity	Drought frequency (3-months)
Bita woshi	7^{0}32'N;36^{0}03'E	1836	Moderate	15
			Severe	6
			Extreme	12
			Total	33
Dimeka	5^{0}17'N;36^{0}53'E	1115	Moderate	21
			Severe	9
			Extreme	0
			Total	30
Hosana	7^{0}57'N;37^{0}85'E	2307	Moderate	18

			Severe	6
			Extreme	9
			Total	33
Jimma	$7^0$67’N;$36^0$82’E	1718	Moderate	15
			Severe	15
			Extreme	12
			Total	42
Jinka	$5^0$77’N;$36^0$55’E	1373	Moderate	18
			Severe	12
			Extreme	9
			Total	39
Lote	$6^0$39’N;$37^0$00’E	1254	Moderate	21
			Severe	9
			Extreme	0
			Total	30
Tibe	$9^0$05’N;$37^0$17’E	1673	Moderate	12
			Severe	6
			Extreme	6
			Total	24
Wolaita	$6^0$81’N;$37^0$73’E	1854	Moderate	18
			Severe	6
			Extreme	9
			Total	33
Woliso	$8^0$55’N;$37^0$98’E	2058	Moderate	21
			Severe	9
			Extreme	6
			Total	36
Wolkite	$8^0$13’N;$37^0$45’E	2000	Moderate	15
			Severe	12
			Extreme	0
			Total	27

CHAPTER FIVE

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusion

The satellite-based rainfall estimate products at local and global scales availability has proved to be valuable in the data gap filling, above all for developing countries that have lack of data in climatic condition study. Evaluating these rainfall products is vital for any application that includes studying drought and water resources problems. In this study, the performances of three satellite rainfall products (CHIRPS, PERSIANN and TMPA) were first examined by comparing them with gauged rainfall data from ten selected independent weather stations in Omo-Gibe basin. The statistical indicators was used for the performance evaluation at monthly,seasonal and yearly time scales. The evaluation process was carried out to find the best satellite rainfall product for spatial and temporal assessment of meteorological drought in the basin. After evaluating the results, the following conclusions were drawn. Accordingly, the performance of the three satellite rainfall products were logically good in detecting the incidence of rainfall and in estimating the amount of monthly, seasonal and yearly rainfall in the basin. Comparison of the three satellite rainfall products have revealed that CHIRPS was the best products; and TMPA showed good performance next to CHIRPS while PERSSIAN showed the poorest performance when evaluated in all statistical measures considered in this study at the monthly time scale. CHIRPS performed very well under all the evaluation criteria considered during the monthly, seasonal and yerly time scales. Relatively higher correlation coefficients ($r > 0.73$) and mean Bias (0.99) whereas correlation coefficient($r >50$)and mean Bias (0.99) were recorded when the CHIRPS and TMPA rainfall product was compared with gauged rainfall on monthly time scale respectively. In addition, CHIRPS scored the best ME and RMSE by 70% and 80% in the total validation weather stations. TMPA scored the next highest performance whereas PERSIANN showed relatively weak. Thus, CHIRPS rainfall was selected and used for further application to study the spatial and temporal patterns of meteorological drought in the Omo-Gibe basin.

The temporal assessment of meteorological drought showed the occurrence of mild to extreme drought events in the Omo-Gibe basin. The severity of the known drought years, such as 1994–1995, 2000, 2002-2003, 2009-2010, 2014–2015, and 2016 was indicated in most of the weather stations. The spatial assessment of drought in the Omo-Gibe basin also showed the occurrence of the extreme drought event that covered mainly the central, eastern and southern parts of the basin. The 2009 drought was notable and clearly indicated in the drought-prone district of the Omo-Gibe basin (i.e., eastern and southern parts). The validity of the result from SPI was computed by Vegetation Condition Index (VCI) and Drought Severity Index (DSI) with R^2 value of 0.45 and 0.31 respectively. The expected drought occurrences for 3-month timescales in the next 100 years shows that more drought events are expected at Jimma by about 42 times with 15(moderate), 15 (severe) and 12 (extreme) severity classes. Henceforth, the CHIRPS rainfall product can be used as an alternative source of information in developing the grid-based drought monitoring tools for the basin that could help in developing early warning systems.

Generally, the results indicated that the CHIRPS rainfall product could be used as an alternative source of information to develop the drought monitoring tools for an early warning system that could help in making better decisions in the basin.

5.2. Recommendation

Based on the results of this study, the following foremost recommendations can be made:

- The spatial distributions of the rainguage stations are not dense in the basin. This affects the accuracy of the spatial representation of the data that finally influences the selection of station for satellite performance evaluation. Hence it is recommended that weather stations should be densely and evenly distributed in the basin.
- The temporal scale of the drought assessment in this study was on 3-month time scale. It would be helpful to test the index used in this study at a finer temporal resolution (monthly). This would help developing an effective drought monitoring system
- The drought indices used for validation in this study was shows weak relationship in seasonal time scale. It would be useful to test the indices used in this study at a finer temporal resolution and also compute the lag time between rainfall deviation and drought indices.
- Since CHIRPS was selected as best performed satellite rainfall product, agriculture and rural development officers including meteorologist should adopt in monitoring drought and early warning system in the basin.
- The drought indices used in this study clarified some aspects of the historic drought events (i.e, severity).Therefore it can be, recommended future study use an additional indices to identify onset and duration of drought events when preparing for drought monitoring and early warning in a specific study area

REFERENCES

Abera, W., Brocca, L., and Rigon, R. (2016). Comparative evaluation of different satellite rainfall estimation products and in the Upper Blue Nile (UBN) basin, *Atmos. Res*.178: 471–483.

Addis Ababa, Ethiopia.

Ahrens, C., D. (2000). Meteorology Today. An Introduction to Weather, Climate and the Environment. Sixth Edition's: Brooks/Cole.

Araya, A., et al., 2010. Determination of local barley (Hordeum vulgare) crop coefficient and comparative assessment of water productivity for crops grown under the present pond water in Tigray, northern Ethiopia.

Barrett, E., C. (1970). The estimation of monthly rainfall from satellite data. *Mon. Wea. Rev*. 40(1), 1927–1942.

Barua, S., Ng, A., and Perera, B. (2011). Comparative evaluation of drought indexes: case study on the Yarra River catchment in Australia. *Journal of Water Resources Planning and Management*. 137, 215–226. doi:10.1061/(ASCE)WR.19435452.0000105.

Bayissa, Y., Tadesse, T., Demisse, G., and Shiferaw, A. (2017). Evaluation of satellite-based rainfall estimates and application to monitor meteorological drought for the Upper Blue Nile Basin, Ethiopia. *Remote Sensing*, 9(7). https://doi.org/10.3390/rs9070669.

Bayissa, YA. (2018). Developing an Impact-Based Combined Drought Index for Monitoring Crop Yield Anomalies in the Upper Blue Nile Basin, Ethiopia. Unpublished dissertation, Netherland.

Bayissa, YA., Moges, SA., Xuan, Y., Van Andel, SJ., Maskey, S., Solomatine, DP., Tadesse, T. (2015). Influence de la durée des chroniques météorologiques sur la caractérisation des sécheresses météorologiques du bassin supérieur du Nil Bleu (Ethiopie). *Hydrological Sciences Journal*. 60(11): 1927–1942.

Beyene, EG., and Meissner, B. (2010). Spatio-temporal analyses of correlation between NOAA satellite RFE and weather stations' rainfall record in Ethiopia. *International Journal of Applied Earth Observation and Geoinformation.*

Birhanu Gediff, Legesse Hadish, Solomon Addisu and Suryabhagavan, K.V. (2014). Drought Risk Assessment using Remote Sensing and GIS: The case of Southern Zone, Tigray Region, Ethiopia. Journal of Natural Sciences Research, 4 (23): 87-94.

Bitew, MM., Gebremichael, M., Ghebremichael, LT., and Bayissa, YA. (2012). Evaluation of high-resolution satellite rainfall products through streamflow simulation in a hydrological modeling of a small mountainous watershed in Ethiopia. *Journal of Hydrometeorology*. 13(1): 338–350.

Bokusheva, R., Kogan, F., Vitkovskaya, I., Conradt, S., Batyrbayeva, M. (2016). Satellite based vegetation health indices as a criterion for insuring against drought-related yield losses. *J. rs.* 3(1), 1–10.

Cancelliere, A., et al., 2007. Drought forecasting using the standardized precipitation index. Water Resources Management, 21, 801–819. doi:10.1007/s11269-006-9062-y

Chaemiso, SE., Abebe A., and Pingale, S. M. (2016). Assessment of the impact of climate change on surface hydrological processes using SWAT: a case study of Omo-Gibe river basin, Ethiopia. *Modeling Earth Systems and Environment*. 2(4): 1–15. https://doi.org/10.1007/s40808-016-0257-9.

Chaulagain, NP. (2006). Impacts of climate change on water resources of Nepal: The physical and socioeconomic dimensions. M.Sc. thesis, University of Flensburg, Germany

Corti T, Muccione V, Köllner-Heck P, Bresch D, Seneviratne SI. (2009). Simulating past droughts and associated building damages in France. Hydrol Earth Syst Sci 2009, 13:1739–1747. doi:10.5194/hess-13-1739.

CSA (2008). Summary and statistical report of the 2007 Population and Housing Census.

Dandridge, C. (2019). Evaluation of satellite based rainfall estimates in the Lower Mekong River, Southesta Asia. *M. s e*. 2(8): 100–110.

Degefu, MA., and Bewket, W. (2015). Trends and Spatial Patterns of Drought Incidence in the Omo-Ghibe River Basin, Ethiopia. *Geografiska Annaler*: Series A, Physical Geogra phy, 97, 395–414. doi:10.1111/geoa.12080.

Demaria, EMC., Rodriguez, DA., Ebert, EE., Salio, P., Su, F., and Valdes, JB. (2010). Evaluation of mesoscale convective systems in South America using multiple satellite products and an object-based approach, *J. Geophys. Res.-Atmos*. 116: 1–13. doi:10.1029/2010JD015157, 2011.

Dinku, T., Chidzambwa, S., Ceccato, P., Connor, S. J., and Ropelewski, CF. (2008). Validation of high-resolution satellite rainfall products over complex terrain. *International Journal of Remote Sensing*. 3(1), 1–10.

Dinku, T., Connor, SJ., and Ceccato, P. (2010). Comparison of CMORPH and TRMM-3B42 over Mountainous Regions of Africa and South America, in: Satellite Rainfall Applications for Surface Hydrology, edited by: Gebremichael, M. and Hossain, F., Springer Netherlands.

Duan, Z., Bastiaanssen, W., and Liu, J. (2012). "Monthly and Annual Validation of TRMM Mulitisatellite Precipitation Analysis (TMPA) Products in the Caspian Sea Region for the Period 1999–2003." Paper presented at the 2012 *IEEE International Geoscience and Remote Sensing Symposium* (IGARSS), Germany, July 22–27.

Ebert, EE. (1996). Results of the 3rd Algorithm Intercomparison Project (AIP-3) of the Global Precipitation Climatology Project (GPCP). Melbourne: Bureau of Meteorology Research Centre.

Edossa, D.C., Babel, M.S., and Gupta, A.D., 2010. Drought analysis in the Awash River Basin, Ethiopia. Water Resources Management, 24, 1441–1460. doi:10.1007/ s11269-009-9508-0

Edwards, DC, and McKee, TB. (1997). Characteristics of 20th Century Drought in the United States at Multiple Scales. *Atmospheric Science Paper* No. 634, May 1–30.

Ellis, A.W., Goodrich, G.B. and Garfin, G.M., 2010. A hydroclimatic index for examining patterns of drought in the Colorado River Basin. International Journal of Climatology, 30, 236–255. doi:10.1002/ joc.1882

EUMETSAT.(1998). Directory of Meteorological Satellites Applications. Coordination Group for Meteorological Satellites (CGMS), EUM BR 08.

FAO. (2004). Review of World Water Resources by Country, Water Reports (23), *Food and Agriculture Organization of the United Nations*,Rome.

Fleig K, Tallaksen LM, Hisdal H, Demuth S. (2006). A global evaluation of streamflow drought characteristics. *Hydrol Earth Syst Sci* 10:535–552. doi:10.5194/hess-10-535-2006.

Gebresenbet, F and Kefale, A.(2012). Traditional coping mechanisms for climate change of pastoralists in South Omo, Ethiopia. *Indian Journal of Traditional Knowledge*, 11 (4), 573–579.

Guttman, N.B. (1999). Accepting the standardized precipitation index: a calculation algorithm. *J. Am. Water Resour. Assoc.* 35 (2), 311–322.

Hao Guo , Anming Bao ,*, Tie Liu , Felix Ndayisaba ming He, Alishir Kurban and Philippe De Maeyer, 2017. Meteorological Drought Analysis in the Lower Mekong Basin Using Satellite-Based Long-Term CHIRPS Product. Sustainability 2017, 9, pp.901.

Harries, J E. (2000). The Geostationary Earth radiation Energy experiment: Status and Science. Proceedings of the 2000 EUMETSAT Meteorological Satellite Data User's Conference, Bologna, EUM-P29, 62 –71.

Hayes M. 2000. Revisiting the SPI: clarifying the process. Drought Network News 12(1): 13–14 [available online at http://enso.unl.edu.ndmc/center/dnn/winspr.pdf]

Heim, R. (2002). A review of twentieth-century drought indices used in the United States. Bull. *Am. Meteorol. Soc*. 83, 1149–1165.

Hewitt, K. (2014). Regions of risk: A geographical introduction to disasters.

Hirpa, F. A., Gebremichael, M., and Hopson, T. (2010). Evaluation of high-resolution satellite precipitation products over very complex terrain in Ethiopia. J*ournal of Applied Meteorology and Climatology*, 49(5), 1044–1051.

Hisdal H, Tallaksen LM, Clausen B, Peters E, Gustard A. (2004). Hydrological drought characteristics. In: Developments in Water Science, vol. 48. Amsterdam, the Netherlands: *Elsevier Science* B.V.; 139–198.

Hong, Y., Gochis, D., Cheng, J., Hsu, K., and Sorooshian, S. (2007). Evaluation of PERSIANN-CCS Rainfall Measurement Using the NAME Event Rain Gauge Network, Journal of Hydrometeorology, 8(3), 469–482, doi:10.1175/JHM574.1.

Hsu, K.-L., Gao, X., Sorooshian, S., and Gupta, H V.(1999). Precipitation Estimation from Remotely Sensed Information Using Artificial Neural Networks, *J. Appl. Meteorol.*, 36, 1176–1190, doi:10.1175/1520-0450.

Hu Q, Yang D, Li Z, Mishra AK, Wang Y, Yang H .(2014). Multi-scale evaluation of six high-resolution satellite monthly rainfall estimates over a humid region in China with dense rain gauges. *Int J Remote Sens* 35:1272–1294.

Huffman, G. J., D. T. Bolvin, E. J. Nelkin, D. B. Wolff, R. F. Adler, G. Gu, Y. Hong, K. P. Bowman, and E. F. Stocker. (2007). The TRMM Mulitisatellite Precipitation Analysis (TMPA): Quasi-Global, Multiyear, Combined-Sensor Precipitation Estimates at Fine Scales. *Journal of Hydrometeorology* Intergovernmental Panel on Climate Change.

information (CODI IV), 22 –30 April, Addis Ababa. United Nations Economic Commission for Africa, 3.

IPCC .(2007). Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. IPCC

IPCC.(2001a). Contribution of Working Groups I, II, and III to the Third Assessment Report of the IPCC. Cambridge University Press, Cambridge, p 398

IPCC.(2014). Impacts, adaptations and vulnerability", Working Group II Contribution to the Fifth Assessment Report of Intergovernmental Panel on Climate Change,Cambridge University Press, Cambridge, MA.

Janowiak JE,KouskyVE, JoyceRJ (2005) Diurnalcycleofprecipitation determinedfromthe CMORPH highspatialandtemporalresolution global precipitation analyses. J Geophys Res: Atmos 110:D23105. https://doi.org/10.1029/2005JD006156

Joyce, R. J., Janowiak, J. E., Arkin, P. A., and Xie, P, CMORPH. (2004). A method that produces global precipitation estimates from passive microwave and infrared data at high spatial and temporal resolution, J. Hydrometeorol., 5, 487–503

Kogan F, Adamenko T, Guo W .(2013). Global and regional drought dynamics in the climate warming era. *Remote Sens* Lett 4(4):36472

Kogan F, Guo W. (2016). Early twenty-first-century droughts during the warmest climate. Geomatics Nat Hazards Risk 7(1):127–137.

Kogan FN. (1990). Remote sensing of weather impacts on vegetation in non-homogeneous area. *Int J Remote Sens* 11(8):1405–1419.

Kogan, F N. (1997). Global Drought Watch from Space. Bulletin of the American Meteorological Society, 78(4), 621–636. Korecha, D., and Barnston, A. G. (2007). Predictability of June-September rainfall in Ethiopia. Monthly Weather Review

Laaha G, Hisdal H, Kroll CN, Van Lanen HAJ, Sauquet E, Tallaksen LM, Woods R, Young A. Prediction of low flows in ungauged basins. In: Blöschl G, Sivapalan M, Wagener T, Viglione A, Savenije H. (2013). Runoff Prediction in Ungauged Basins. Cambridge, UK: Cambridge University Press.

Labedzki, L. (2007).Estimation of local drought frequency in central Poland using the precipitation index SPI. 2007. *Irrigation and Drainage*, 56 (1), 67–77. doi:10.1002/ ird.285

Li Z, Yang D, Hong Y (2013) Multi-scale evaluation of high-resolution multi-sensor blended global precipitation products over the Yangtze River. J Hydrol 500:157–169. https://doi.org/10.1016/ j.j hydrol. 2013.07.023

Li, J., Lewis, J., Rowland, J., Tappan, G. and Tieszen, L.L. (2004). Evaluation of land performance in Senegal using multi-temporal NDVI and rainfall series. *Journal of Arid Environments.*

Li, W., et al., 2008. Observed change of the standardized precipitation index, its potential cause and implications to future climate change in the Amazon region. Philosophical Transactions of the Royal Society B: Biological Sciences, 363, 1767. doi:10.1098/rstb.2007.0022

Lloyd-Hughes, B., Saunders, M. (2002). A drought climatology for Europe. Int. J. Climatol. 22, 1571–1592.

Logan, K. E., Brunsell, N. A., Jones, A. R., and Feddema, J. J. (2010). Assessing spatiotemporal variability of drought in the US central plains. *Journal of Arid Environments*, 74(2), 247-255.

Maggioni, V., Meyers, P. C., and Robinson, M. D. (2016). A Review of Merged High-Resolution Satellite Precipitation Product Accuracy during the Tropical Rainfall Measuring Mission (TRMM) Era,*J.Hydrometeorol.*,17.

Maidment, R. I., D. I. Grimes, R. P. Allan, H. Greatrex, O. Rojas, and O. Leo. (2013). Evaluation of Satellite-Based and Model Re-Analysis Rainfall Estimates for Uganda. *Meteorological Applications* 20 (3): 308–317.

Manatsa, D., Chingombe, W. and Matarira, C. H. (2008). The impact of the positive Indian Ocean dipole on Zimbabwe droughts Tropical climate is understood to be dominated by. *International Journal of Climatology,* 2029 (March 2008).

Mantas, V., Liu, Z., Caro, C., and Pereira, A.(2015). Validation of TRMM multi-satellite precipitation analysis (TMPA) products in the Peruvian Andes, Atmos. Res., 163, 132–145.

McKee, T.B., Doesken, N.J., Kleist, J. (1993). The Relationship of Drought Frequency and Duration to Time Scales, Paper Presented at 8th Conference on Applied Climatology. *American Meteorological Society,* Anaheim, CA.

Measho, S., Chen, B., Trisurat, Y., Pellikka, P., and Guo, L. (2019). Spatio-Temporal Analysis of Vegetation Dynamics as a Response to Climate Variability and Drought Patterns in the Semiarid Region , Eritrea.

Melese, A., Suryabhagavan, K. V, and Balakrishnan, M. (2018). Multi-model and Vegetation Indices for Drought Vulnerability Assessment : A Case Study of Afar Region in Ethiopia. 2(1), 1–14.

Mishra, A., and Singh, V. (2010). A review of drought concepts. *Journal of Hydrology,* 391(1–2), 202–216.

Mishra, A.K., Desai, V.R. (2005a). Spatial and temporal drought analysis in the Kansabati River Basin, India. *Int. J. River Basin Manage*. 3 (1), 31–41.

Mishra, A.K., Singh, V.P. (2009). Analysis of drought severity-area-frequency curves using a general circulation model and scenario uncertainty. *J. Geophys.*

Mokonnen, D. (2007). Satellite-Based Rainfall Estimation: Evaluation and Characterization (A Case Study Over Omo-Gibe River Basin).

MoWR (Ministry of Water Resources) .(1996). Integrated development of Omo-Gibe River Basin Master Plan Study, vol XI F1, F2, F3, Addis Ababa

Mu, Q., Zhao, M., Kimball, J. S., McDowel, N. G. and Runnin, S. W. (2013). A Remotely Sensed Global Terrestrial Drought Severity Index. Bulletin of the American Meteorological Society.

Nesbitt, S. W., Gochis, D. J., and Lang, T. J (2008). The Diurnal Cycle of Clouds and Precipitation along the Sierra Madre Occidental Observed during NAME-Implications for Warm Season Precipitation Estimation in Complex Terrain, J. Hydrometeorol., 9(4), 728–743, 200

Owusu, C., Adjei, K. A., and Odai, S. N. (2019). Evaluation of Satellite Rainfall Estimates in the Pra Basin of Ghana. *Environmental Processes,* 6(1), 175–190. https://doi.org/10.1007/s40710-018-0344-1

Özger, M., Mishra, A.K., Singh, V.P. (2009). Low frequency variability in drought events associated with climate indices. *J. Hydrol.*

Palmer, W.C. (1965). Meteorological drought. Research Paper No. 45, 1-58. US. Department of Commerce Weather Bureau, Washington, D.C.

Panu, U.S., Sharma, T.C. (2002). Challenges in drought research: some perspectives and future directions. *J. Hydrol*. Sci. 47, 19–30.

Quiring, S.M., Papakyriakou, T.N. (2003). An evaluation of agricultural drought indices for the Canadian prairies. *Agric. For. Meteorol*. 118, 49–62.

Rao, P. K., S. J. Holmes, R. K. Anderson, J. S. Winston, and P. E. Lehr. (1990). Weather Satellites: System, Data, and Environmental Applications. *American Meteorological Society*, Boston.

Rhee J, Im J, Carbone GJ. (2010). Monitoring agricultural drought for arid and humid regions using multi-sensor remote sensing data. Remote Sens Environ 114(12):2875–2887

Richard Woodroofe and associates. (1996). Omo-Gibe River basin Integrated Development Master Plan Study Final Report, Vol. VI Water resources Surveys and Inventories, ministry of Water Resources, Addis Ababa

Rogelis, MC and Werner, MG. (2013). Spatial Interpolation for Real Time Rainfall Field Estimation in Areas with Complex Topography, *J. Hydrometeorol.*, 14, 85–104,.

Romilly, T. G., and Gebremichael, M. (2011). Evaluation of satellite rainfall estimates over Ethiopian river basins. *Hydrology and Earth System Sciences.*

Scheel, M. L. M., Rohrer, M., Huggel, Ch., Santos Villar, D., Silvestre, E., and Huffman, G. J. (2011). Evaluation of TRMM Multi-satellite Precipitation Analysis (TMPA) performance in the Central Andes region and its dependency on spatial and temporal resolution, *Hydrol. Earth Syst.*

Schipper, O. (2003). Declining water resources raise food concerns. *Environmental Science and Technology*, 37(15)273A-274A.

Schmetz, J. P. Pili, S. Tjemkes, D. Just, J. Kerkmann, S. Rota, and A. Ratier. (2002). An Introduction to Meteosat Second Generation (MSG). Bull Amer. Meteor. Soc., 83,977 – 992.

Scofield, R. A. and Kuligowski, R. J. (2007). Satellite Precipitation Algorithms for Extreme Precipitation Events, *Springer*, Netherlands, 485–495.

Senay, G.B., Bohms, S., Verdin, J.P., 2012. Remote sensing of evapotranspiration for operational drought monitoring using principles of water and Energy balance. In: Wardlow, B.D., Anderson, M.C., Verdin, J.P. (Eds.), Remote Sensing of Drought: Innovative Monitoring Approaches. CRC Press, pp. 123e144.

Senay, G.B., Verdin, J., 2003. Characterization of yield reduction in Ethiopia using a GIS-basedcrop water balance model. Can. J. Remote Sens. 29 (6), 687e692.

Shafer, B.A., Dezman, L.E. (1982). Development of a Surface Water Supply Index (SWSI) to Assess the Severity of Drought Conditions in Snowpack Runoff Areas. In: Preprints, Western Snow Conf., Reno, NV, Colorado State University, pp. 164–175.

Shaheen, A. and Baig, M. A. (2011). Drought severity assessment in arid area of Thal Doab using remote sensing and GIS. *International Journal of Water Resources and Arid Environments.*

Shatanawi,K.,Rahbeh,M.andShatanawi,M. (2013), "Characterizing, monitoring and forecasting of drought in Jordan river basin", *Journal of Water Resource and Protection*, Vol. 5 No. 12, pp.1192-1202.

Sheffield J, Wood EF. (2011). Drought: Past Problems and Future Scenarios. London and Washington DC: *Earth scan.*

Sheffield, J., and Wood, E.F. (2012). Drought: Past problems and future scenarios, Routledge.

Sims, A.P., Niyogi, D.S., Raman, S., 2002. Adopting drought indices for estimating soil moisture: a North Carolina case study. *Geophys. Res. Lett*. 29 (8), 1183.

Singh, S. (2006). Drought and its management in India, Short term course on Drought analysis and management, IIT, Roorkee, SS.

Smakhtin, V.U., Hughes, D.A. (2004). Review, Automated Estimation and Analyses of Drought Indices in South Asia. IWMI Working Paper N 83 - Drought Series Paper No. 1.

Sönmez, F.K., et al., 2005. An analysis of spatial and temporal dimension of drought vulnerability in Turkey using the standardized precipitation index. Natural Hazards, 35, 243–264. doi:10.1007/s11069-004-5704-7

Sorooshian S, Hsu K-L, Gao X, Gupta HV, Imam B, Braithwaite D (2000) Evaluation of PERSIANN system satellite-based estimates of tropical rainfall. Bull Am Meteorol Soc 81:2035– 2046. https://doi.org/10.1175/1520-0477(2000)081<2035: EOPSSE>2.3.CO;2

Springs, C., Springs, C., Springs, C., Springs, C., Climatic, N., Carolina, N., Springs, C. (2010). The NCEP Climate Forecast System Reanalysis.

Steinemann, A.C., Hayes, M.J. and Cavalcanti, L.F.N. (2005). "Drought indicators and triggers", in Wilhite, D.A. (Ed.), Drought and Water Crises: Science, Technology, and Management Issues, CRC Press.

Sternberg, T., Thomas, D. and Middleton, N. (2010). Short communication drought dynamics on the Mongolian steppe, 1970–2006. *International Journal of Climatology*, 31, 1823–1830. doi:10.1002/joc.2195

Su Z, Yacob A, He Y, Boogaard H, Wen J, Gao B, Roerink G, van Diepen K .(2003a). Assessing relative soil moisture with remote sensing data: theory and experimental validation. *Phys Chem Earth* 28(1–3):89–101

Suryabhagavan, K. V. (2017). GIS-based climate variability and drought characterization in Ethiopia over three decades.Weather and Climate Extremes, 15 (2016), 11–23. https://doi.org/10.1016/ j.wace. 2016.11.005

Svoboda, M., (2000). An introduction to the drought monitor. *Drought Network News* 12, 15–20.

Tadesse, T., Senay, G. B., Berhan, G., Regassa, T., and Beyene, S. (2015). Evaluating a satellite-based seasonal evapotranspiration product and identifying its relationship with other satellite-derived products and crop yield: A case study for Ethiopia. *International Journal of Applied Earth*.

Tagel, G., van der Veen, A., and Maathuis, B. (2011). Spatial and temporal assessment of drought in the Northern highlands of Ethiopia. *International Journal of Applied Earth observation and Geo information*, v. 13, p. 309-321.

Taylor, P., Liu, W. T., and Kogan, F. N. (2007). International Journal of Remote Sensing Monitoring regional drought using the Vegetation Condition Index.

Tesfamariam, B. G. (2019). Rainfall retrieval and drought monitoring skill of satellite rainfall estimates in the Ethiopian Rift Valley Lakes Basin. 13(1). https://doi.org/10.1117/1.JRS.13.014522

Thenkabail, P.S., Gamage, M.S.D.N., Smakhtin, V.U. (2004). The Use of Remote Sensing Data for Drought Assessment and Monitoring in Southwest Asia, 85. *International Water Management Institute*. Research Report.

Thiemig, V., Rojas, R., Zambrano-Bigiarini, M., Levizzani, V., and De Roo, A. (2012). Validation of Satellite-Based Precipitation Products over Sparsely Gauged African River Basins, *J. Hydrometeorol.*

Tian, Y. and Peters-Lidard, C. D.(2010). A global map of uncertainties in satellite-based precipitation measurements, *Geophys. Res. Lett*.

Toté, C., D. Patricio, H. Boogaard, R. Van der Wijngaart, E. Tarnavsky, and C. Funk. (2015). “Evaluation of Satellite Rainfall Estimates for Drought and Flood Monitoring in Mozambique.” *Remote Sensing.*

Trambauer, P., Maskey, S., Werner, M., Pappenberger, F., Beek, L. P. H. Van, Uhlenbrook, S., Section, W. R. (2014). Identification and simulation of space – time variability of past hydrological drought events in the Limpopo River basin, *southern Africa*. 2925–2942.

Tshiabukole, K., Khonde, P., Muku, M., Vumilia, K., and Lunekua, K. (2016). Influence of Climate Variability on Seasonal Rainfall Patterns in South-Western DR Congo.

Tucker, C. J. (1979). Red and photographic infrared linear combinations for monitoring vegetation, Remote Sensing of Environment, 8:127–150.

Tucker, C., Pinzon, J., Brown, M., Slayback, D., Pak, E., Mahoney, R., Vermote, E., Saleous,E.L.Andnazmi,E.S.(2005).AnextendedAVHRR8kmNDVIdatasetcompatiblewithMODIS and SPOT vegetation NDVI data. International Journal of Remote Sensing.

UNICA/WMO .(1996). International conference on water resources management and policy in drought prone areas. *International workshop proceeding,* Addis Ababa 18-22.

Van der Molen MK, Dolman AJ, Ciais P, Eglin T, Gobron N, Law BE, Meir P, Peters W, Phillips OL, Reichstein M. (2011). Drought and ecosystem carbon cycling. Agric For Meteorol, 151:765–773.

Verdin, J., Klaver, R. (2002). Grid cell based crop water accounting for the famine early warning system. *Hydrol. Processes* 16, 1617-1630.

Viau, A.A., Vogt, J.V. and Beaudin, I., (2000). Comparison of a satellite-based and a precipitation-based drought index. *Canadian Journal of Remote Sensing*, 26, pp. 580–585.

Vicente-Serrano,S.M.,Chura,O.,López-Moreno,J.I.,Azorin-Molina,C.,Sánchez Lorenzo,A.,Aguilar,E. and Nieto, J.J. (2015), "Spatio-temporal variability of droughts in Bolivia: 1955-2012", International Journal of Climatology.

Vila D. A., L. de Goncalves, D. L. Toll and J. R. Rozante, (2009). Statistical evaluation of combined daily gauge observations and rainfall satellite estimates over continental South America. J. Hydrometeorol. 10, 533-543, doi:10.1175/2008JHM1048.1.

Viste, E., Korecha, D., Sorteberg, A., 2013. Research drought and precipitation tendencies in Ethiopia. Theoretical and Applied Climatology. 112, pp.535–551.

Vogt, J.V., Viau, A.A. and Paquet, F. (2012). Drought monitoring from space using empirical indices and physical indicators. In *International Symposium on Satellite Based Observation:* A Toll for the Study of Mediterranean Basin (Tunisia: Tunis).

Wagaw, M., et al., 2005. GIS implementation to support poverty reduction policy and drought management in Ethiopia. In: Fourth meeting of the committee on development

WAN, Z., WANG, P. and L I, X. (2004). Using MODIS land surface temperature and Normalized Difference Vegetation Index products for monitoring drought in the Southern Great Plains, USA. *International Journal of Remote Sensing.*

Wang, W., Estsen, M.W., Svoboda, M.D., Hafeez, M.(2016). Propagation of drought: from meteorological drought to agricultural and hydrological drought. *Adv. Meteorol.*2016.

Wilhite, D. A. (2007). Drought as a natural hazard: Concepts and definitions. In Wilhite, D. A. (ed.), Drought: *A Global Assessment*, Vol. 1. Routledge, London: 3–18.

Willmott C, Matsuura K. (2005). Advantages of the mean absolute error (MAE) over the root mean square error (RMSE) in assessing average model performance. *Climate Res*.; 30(1): 79-82.

WMO, (1995). In remote sensing for hydrology Progress and prospect, operational report.No.36.WMO No.7

WMO, (2012). Commission for Agricultural Meteorology (CAgM) Report No.101 impacts of desertification and drought and other extreme meteorological events report of the working group on the impacts of desertification and drought and of other extreme meteorological events.

Woldemeskel, F. M., Sivakumar, B., and Sharma, A. (2013). Merging gauge and satellite rainfall with specification of associated uncertainty across Australia, *J. Hydrol.*, 499, 167–176.

Wu, H., et al., 2007. Appropriate application of the standardized precipitation index in arid locations and dry seasons. International JournalofClimatology,27,65–79.doi:10.1002/(ISSN)1097-0088

Xie, P., Arkin, P.A. (1997). A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs. *Bull. Am. Meteorol. Soc*. 78 (11), 2539-2558.

Yu, Z., Yu, H., and Chen, P. (2009). Verification of Tropical Cyclone-Related Satellite Precipitation Estimates in Mainland China, *J. Appl. Meteorol. Clim.*, 48(11), 2227–2241.

Zargar, A., Sadiq, R., Naser, B. and Khan, F.I. (2011). “A review of drought indices”, Environmental Reviews, Vol. 19, pp. 333 -349.

Zhang, A., and Jia, G. (2013). Remote Sensing of Environment Monitoring meteorological drought in semiarid regions using multi-sensor microwave remote sensing data. *Remote Sensing of Environment*, 134, 12–23. https://doi.org/10.1016/j.rse.2013.02.023.

APPENDICES

Appendix 1: 3-months SPI value from 1986 to 2019

year	Bita Woshi	Dimeka	Hosana	Jimma	Jinka	Lote	Tibe	Wolaita	Woliso Giyon	Wolkite
1986	0.49	0.06	-2.76	-1.69	0.04	-0.09	-1.07	0.12	-0.58	-0.83
1987	0.36	-1.81	-2.52	0.27	-2.03	-1.67	-0.39	-2.08	0.33	-0.10
1988	0.40	1.81	0.88	1.88	1.33	0.48	-1.25	1.27	1.26	1.01
1989	-0.93	0.01	-1.08	-0.16	0.17	-1.13	0.34	-0.03	0.16	0.58
1990	2.69	-1.87	-0.65	2.31	-1.05	-1.23	0.10	-1.53	0.52	0.86
1991	0.18	-0.65	0.77	1.79	-1.60	-0.50	0.89	-0.04	-1.01	1.00
1992	1.32	-0.49	1.13	0.63	-1.36	-0.32	0.38	0.04	1.52	1.03
1993	-2.11	-0.50	-0.39	-2.01	0.16	-0.19	-1.68	-1.56	-2.14	-1.25
1994	1.16	0.59	-0.25	0.05	-0.15	-0.46	0.15	0.37	0.96	1.49
1995	-0.52	-0.85	-1.13	-1.53	-1.21	-1.06	-0.47	-1.01	0.09	-1.08
1996	-0.42	0.23	0.12	-0.19	0.57	0.61	-0.57	1.59	1.52	1.52
1997	-0.43	-0.68	-0.58	-1.32	-1.15	-1.07	-1.01	-2.05	-0.01	-0.74
1998	2.28	0.23	0.37	1.72	0.32	-0.09	1.37	0.35	1.84	2.18
1999	-1.33	-0.77	-0.89	-1.33	-0.41	-0.33	-0.53	0.03	1.18	1.03
2000	-2.15	-1.60	-1.88	-1.50	-0.36	0.43	0.52	-1.24	-1.81	-0.45
2001	1.07	-0.41	1.19	0.39	-0.26	0.44	1.94	1.01	-1.03	0.97
2002	-1.63	-1.31	0.34	-2.58	-2.04	-1.05	-2.09	-1.24	0.38	-1.07
2003	-1.40	1.18	0.54	0.57	1.52	2.21	0.42	0.81	-0.12	0.03
2004	0.04	-1.25	-0.44	-0.36	-1.36	-1.54	0.02	-1.02	-0.03	-0.09
2005	0.45	-0.97	-1.29	-1.57	-1.30	-1.55	-0.39	-0.47	-0.57	-0.48
2006	1.38	0.76	1.36	0.24	-0.14	-0.46	1.93	0.19	0.98	0.21
2007	0.00	2.72	0.78	-1.26	2.12	1.94	1.33	1.24	-0.22	-0.13
2008	-1.11	-0.84	-1.12	1.63	0.32	1.00	0.77	0.62	-0.62	0.99
2009	-2.08	-1.52	-1.37	-2.06	-1.64	-1.24	0.65	-2.08	-1.22	-1.61
2010	-0.33	-0.43	0.12	-0.44	-2.07	0.23	-0.46	-0.39	1.47	-0.04
2011	2.32	1.11	-0.24	-0.40	1.70	0.49	0.16	0.16	-0.25	-0.30
2012	1.18	1.67	0.95	0.08	1.67	1.85	0.14	0.68	-2.00	-1.10
2013	0.87	-0.44	2.29	0.11	0.27	1.06	0.06	2.57	-1.01	-0.89
2014	0.46	0.33	-0.37	-2.48	0.06	-0.10	-2.58	0.15	-1.26	-1.59
2015	-1.15	0.03	-0.99	-1.15	0.46	0.44	-1.07	0.40	-1.01	-1.43
2016	-2.09	-1.05	-2.23	-1.53	-1.14	-1.16	-1.85	-1.22	-1.18	-1.58
2017	-0.25	0.27	-0.65	-1.04	-0.15	0.04	0.72	-0.21	-1.55	-1.68
2018	0.52	0.53	-0.34	-0.02	0.25	0.02	-0.20	-1.10	0.82	0.92
2019	2.29	1.64	1.70	0.95	1.45	1.83	0.52	1.50	-1.59	-0.71

Appendix 2**:** 12-months SPI value from 2000 to 2019

Year	Bita Woshi	Dimeka	Hosana	Jimma	Jinka	Lote	Tibe	Wolaita	Woliso Giyon	Wolkite
2000	-2.24	-2.51	-0.64	-0.52	-1.43	-1.20	0.22	-0.73	-0.29	-1.09
2001	-0.56	-1.16	0.80	1.29	0.90	0.66	1.48	0.75	-1.19	0.99
2002	-1.04	0.17	-0.12	-2.22	-0.42	-1.00	-1.37	-1.60	-0.46	-1.93
2003	-0.68	0.09	-0.31	-1.49	-0.31	-0.18	-0.74	-0.30	0.03	-1.19
2004	-0.75	-1.48	-0.54	0.74	-1.31	-1.10	-0.72	-0.83	0.46	-0.45
2005	-0.38	-0.90	-0.32	-0.58	-1.04	-0.47	-0.44	0.68	0.28	0.98
2006	1.11	1.03	0.34	0.91	0.93	0.35	1.26	0.61	1.78	0.63
2007	-0.39	0.89	0.16	-0.62	1.20	1.12	0.86	0.38	-0.01	-0.45
2008	0.67	-1.34	-0.74	1.22	-1.18	-0.59	1.11	-0.15	0.54	1.39
2009	-0.54	-1.23	-0.79	-0.58	-1.20	-2.27	1.20	-1.70	-1.51	0.26
2010	-0.01	-0.42	0.03	0.61	0.03	0.43	0.13	0.47	1.65	0.18
2011	0.99	1.08	-1.36	-0.40	1.49	-0.30	-0.26	-0.27	-0.29	-0.59
2012	-0.68	0.40	-1.13	-0.91	1.10	0.65	-0.77	-0.67	-1.69	-1.79
2013	0.17	0.71	1.35	0.08	1.01	1.61	-0.51	2.42	0.66	0.34
2014	0.82	0.08	1.33	0.69	-0.05	0.22	-1.16	0.54	-0.40	0.24
2015	0.35	0.25	-1.68	1.10	0.06	0.61	-0.86	-0.36	-1.14	-0.49
2016	-1.25	-1.37	-0.06	0.07	-1.37	-1.38	-1.40	-1.12	0.98	0.90
2017	-0.23	0.25	-0.23	0.86	-1.10	0.14	1.10	-0.12	-0.85	-0.68
2018	-0.63	1.35	1.09	-1.16	0.05	-0.11	-0.13	-0.11	1.01	1.68
2019	3.00	1.61	2.18	0.39	1.18	1.59	1.21	1.38	0.16	-0.02

Appendix 3: Relationship between SPI and VCI (left) and SPI and DSI (right)

Year	Mean SPI	VCI
2005	-0.72	63.4
2006	0.48	51.6
2007	0.45	60
2008	0.86	57
2009	-1.33	37.7
2010	-0.37	57
2011	0.52	61.5
2012	0.92	62
2013	-0.01	51
2014	-0.14	51.7
2015	-0.43	64.9
2016	-1.1	48.6
2017	-0.8	58
2018	0.65	58.5
2019	0.2	65

Year	Mean SPI	DSI
2005	-0.72	0.002
2006	0.4	-0.013
2007	0.4	0.007
2008	0.86	0.053
2009	-1.33	-0.034
2010	-0.37	0.001
2011	0.52	0.013
2012	0.92	0.018
2013	-0.01	-0.02
2014	-0.14	-0.018
2015	-0.43	0.024
2016	-1.1	-0.009
2017	-0.8	-0.027
2018	0.65	0.007
2019	0.2	0.019

Appendix 4: Rainfall values observed at station and Simulated by satellite rainfall products

Months	Bita woshi				Dimeka				Hosana				Jimma				Jinka			
	CHRIPS	PERSIANN	TMPA	Station	CHRIPS	PERSIANN	TMPA	station	CHRIPS	PERSIANN	TMPA	Station	CHRIPS	PERSIANN	TMPA	Station	CHRIPS	PERSIANN	TMPA	Station
01/2000	15	5.5	8.9	5.7	9	14.9	1.7	9.7	8	1.6	2.8	0	6.0	1.4	1.7	0.0	9.0	11.8	2.8	0.0
02/2000	11	3.9	5.9	13.1	6	1.1	1.2	49.3	8	0.7	1.9	0	9.0	2.3	2.4	1.0	9.0	7.6	1.4	0.0
03/2000	60	48.4	58.9	91.7	51	46.1	48.6	2.5	22	12.4	23.8	15.4	34.0	21.8	38.5	39.3	55.0	67.7	63.4	74.5
04/2000	173	206.0	173.9	143.6	77	104.1	141.8	107.7	183	152.5	159.3	205.8	113.0	169.8	158.2	194.7	127.0	196.0	181.9	183.4
05/2000	234	257.5	300.1	250.9	51	47.8	93.4	63.9	151	176.6	145.3	105.2	265.0	331.2	254.6	237.7	159.0	89.1	167.1	115.3
06/2000	130	171.9	209.0	142.7	23	7.0	32.0	2.5	139	144.5	132.2	145.5	166.0	233.4	224.7	153.7	77.0	41.4	78.9	64.9
07/2000	180	196.3	252.4	302.4	26	9.5	43.0	82.5	145	144.1	140.4	86.2	313.0	223.3	249.6	265.9	95.0	60.0	110.9	83.4
08/2000	136	145.1	209.1	118	86	34.6	62.3	17	188	167.5	172.9	124.5	179.0	164.7	204.1	158.7	83.0	55.8	114.0	105.3
09/2000	143	172.1	219.4	172.8	42	19.2	34.2	41.6	175	210.1	189.2	177.9	222.0	236.7	241.9	255.2	101.0	51.7	87.7	65.3
10/2000	157	160.8	283.1	164.5	140	149.4	194.4	157.4	103	98.2	104.8	64.9	148.0	185.7	231.9	244.0	287.0	195.5	317.5	257.5
11/2000	89	67.5	83.2	67.5	78	51.1	98.1	50.2	18	41.7	36.3	21	49.0	69.2	56.4	46.8	67.0	44.3	99.0	118.2
12/2000	31	32.8	27.9	23.2	33	21.4	57.7	27.7	45	40.1	22.1	45.5	22.0	38.1	20.3	24.9	32.0	24.4	47.2	67.5
01/2001	18	14.5	13.4	40.8	20	16.2	49.8	49.1	11	10.7	14.2	4.8	30.0	23.3	14.9	16.2	41.0	36.5	55.9	67.9
02/2001	61	108.5	80.1	58.5	20	40.0	31.4	55.5	36	14.4	38.3	70.1	27.0	56.3	52.9	12.9	34.0	63.5	51.0	39.8
03/2001	119	97.8	109.6	127	111	142.7	181.1	139.4	157	175.1	167.7	184	128.0	122.9	133.4	85.9	173.0	178.8	191.7	213.5
04/2001	194	202.9	200.5	166.8	187	217.5	255.4	184.4	104	112.6	70.6	109.6	102.0	139.7	123.9	116.8	242.0	248.5	289.7	243.4
05/2001	204	264.5	295.8	235.6	57	30.2	97.8	29.1	219	298.2	215.2	172.1	247.0	275.1	303.7	341.2	165.0	98.3	197.5	180.5
06/2001	208	186.5	286.8	190.4	46	34.0	38.4	26	174	175.1	174.9	91	235.0	234.2	291.5	299.4	109.0	78.3	107.6	79.9
07/2001	214	164.0	277.5	247.5	32	25.5	29.4	38.7	180	160.3	202.1	151.9	287.0	162.3	279.8	312.3	68.0	53.6	71.3	58.8
08/2001	183	198.0	222.6	204.1	52	13.0	25.2	13.5	232	189.6	196.8	188	200.0	180.8	212.6	160.8	86.0	52.1	74.5	35.8
09/2001	159	5.5	222.6	245.9	79	14.9	25.2	77.8	142	1.6	196.8	101.8	247.0	1.4	212.6	183.4	209.0	11.8	74.5	197.2
10/2001	151	3.9	208.7	230.7	103	1.1	122.1	103.8	109	0.7	84.1	62	187.0	2.3	186.6	162.9	174.0	7.6	162.9	113.9
11/2001	63	48.4	20.8	97	79	46.1	24.1	58.5	6	12.4	13.5	4.7	51.0	21.8	33.7	75.8	144.0	67.7	31.6	162.8
12/2001	43	206.0	93.2	31.7	27	104.1	137.5	17.2	12	152.5	15.0	5.5	11.0	169.8	67.8	3.8	15.0	196.0	153.0	13.3

01/2002	44	257.5	21.9	68.3	68	47.8	36.8	109.9	39	176.6	3.5	83.3	63.0	331.2	6.3	68.9	88.0	89.1	28.1	140.6
02/2002	15	171.9	58.8	5.3	27	7.0	104.5	61.5	40	144.5	83.9	47.2	11.0	233.4	59.4	5.0	20.0	41.4	109.2	20.2
03/2002	144	196.3	13.3	169.5	134	9.5	17.7	138.9	111	144.1	29.1	150.7	116.0	223.3	14.4	91.2	184.0	60.0	22.1	177.8
04/2002	185	145.1	145.0	156.4	132	34.6	145.9	161.4	98	167.5	116.6	111.7	90.0	164.7	124.7	89.7	129.0	55.8	219.0	129.1
05/2002	160	172.1	126.9	140.4	194	19.2	135.6	276	152	210.1	73.3	135.5	106.0	236.7	89.3	137.3	159.0	51.7	148.8	239.7
06/2002	200	160.8	163.6	126.8	24	149.4	210.2	30.1	135	98.2	109.0	90	200.0	185.7	150.2	241.6	58.0	195.5	215.0	23.7
07/2002	137	67.5	273.6	206.6	19	51.1	13.4	12.2	143	41.7	125.2	103.6	256.0	69.2	247.2	149.7	60.0	44.3	43.9	60.6
08/2002	159	32.8	184.9	186.4	28	21.4	28.4	0	248	40.1	152.9	314.7	178.0	38.1	202.2	234.9	52.0	24.4	70.6	27.9
09/2002	128	14.5	184.9	104.2	73	16.2	28.4	35.8	165	10.7	152.9	154.7	141.0	23.3	202.2	165.3	98.0	36.5	70.6	97.3
10/2002	177	108.5	175.1	151.9	118	40.0	64.8	80.5	21	14.4	128.6	2.8	52.0	56.3	179.8	79.6	176.0	63.5	127.9	155.1
11/2002	41	97.8	152.9	31.8	57	142.7	132.5	100	5	175.1	15.7	0.4	10.0	122.9	81.7	8.1	78.0	178.8	153.0	42.9
12/2002	153	202.9	36.0	81.9	128	217.5	62.2	224.7	99	112.6	2.2	151.8	90.0	139.7	17.0	138.4	154.0	248.5	65.7	22.3
01/2003	48	264.5	88.1	48.5	21	30.2	241.8	41.8	31	298.2	109.5	35.8	24.0	275.1	95.3	28.7	51.0	98.3	217.6	33.1
02/2003	56	186.5	8.9	19.2	10	34.0	1.7	9.1	49	175.1	2.8	58.9	48.0	234.2	1.7	61.3	20.0	78.3	2.8	42.6
03/2003	120	164.0	6.5	115.5	89	25.5	1.2	110.2	101	160.3	1.9	118.7	85.0	162.3	2.4	86.9	101.0	53.6	1.4	100.0
04/2003	153	198.0	58.9	193.8	204	13.0	48.6	158.8	197	189.6	23.8	194.4	135.0	180.8	38.5	111.3	182.0	52.1	63.4	216.1
05/2003	102	5.5	179.7	88.9	204	14.9	141.8	139.9	75	1.6	159.3	78.7	38.0	1.4	158.2	12.2	169.0	11.8	181.9	233.4
06/2003	269	3.9	300.1	301.6	33	1.1	93.4	23.7	160	0.7	145.3	108.3	286.0	2.3	254.6	272.2	98.0	7.6	167.1	59.5
07/2003	159	48.4	216.0	158.5	26	46.1	32.0	19.9	199	12.4	132.2	113.9	246.0	21.8	224.7	186.7	65.0	67.7	78.9	62.3
08/2003	186	206.0	252.4	163.5	176	104.1	43.0	84.6	181	152.5	140.4	213.3	201.0	169.8	249.6	150.9	236.0	196.0	110.9	286.0
09/2003	198	257.5	209.1	200.2	43	47.8	62.3	2	171	176.6	172.9	182.9	219.0	331.2	204.1	238.9	88.0	89.1	114.0	80.0
10/2003	119	171.9	219.4	112.2	51	7.0	34.2	12.2	22	144.5	189.2	11.7	60.0	233.4	241.9	91.7	119.0	41.4	87.7	144.6
11/2003	124	196.3	283.1	64.9	80	9.5	194.4	64.4	17	144.1	104.8	14.3	35.0	223.3	231.9	29.9	99.0	60.0	317.5	132.4
12/2003	65	145.1	83.2	54	54	34.6	98.1	116.5	28	167.5	36.3	0	27.0	164.7	56.4	14.6	46.0	55.8	99.0	70.6
01/2004	79	172.1	27.9	95.3	61	19.2	57.7	27.6	70	210.1	22.1	96.8	63.0	236.7	20.3	51.0	76.0	51.7	47.2	79.3
02/2004	24	160.8	83.2	50.5	18	149.4	64.5	25	28	98.2	67.6	19.4	45.0	185.7	72.9	28.4	34.0	195.5	81.2	31.2
03/2004	59	67.5	30.0	56.9	33	51.1	22.1	61.1	93	41.7	39.8	90.6	47.0	69.2	37.8	46.1	51.0	44.3	43.6	56.2
04/2004	177	32.8	54.0	280.6	193	21.4	43.7	147.8	167	40.1	74.2	155.38	147.0	38.1	55.7	130.9	197.0	24.4	65.8	203.7
05/2004	186	14.5	180.5	306.1	79	16.2	203.7	32.4	76	10.7	148.2	104.6	239.0	23.3	145.4	161.9	139.0	36.5	243.0	54.2
06/2004	148	108.5	189.0	178.3	23	40.0	52.5	3.5	108	14.4	81.8	123.4	218.0	56.3	153.4	128.4	62.0	63.5	87.4	60.7
07/2004	195	97.8	171.1	115.8	15	142.7	34.0	25.3	170	175.1	119.2	113.9	193.0	122.9	183.1	216.3	47.0	178.8	92.5	39.5

08/2004	182	202.9	246.7	210.2	37	217.5	20.8	183.3	193	112.6	203.9	152.3	263.0	139.7	257.6	219.4	69.0	248.5	68.6	59.9
09/2004	196	264.5	271.2	217.1	69	30.2	54.9	32.1	173	298.2	188.1	181.8	223.0	275.1	245.3	201.0	144.0	98.3	111.1	127.8
10/2004	103	186.5	210.7	142.5	53	34.0	71.0	107	87	175.1	159.2	35.35	140.0	234.2	234.8	133.2	83.0	78.3	131.5	66.5
11/2004	142	164.0	144.4	78.5	154	25.5	65.2	54.4	9	160.3	74.8	17.3	54.0	162.3	118.5	67.3	166.0	53.6	89.1	154.9
12/2004	97	198.0	101.7	68.6	33	13.0	213.4	39.5	25	189.6	36.1	14	51.0	180.8	62.2	84.2	52.0	52.1	148.7	92.4
01/2005	25	5.5	72.1	23.7	36	14.9	34.1	36.1	24	1.6	26.3	31.5	42.0	1.4	98.7	44.5	48.0	11.8	64.5	62.9
02/2005	15	3.9	26.8	1.4	13	1.1	35.3	40.3	12	0.7	51.7	18.8	3.0	2.3	55.3	0.5	14.0	7.6	118.9	12.5
03/2005	170	48.4	6.1	148.6	115	46.1	3.4	87	115	12.4	6.3	177.8	144.0	21.8	4.1	193.8	159.0	67.7	9.3	162.4
04/2005	168	206.0	250.2	142.9	142	104.1	189.4	142.3	171	152.5	138.8	162.1	126.0	169.8	421.8	141.4	168.0	196.0	242.0	154.3
05/2005	241	257.5	151.1	252.2	245	47.8	200.3	226.5	178	176.6	179.4	197.2	219.0	331.2	136.6	173.8	292.0	89.1	240.8	272.8
06/2005	164	171.9	245.7	136.4	25	7.0	234.2	13.6	92	144.5	187.9	64.6	194.0	233.4	200.2	177.2	62.0	41.4	355.6	51.5
07/2005	243	196.3	309.5	169.1	37	9.5	24.2	8.6	171	144.1	101.6	160.1	201.0	223.3	195.6	273.5	59.0	60.0	65.0	56.6
08/2005	150	145.1	231.5	133.9	31	34.6	27.7	47.5	176	167.5	142.7	98.9	203.0	164.7	234.5	227.8	62.0	55.8	46.9	75.5
09/2005	223	172.1	288.1	224.9	60	19.2	26.0	132.4	170	210.1	194.6	162.6	227.0	236.7	307.7	229.1	110.0	51.7	95.9	91.7
10/2005	144	160.8	211.1	136.9	83	149.4	48.3	70	93	98.2	180.8	37.7	110.0	185.7	202.1	68.3	128.0	195.5	116.1	105.1
11/2005	91	67.5	118.8	50.9	58	51.1	56.5	93.5	20	41.7	53.8	67.7	44.0	69.2	110.2	29.7	53.0	44.3	145.0	67.2
12/2005	11	32.8	43.0	2.8	6	21.4	23.4	0	7	40.1	14.2	0	5.0	38.1	25.6	0.0	6.0	24.4	52.0	0.0
01/2006	31	14.5	0.1	34.3	11	16.2	7.8	19.5	15	10.7	0.0	28.9	22.0	23.3	0.0	15.8	15.0	36.5	8.4	17.3
02/2006	58	108.5	16.9	66.7	35	40.0	4.9	45.5	43	14.4	12.0	53.9	64.0	56.3	9.8	77.1	67.0	63.5	10.1	90.4
03/2006	177	97.8	82.0	202.2	99	142.7	101.1	154.6	149	175.1	57.3	135.5	169.0	122.9	73.6	181.8	173.0	178.8	84.8	189.9
04/2006	155	202.9	184.1	117.2	133	217.5	194.0	179.4	144	112.6	150.2	160	84.0	139.7	185.2	110.3	158.0	248.5	226.1	189.2
05/2006	244	264.5	106.1	147.4	141	30.2	171.8	113.1	114	298.2	105.0	75.8	134.0	275.1	86.9	211.5	180.0	98.3	224.3	209.2
06/2006	220	186.5	212.2	225.9	41	34.0	96.3	10.2	179	175.1	108.5	169.8	256.0	234.2	177.7	207.4	90.0	78.3	204.3	78.9
07/2006	205	164.0	235.9	165.1	18	25.5	23.8	0	199	160.3	216.1	183.9	263.0	162.3	242.2	327.2	52.0	53.6	89.9	19.3
08/2006	204	198.0	279.1	133	148	13.0	20.2	62.5	220	189.6	287.4	222.2	193.0	180.8	317.0	240.2	130.0	52.1	74.0	180.7
09/2006	125	5.5	236.8	209.9	50	14.9	106.5	0	106	1.6	184.1	88.2	224.0	1.4	228.4	169.9	111.0	11.8	109.0	70.2
10/2006	185	3.9	226.5	167.4	125	1.1	39.9	134.1	119	0.7	146.8	50.3	151.0	2.3	207.5	91.1	190.0	7.6	64.8	279.1
11/2006	148	48.4	130.7	99.7	184	46.1	111.3	228.9	7	12.4	69.2	6	69.0	21.8	121.9	127.6	151.0	67.7	170.2	214.9
12/2006	121	206.0	89.5	108.9	139	104.1	227.3	152.5	24	152.5	39.8	27.2	75.0	169.8	118.8	100.2	148.0	196.0	166.7	189.7
01/2007	52	257.5	101.3	95.4	44	47.8	143.1	45	31	176.6	39.2	31.8	67.0	331.2	77.8	37.5	98.0	89.1	175.8	120.7
02/2007	75	171.9	39.3	51.5	33	7.0	22.6	28.5	81	144.5	31.1	50.7	51.0	233.4	43.5	51.0	64.0	41.4	77.5	102.0

03/2007	145	196.3	67.9	107.5	86	9.5	57.3	36.2	92	144.1	79.3	119.4	104.0	223.3	115.5	80.8	92.0	60.0	123.8	80.6
04/2007	180	145.1	140.6	179.1	207	34.6	72.2	264.1	113	167.5	100.4	152.1	112.0	164.7	153.9	121.6	202.0	55.8	132.1	241.8
05/2007	249	172.1	167.7	240.6	114	19.2	242.1	94.5	138	210.1	159.1	121.3	191.0	236.7	122.1	196.1	155.0	51.7	259.7	163.0
06/2007	163	160.8	243.0	168.3	151	149.4	134.1	134.1	173	98.2	179.0	163.1	182.0	185.7	235.1	142.6	208.0	195.5	194.0	374.9
07/2007	191	67.5	159.4	152	61	51.1	98.1	55.5	210	41.7	125.1	179.9	247.0	69.2	138.2	247.4	109.0	44.3	99.0	102.4
08/2007	168	32.8	286.1	227.2	124	21.4	83.6	43.5	174	40.1	202.1	127.3	207.0	38.1	278.6	177.0	128.0	24.4	97.1	147.1
09/2007	234	14.5	177.3	257.3	105	16.2	50.0	70	216	10.7	157.8	210.3	254.0	23.3	185.2	256.2	203.0	36.5	92.6	126.8
10/2007	105	108.5	293.3	99.3	68	40.0	116.1	33.2	53	14.4	229.7	19.4	65.0	56.3	293.7	50.8	101.0	63.5	170.5	78.0
11/2007	66	97.8	84.6	127.9	100	142.7	65.4	166.6	5	175.1	33.4	0	29.0	122.9	63.4	5.9	134.0	178.8	110.1	117.4
12/2007	15	202.9	52.6	2.3	12	217.5	98.3	10	8	112.6	0.9	0	4.0	139.7	10.1	0.0	12.0	248.5	120.0	12.7
01/2008	69	264.5	2.6	63.9	16	30.2	6.2	19	7	298.2	0.0	0	28.0	275.1	0.2	34.0	25.0	98.3	6.5	22.8
02/2008	56	186.5	66.0	35.6	18	34.0	16.7	0	12	175.1	23.2	1.2	26.0	234.2	43.3	12.3	21.0	78.3	15.0	58.6
03/2008	51	164.0	39.6	47.7	53	25.5	11.5	138.5	35	160.3	9.3	43	32.0	162.3	23.4	39.4	53.0	53.6	13.8	81.4
04/2008	254	198.0	67.7	234.5	154	13.0	68.8	103.4	95	189.6	33.3	64.3	117.0	180.8	34.5	112.7	127.0	52.1	59.4	145.1
05/2008	246	5.5	151.6	311.5	45	14.9	154.9	55.6	182	1.6	83.7	238.9	290.0	1.4	97.7	249.0	103.0	11.8	179.1	79.5
06/2008	200	3.9	255.5	116.9	27	1.1	71.3	14.5	155	0.7	240.7	144.6	176.0	2.3	297.5	238.2	84.0	7.6	180.1	126.7
07/2008	194	48.4	240.7	233	53	46.1	23.4	25	218	12.4	180.7	192.5	293.0	21.8	265.9	209.8	88.0	67.7	129.1	99.1
08/2008	204	206.0	186.4	305.4	77	104.1	30.3	16.5	164	152.5	185.1	136.2	331.0	169.8	211.3	236.8	135.0	196.0	86.2	76.9
09/2008	154	257.5	228.2	193.7	96	47.8	39.2	66	157	176.6	204.4	139	190.0	331.2	258.6	133.4	174.0	89.1	136.2	178.4
10/2008	191	171.9	167.2	231.2	154	7.0	126.0	163.1	81	144.5	162.1	126.1	159.0	233.4	175.3	186.1	219.0	41.4	168.9	213.6
11/2008	138	196.3	141.6	56.4	80	9.5	144.8	137	58	144.1	82.7	116.5	73.0	223.3	137.7	92.9	96.0	60.0	156.1	96.6
12/2008	49	145.1	76.0	62.5	15	34.6	129.3	0	8	167.5	97.9	0.5	29.0	164.7	88.8	6.3	15.0	55.8	112.9	20.2
01/2009	55	172.1	26.2	26.5	31	19.2	10.0	60.1	34	210.1	0.4	43.1	45.0	236.7	5.8	63.0	45.0	51.7	15.8	65.8
02/2009	50	160.8	62.3	28	16	149.4	24.4	28.1	18	98.2	60.8	4.8	23.0	185.7	60.0	29.5	23.0	195.5	45.2	17.8
03/2009	159	67.5	52.1	138.6	72	51.1	33.1	64.4	73	41.7	22.0	73.4	79.0	69.2	36.4	79.8	103.0	44.3	47.3	112.8
04/2009	241	32.8	125.3	188.5	156	21.4	44.1	85.3	91	40.1	43.5	85.5	134.0	38.1	77.1	103.1	158.0	24.4	92.4	188.0
05/2009	171	14.5	193.4	163.3	104	16.2	118.1	177	99	10.7	66.6	120.1	150.0	23.3	127.1	243.6	117.0	36.5	181.9	151.7
06/2009	198	108.5	181.5	280.3	32	40.0	72.8	6	130	14.4	138.1	122.7	240.0	56.3	206.5	160.3	61.0	63.5	196.4	39.6
07/2009	120	97.8	159.3	110.1	11	142.7	10.5	13.6	182	175.1	101.2	188.5	182.0	122.9	153.9	149.6	31.0	178.8	38.8	12.2
08/2009	159	202.9	172.6	149.8	59	217.5	35.0	0	193	112.6	137.9	181.1	214.0	139.7	169.9	304.7	65.0	248.5	29.4	16.2
09/2009	149	264.5	287.6	199	73	30.2	43.5	43.4	104	298.2	216.2	156.7	196.0	275.1	296.5	209.4	137.0	98.3	46.4	140.0

10/2009	148	186.5	240.0	168.5	79	34.0	24.9	121.3	148	175.1	123.2	169.4	146.0	234.2	160.4	92.2	189.0	78.3	136.5	184.8
11/2009	94	164.0	140.5	75.1	75	25.5	86.8	31	9	160.3	76.1	5.1	47.0	162.3	141.4	78.4	109.0	53.6	219.0	85.6
12/2009	76	198.0	140.5	59.9	95	13.0	86.8	105.9	84	189.6	76.1	27.2	62.0	180.8	141.4	67.7	99.0	52.1	219.0	158.2
01/2010	47	5.5	56.7	36.3	31	14.9	137.9	52.9	26	1.6	60.0	11.8	20.0	1.4	71.2	27.3	54.0	11.8	141.5	56.5
02/2010	103	3.9	52.8	100.1	46	1.1	52.5	24.9	69	0.7	35.2	110	91.0	2.3	33.9	88.4	76.0	7.6	58.8	35.7
03/2010	107	48.4	123.7	94	144	46.1	61.7	203.7	113	12.4	139.5	139.9	80.0	21.8	102.8	67.4	200.0	67.7	154.7	211.2
04/2010	145	206.0	73.7	189.6	133	104.1	106.6	101	137	152.5	104.1	111.3	147.0	169.8	60.6	101.4	188.0	196.0	158.2	164.8
05/2010	288	257.5	202.7	277.1	214	47.8	124.4	227.9	177	176.6	158.7	182.8	242.0	331.2	108.5	192.9	214.0	89.1	233.4	189.1
06/2010	251	171.9	171.7	229.6	37	7.0	88.7	21.9	140	144.5	146.5	94.4	314.0	233.4	150.7	394.7	103.0	41.4	110.8	83.7
07/2010	177	196.3	262.4	92.3	39	9.5	50.8	23.2	186	144.1	210.1	116	155.0	223.3	372.2	181.3	81.0	60.0	122.7	100.6
08/2010	169	145.1	158.8	150.9	53	34.6	70.3	27	184	167.5	166.0	145	200.0	164.7	177.7	203.5	78.0	55.8	95.1	24.2
09/2010	228	172.1	147.0	247.6	78	19.2	28.8	64.5	185	210.1	153.6	138.5	245.0	236.7	184.1	186.5	158.0	51.7	68.7	78.6
10/2010	68	160.8	181.4	141.3	77	149.4	60.1	48	26	98.2	120.6	18.8	58.0	185.7	214.8	96.0	105.0	195.5	98.4	90.2
11/2010	79	67.5	101.1	66	22	51.1	80.3	5.5	12	41.7	34.1	19.3	51.0	69.2	74.9	96.2	43.0	44.3	111.3	32.2
12/2010	40	32.8	56.1	62.5	44	21.4	25.7	3.8	22	40.1	24.7	33.7	64.0	38.1	44.9	10.5	26.0	24.4	71.2	37.0
01/2011	23	14.5	21.4	16.2	7	16.2	11.1	0	12	10.7	9.5	15.5	18.0	23.3	17.0	24.1	9.0	36.5	31.8	2.1
02/2011	26	108.5	18.7	15.7	31	40.0	4.9	4.5	19	14.4	12.4	11.2	15.0	56.3	17.8	7.5	30.0	63.5	10.4	18.1
03/2011	83	97.8	51.1	69.6	52	142.7	57.5	85.9	62	175.1	67.7	101.7	57.0	122.9	53.4	39.3	71.0	178.8	124.8	80.5
04/2011	212	202.9	122.8	169	102	217.5	60.7	78.5	97	112.6	63.8	115.9	137.0	139.7	98.1	151.2	124.0	248.5	174.7	130.3
05/2011	321	264.5	199.5	236.7	170	30.2	50.6	51.9	214	298.2	160.8	232.8	240.0	275.1	231.7	192.9	237.0	98.3	244.6	196.3
06/2011	240	186.5	235.0	194.7	44	34.0	42.8	187.5	114	175.1	147.9	119.8	242.0	234.2	253.9	311.2	105.0	78.3	87.6	97.3
07/2011	252	164.0	112.5	188.4	94	25.5	52.1	54	155	160.3	115.4	158.8	207.0	162.3	161.3	189.9	140.0	53.6	103.5	143.5
08/2011	209	198.0	211.0	191.1	92	13.0	81.2	83.1	216	189.6	197.6	182.5	223.0	180.8	207.4	192.1	168.0	52.1	207.5	177.4
09/2011	238	5.5	335.4	315.5	103	14.9	147.8	95.9	137	1.6	255.4	119.3	264.0	1.4	305.1	269.5	189.0	11.8	320.7	157.4
10/2011	81	3.9	40.7	36.2	106	1.1	122.0	104.8	14	0.7	0.0	0	15.0	2.3	19.6	10.3	162.0	7.6	139.1	173.3
11/2011	132	48.4	93.5	61.6	261	46.1	300.9	449	40	12.4	50.1	49.2	105.0	21.8	147.9	104.9	280.0	67.7	224.4	205.2
12/2011	38	206.0	17.1	32.1	70	104.1	17.4	75.1	7	152.5	1.9	0	17.0	169.8	11.8	26.0	36.0	196.0	13.2	58.0
01/2012	17	257.5	41.1	23.1	5	47.8	7.2	0	8	176.6	0.1	0	11.0	331.2	3.3	2.1	10.0	89.1	38.0	0.0
02/2012	13	171.9	19.1	6.9	6	7.0	9.4	12	9	144.5	4.8	0	6.0	233.4	9.0	1.8	10.0	41.4	45.2	5.9
03/2012	96	196.3	103.3	101	42	9.5	48.1	2.6	41	144.1	62.8	67.4	72.0	223.3	62.6	55.8	59.0	60.0	120.3	42.4
04/2012	176	145.1	226.2	277.7	220	34.6	108.3	145.4	153	167.5	108.4	138.3	164.0	164.7	198.3	154.5	278.0	55.8	242.5	223.1

05/2012	192	172.1	307.0	138.5	113	19.2	115.8	150.8	69	210.1	257.1	68.3	109.0	236.7	259.5	118.7	156.0	51.7	156.7	194.6
06/2012	218	160.8	186.9	180.7	51	149.4	28.8	58.5	173	98.2	172.6	150.3	248.0	185.7	256.3	335.0	89.0	195.5	67.3	102.7
07/2012	207	67.5	155.1	236.8	96	51.1	33.3	161.7	220	41.7	163.1	233.1	268.0	69.2	141.6	223.9	177.0	44.3	70.9	190.8
08/2012	188	32.8	134.4	189.1	120	21.4	63.2	54	176	40.1	145.5	155.9	186.0	38.1	123.3	132.7	145.0	24.4	135.7	172.3
09/2012	202	14.5	208.7	283.3	138	16.2	94.3	128.3	215	10.7	227.7	163.5	279.0	23.3	265.2	250.5	258.0	36.5	226.7	206.5
10/2012	105	108.5	19.2	69.6	91	40.0	207.0	83.5	30	14.4	7.9	1.4	32.0	56.3	22.6	32.8	136.0	63.5	86.3	124.5
11/2012	118	97.8	58.4	92.4	82	142.7	75.6	134.4	12	175.1	14.1	2.4	66.0	122.9	45.2	77.4	111.0	178.8	129.9	138.6
12/2012	67	202.9	56.2	55.3	71	217.5	96.6	97.8	12	112.6	29.0	7.7	36.0	139.7	43.1	57.7	62.0	248.5	96.0	74.5
01/2013	37	264.5	49.7	98	33	30.2	11.9	58.5	16	298.2	16.4	1	62.0	275.1	31.6	34.9	61.0	98.3	31.6	12.4
02/2013	37	186.5	37.1	42.5	22	34.0	34.8	18.6	15	175.1	12.1	17.4	34.0	234.2	33.9	31.3	26.0	78.3	41.8	24.0
03/2013	107	164.0	102.4	131.9	118	25.5	112.9	61.4	92	160.3	85.5	143.6	48.0	162.3	88.3	109.4	115.0	53.6	127.6	84.1
04/2013	146	198.0	117.8	111.7	250	13.0	247.4	131.6	175	189.6	104.9	67.9	91.0	180.8	148.3	95.8	270.0	52.1	342.6	335.4
05/2013	296	5.5	323.9	236.8	109	14.9	73.6	146.2	152	1.6	173.8	131.6	178.0	1.4	316.8	306.0	115.0	11.8	146.3	58.2
06/2013	185	3.9	202.6	192.3	49	1.1	59.3	3	194	0.7	175.5	182.2	220.0	2.3	180.3	193.3	139.0	7.6	110.2	120.4
07/2013	210	48.4	204.3	270.9	28	46.1	44.0	161.7	219	12.4	197.2	200.8	254.0	21.8	180.7	151.5	80.0	67.7	81.6	67.9
08/2013	194	206.0	221.9	129.4	51	104.1	35.8	11.5	251	152.5	190.8	211	230.0	169.8	239.2	255.2	84.0	196.0	92.9	80.9
09/2013	205	257.5	186.9	257.8	90	47.8	50.4	58.6	174	176.6	164.0	173	244.0	331.2	179.2	183.3	219.0	89.1	105.9	159.1
10/2013	143	171.9	180.9	198	120	7.0	108.9	83.7	145	144.5	97.2	46.4	142.0	233.4	130.2	167.8	171.0	41.4	164.8	168.8
11/2013	154	196.3	119.4	200.6	197	9.5	102.8	62	17	144.1	41.1	0.4	94.0	223.3	74.4	114.7	188.0	60.0	118.0	54.1
12/2013	15	145.1	6.7	4.1	12	34.6	18.6	32.1	7	167.5	0.0	0	4.0	164.7	0.9	1.0	9.0	55.8	52.4	20.2
01/2014	20	172.1	15.2	12.1	9	19.2	7.7	0	16	210.1	15.6	25	16.0	236.7	19.4	17.8	12.0	51.7	21.0	19.2
02/2014	50	160.8	50.4	81.4	47	149.4	38.1	12	62	98.2	41.8	117.8	34.0	185.7	33.7	16.8	54.0	195.5	43.2	22.2
03/2014	164	67.5	109.8	170.7	123	51.1	53.5	65.8	109	41.7	79.4	76.6	173.0	69.2	106.9	140.1	169.0	44.3	91.7	159.8
04/2014	281	32.8	337.3	137.9	125	21.4	122.3	110.3	163	40.1	154.0	134.9	195.0	38.1	373.8	242.0	130.0	24.4	208.8	159.6
05/2014	261	14.5	304.1	214.8	160	16.2	128.8	146.6	255	10.7	238.8	251.8	224.0	23.3	294.2	253.0	171.0	36.5	231.3	166.6
06/2014	170	108.5	172.7	138.2	63	40.0	36.2	142.1	78	14.4	100.4	76.2	130.0	56.3	177.0	117.4	110.0	63.5	119.7	189.8
07/2014	163	97.8	202.0	271.1	29	142.7	59.1	162.4	154	175.1	178.6	188.3	299.0	122.9	225.8	271.3	71.0	178.8	115.8	133.7
08/2014	225	202.9	278.6	115.1	87	217.5	60.1	61.3	244	112.6	204.5	270.9	181.0	139.7	240.9	265.6	106.0	248.5	126.8	114.2
09/2014	157	264.5	160.2	131.3	100	30.2	48.9	105.8	189	298.2	148.5	193	204.0	275.1	166.7	142.3	171.0	98.3	84.2	147.0
10/2014	192	186.5	196.9	124.5	104	34.0	147.5	216.2	155	175.1	131.8	46.2	154.0	234.2	178.8	227.1	159.0	78.3	237.4	296.9
11/2014	111	164.0	119.4	63.9	109	25.5	102.8	92.5	7	160.3	41.1	23.2	39.0	162.3	74.4	39.6	137.0	53.6	118.0	150.9

12/2014	35	198.0	14.8	29.7	33	13.0	13.1	40.6	22	189.6	9.6	22.4	28.0	180.8	8.8	34.3	24.0	52.1	30.5	5.3
01/2015	42	5.5	8.3	0	13	14.9	3.7	0	24	1.6	6.4	0	16.0	1.4	6.2	6.1	20.0	11.8	14.4	0.0
02/2015	66	3.9	38.0	56	13	1.1	7.6	31.3	24	0.7	9.1	3	27.0	2.3	23.1	16.9	25.0	7.6	50.3	24.3
03/2015	119	48.4	89.0	177.6	43	46.1	57.0	136.8	102	12.4	65.9	45.1	101.0	21.8	73.8	77.5	64.0	67.7	100.6	72.1
04/2015	234	206.0	101.2	231.6	202	104.1	122.3	172.7	87	152.5	19.5	19.2	142.0	169.8	96.9	176.3	207.0	196.0	158.5	280.6
05/2015	215	257.5	281.5	222.1	168	47.8	66.8	146.3	151	176.6	196.6	136.9	185.0	331.2	247.4	212.5	172.0	89.1	150.7	151.9
06/2015	229	171.9	197.1	186.9	65	7.0	68.4	66.3	139	144.5	185.1	213	249.0	233.4	253.1	308.6	136.0	41.4	111.7	97.3
07/2015	181	196.3	197.1	113.1	53	9.5	43.4	60	123	144.1	158.6	142.6	203.0	223.3	244.0	256.9	121.0	60.0	120.8	62.2
08/2015	123	145.1	212.1	159.2	41	34.6	21.7	0	170	167.5	192.5	181.6	259.0	164.7	243.3	243.2	61.0	55.8	66.4	25.2
09/2015	175	172.1	245.1	299.7	73	19.2	24.2	22.6	134	210.1	178.6	142.2	278.0	236.7	214.5	249.9	112.0	51.7	113.0	62.6
10/2015	136	160.8	132.1	149.1	111	149.4	97.5	56.1	55	98.2	35.8	0	98.0	185.7	113.3	143.1	191.0	195.5	173.0	213.9
11/2015	132	67.5	92.3	195.2	167	51.1	127.5	250.7	14	41.7	27.9	31.3	130.0	69.2	77.7	155.2	169.0	44.3	134.7	197.6
12/2015	105	32.8	94.8	33.9	65	21.4	179.4	220.3	20	40.1	35.3	11.5	40.0	38.1	57.4	88.8	53.0	24.4	97.5	182.6
01/2016	23	14.5	25.0	53.8	16	16.2	3.9	20.5	31	10.7	92.3	92.8	29.0	23.3	41.7	39.4	19.0	36.5	25.9	24.1
02/2016	24	108.5	59.1	36.4	24	40.0	30.6	22.7	28	14.4	48.5	0	35.0	56.3	81.5	70.7	24.0	63.5	79.3	25.8
03/2016	78	97.8	112.5	59.6	42	142.7	30.0	78.7	59	175.1	82.6	81.2	59.0	122.9	114.8	81.4	66.0	178.8	162.7	114.2
04/2016	215	202.9	160.4	183.9	194	217.5	194.3	159.5	214	112.6	155.0	258.6	123.0	139.7	154.7	238.3	246.0	248.5	313.3	288.3
05/2016	286	264.5	337.6	441.5	152	30.2	96.1	123.2	257	298.2	205.9	135.9	331.0	275.1	276.8	286.8	169.0	98.3	112.8	110.6
06/2016	160	186.5	183.8	169.3	44	34.0	42.3	109.7	120	175.1	107.1	122.8	182.0	234.2	153.5	150.4	103.0	78.3	81.4	66.0
07/2016	192	164.0	203.1	168	21	25.5	19.1	19.6	120	160.3	158.5	176.8	266.0	162.3	224.2	185.2	49.0	53.6	52.5	107.5
08/2016	176	198.0	278.6	95.9	37	13.0	47.1	60.4	134	189.6	199.6	123.8	207.0	180.8	290.2	344.3	66.0	52.1	115.9	26.3
09/2016	125	5.5	200.5	135.5	42	14.9	22.0	4.2	140	1.6	179.6	138	142.0	1.4	216.5	174.0	62.0	11.8	79.9	27.0
10/2016	147	3.9	151.4	148.9	94	1.1	67.6	59.6	125	0.7	147.2	68.8	135.0	2.3	126.5	171.9	158.0	7.6	115.0	143.8
11/2016	51	48.4	39.0	73.3	93	46.1	71.6	75.7	21	12.4	13.6	111.2	40.0	21.8	14.6	6.5	123.0	67.7	131.9	111.2
12/2016	35	206.0	17.0	82.3	25	104.1	12.0	6.8	15	152.5	1.9	21.7	51.0	169.8	5.5	34.5	26.0	196.0	39.5	12.2
01/2017	13	257.5	7.5	0.9	16	47.8	10.4	9.9	7	176.6	3.3	0.6	4.0	331.2	3.4	0.0	16.0	89.1	19.7	36.1
02/2017	148	171.9	75.2	92.2	34	7.0	52.4	14.8	73	144.5	76.0	69.5	102.0	233.4	149.4	84.5	52.0	41.4	152.5	89.5
03/2017	78	196.3	80.4	79.9	64	9.5	50.2	34.9	109	144.1	72.5	77.9	87.0	223.3	90.0	91.8	72.0	60.0	104.9	70.4
04/2017	172	145.1	196.1	263.2	118	34.6	50.2	78.5	74	167.5	65.6	44.6	152.0	164.7	113.8	97.8	113.0	55.8	161.5	185.9
05/2017	197	172.1	250.8	264.8	170	19.2	126.0	92	188	210.1	201.3	183.9	166.0	236.7	247.4	250.5	161.0	51.7	189.4	128.4
06/2017	160	160.8	164.9	185.4	17	149.4	11.4	2.5	119	98.2	127.5	189.3	211.0	185.7	171.4	196.2	37.0	195.5	31.1	11.4

07/2017	183	67.5	133.9	163.4	89	51.1	60.6	139.3	144	41.7	111.5	143	221.0	69.2	159.1	162.0	133.0	44.3	82.9	130.0
08/2017	160	32.8	154.0	160.9	69	21.4	59.0	7.2	193	40.1	194.4	90.8	237.0	38.1	190.0	140.5	101.0	24.4	118.4	183.6
09/2017	250	14.5	300.6	242.2	122	16.2	47.0	148.8	227	10.7	314.2	225.5	283.0	23.3	293.8	254.4	171.0	36.5	149.4	260.1
10/2017	224	108.5	145.9	246.7	209	40.0	135.6	317.9	88	14.4	89.3	12.4	199.0	56.3	156.0	209.5	213.0	63.5	129.8	260.3
11/2017	64	97.8	36.9	98.3	94	142.7	64.8	66.1	12	175.1	14.5	1.2	32.0	122.9	23.7	36.6	80.0	178.8	54.7	166.2
12/2017	18	202.9	6.1	5	11	217.5	7.1	0	7	112.6	10.8	21.7	4.0	139.7	0.0	0.0	4.0	248.5	11.3	0.0
01/2018	15	264.5	2.0	26.6	7	30.2	3.6	7.2	7	298.2	2.7	0	16.0	275.1	9.2	5.7	11.0	98.3	16.5	2.7
02/2018	88	186.5	71.3	29.1	67	34.0	133.6	83.7	94	175.1	83.0	106	54.0	234.2	83.4	29.5	71.0	78.3	91.8	30.9
03/2018	101	164.0	63.7	79.9	147	25.5	69.5	33.3	70	160.3	61.2	47.7	75.0	162.3	53.9	80.7	135.0	53.6	73.0	137.8
04/2018	221	198.0	119.0	139.4	344	13.0	358.9	290.4	267	189.6	171.1	258.5	125.0	180.8	134.7	139.3	274.0	52.1	253.7	362.8
05/2018	230	5.5	168.7	153.8	167	14.9	54.2	102.1	229	1.6	137.2	151.9	165.0	1.4	179.4	158.9	211.0	11.8	164.4	243.5
06/2018	214	3.9	221.7	143	85	1.1	58.5	134.5	175	0.7	152.6	100.9	185.0	2.3	203.1	150.3	152.0	7.6	97.3	201.5
07/2018	153	48.4	254.0	161.1	17	46.1	62.6	0	92	12.4	203.6	109.7	244.0	21.8	263.6	166.4	35.0	67.7	107.9	27.9
08/2018	195	206.0	258.0	163.4	90	104.1	64.6	11.4	211	152.5	210.4	158.1	267.0	169.8	262.9	237.3	115.0	196.0	121.2	111.8
09/2018	142	257.5	226.8	132.7	69	47.8	78.3	18.1	143	176.6	154.6	131.7	153.0	331.2	217.3	134.8	98.0	89.1	133.8	102.6
10/2018	91	171.9	62.2	94.7	75	7.0	106.6	55.4	85	144.5	167.9	96.7	85.0	233.4	113.3	94.8	107.0	41.4	132.7	123.6
11/2018	115	196.3	82.4	63.6	67	9.5	42.5	63.6	42	144.1	84.2	147.7	60.0	223.3	93.2	63.8	90.0	60.0	113.9	63.5
12/2018	42	145.1	29.3	34	34	34.6	47.4	33.4	7	167.5	6.0	5.3	17.0	164.7	17.1	40.4	30.0	55.8	53.7	108.4
01/2019	12	172.1	9.2	26.8	8	19.2	4.4	29.8	7	210.1	3.1	0	16.0	236.7	2.9	26.7	13.0	51.7	12.7	40.2
02/2019	71	160.8	60.1	29.3	18	149.4	18.8	29.9	25	98.2	40.3	40	37.0	185.7	65.0	29.5	25.0	195.5	32.5	36.4
03/2019	197	67.5	102.8	80.3	68	51.1	34.7	86.1	68	41.7	65.8	99.5	92.0	69.2	71.4	80.7	90.0	44.3	55.4	116.9
04/2019	237	32.8	177.0	139	124	21.4	166.9	147.5	260	40.1	248.8	134.2	165.0	38.1	259.4	139.3	182.0	24.4	257.2	211.8
05/2019	233	14.5	227.1	154	133	16.2	117.2	126.1	218	10.7	148.2	148.7	190.0	23.3	204.2	158.9	186.0	36.5	198.7	165.2
06/2019	280	108.5	302.0	143	99	40.0	80.5	52.1	161	14.4	217.6	130.1	256.0	56.3	362.6	150.3	170.0	63.5	160.3	101.6
07/2019	238	97.8	252.7	161.5	94	142.7	59.9	56	163	175.1	131.0	154.9	224.0	122.9	223.5	166.4	129.0	178.8	119.9	82.0
08/2019	181	202.9	177.9	163.6	72	217.5	51.4	41.3	298	112.6	187.3	172.5	277.0	139.7	254.4	168.5	95.0	248.5	106.2	101.4
09/2019	193	264.5	223.6	132.4	75	30.2	66.7	60.4	195	298.2	233.1	156.9	145.0	275.1	214.6	139.5	86.0	98.3	83.3	125.0
10/2019	263	186.5	97.3	94.8	164	34.0	161.5	105.7	127	175.1	47.9	45.8	120.0	234.2	76.5	97.5	193.0	78.3	211.0	168.1
11/2019	193	164.0	112.0	63.8	237	25.5	176.3	114.9	33	160.3	44.4	33.6	94.0	162.3	80.0	63.8	228.0	53.6	113.2	121.7
12/2019	65	198.0	31.8	33.9	115	13.0	110.5	63.4	16	189.6	12.4	20.8	24.0	180.8	15.0	34.4	106.0	52.1	112.8	60.3

Months	Lote				Tibe				Wolaita				Woliso				Wolkite			
	CHRIPS	PERSIANN	TMPA	Station	CHRIPS	PERSIANN	TMPA	Station	CHRIPS	PERSIANN	TMPA	Station	CHRIPS	PERSIANN	TMPA	Station	CHRIPS	PERSIANN	TMPA	Station
01/2000	9	2.2	1.3	0	0	0.0	3.7	0	8	0.0	1.9	2.5	0	0.0	8.9	0.0	1	0.0	0.1	0.0
02/2000	15	3.9	1.4	0	0	1.1	1.7	0	7	5.9	2.1	0	0	0.3	11.8	0.0	1	0.8	0.1	27.
03/2000	52	37.9	38.9	5.9	0	9.5	9.2	0	29	31.4	30.3	31	4	7.8	14.8	4.2	8	8.9	17.6	0.0
04/2000	175	241.2	176.5	134.1	159	112.8	103.2	159.5	184	254.6	147.5	151.7	110	107.4	95.7	110.3	101	130.1	124.6	132.9
05/2000	264	165.1	217.8	191	108	164.9	170.8	108.1	180	209.5	225.5	224.8	101	122.8	125.0	101.1	96	215.0	175.3	145.2
06/2000	157	103.6	113.0	85.6	216	353.7	322.7	216.2	144	100.4	130.8	197.9	120	184.6	158.9	120.4	110	177.5	181.4	169.2
07/2000	229	130.0	162.9	224.1	219	295.2	286.1	219.1	197	140.9	145.5	124.2	327	317.4	246.8	327.3	282	270.0	216.9	310.1
08/2000	131	79.5	134.7	121.9	318	248.3	320.1	318.5	153	106.5	153.1	223.4	250	282.3	227.2	249.7	220	202.4	200.5	165.8
09/2000	129	123.3	98.3	61.7	102	178.1	272.8	102.1	119	237.7	159.3	169.5	172	151.7	183.6	171.7	126	295.0	197.3	138.6
10/2000	353	176.6	320.5	203.5	120	170.1	154.5	120.1	196	236.4	201.4	168	23	86.0	78.0	23.2	65	146.4	113.1	54.1
11/2000	83	61.5	74.7	58.4	23	41.6	51.3	22.6	73	53.4	67.6	59.8	16	31.8	40.0	15.6	18	43.0	48.3	26.8
12/2000	21	30.8	24.7	47.9	4	21.2	21.3	3.5	26	54.2	22.4	11.3	13	27.4	13.2	12.6	6	30.1	11.2	4.2
01/2001	37	21.1	28.8	26.8	0	3.2	5.2	0	19	11.9	22.2	19.1	11	5.4	10.1	11.1	14	0.8	12.3	6.2
02/2001	66	66.1	66.9	39.3	30	31.9	21.7	30.2	36	30.0	46.3	11.6	8	24.1	14.2	8.3	12	38.6	18.2	11.1
03/2001	187	174.7	175.6	158.3	44	77.7	92.6	43.5	135	181.2	130.1	107.4	82	178.0	121.6	82.5	89	135.3	126.3	67.1
04/2001	264	252.1	244.9	195.3	46	38.1	73.4	46	131	268.1	131.2	89.8	31	43.8	54.2	31.0	44	65.1	82.5	37.4
05/2001	289	202.3	217.4	127.9	136	197.8	218.6	135.9	220	271.4	242.4	295.4	85	127.2	145.5	84.8	130	248.0	192.8	105.4
06/2001	178	138.6	156.3	192.3	303	227.4	268.4	303.4	158	161.0	164.6	163.7	153	273.8	207.9	152.9	218	251.6	229.0	154.6
07/2001	159	93.9	95.9	60	324	310.1	318.5	324.2	249	155.7	165.3	233.5	326	326.2	283.7	326.2	338	242.5	266.3	400.8
08/2001	182	95.5	132.5	112.3	275	216.5	279.5	275.2	224	114.9	175.7	252.2	176	229.1	221.9	176.4	171	191.2	222.0	273.2
09/2001	280	2.2	132.5	238.5	181	0.0	279.5	180.9	153	0.0	175.7	113.2	110	0.0	221.9	109.8	128	0.0	222.0	116.8
10/2001	250	3.9	154.4	156.7	164	1.1	123.2	163.9	181	5.9	134.5	134	32	0.3	68.5	31.9	94	0.8	117.8	97.8
11/2001	73	37.9	22.0	43	28	9.5	6.8	28.2	34	31.4	22.0	43.8	6	7.8	17.2	6.3	14	8.9	14.5	3.4
12/2001	16	241.2	62.2	15.4	31	112.8	15.0	31	21	254.6	49.4	42.3	0	107.4	6.2	0.0	7	130.1	14.6	5.5

01/2002	80	165.1	18.5	24.4	26	164.9	13.4	26.3	57	209.5	20.1	47.8	25	122.8	5.3	24.6	35	215.0	6.6	47.0
02/2002	30	103.6	74.1	25.8	3	353.7	49.6	2.9	23	100.4	55.9	5.5	26	184.6	55.6	26.3	11	177.5	68.0	6.0
03/2002	277	130.0	15.2	215.3	77	295.2	10.7	76.8	149	140.9	22.7	121.9	82	317.4	17.3	82.1	68	270.0	13.3	76.8
04/2002	154	79.5	222.8	149.6	78	248.3	85.5	77.6	111	106.5	134.7	97.7	59	282.3	69.0	58.9	54	202.4	85.4	58.3
05/2002	229	123.3	123.0	137.8	29	178.1	68.5	28.6	128	237.7	111.0	173.3	59	151.7	54.9	58.9	65	295.0	71.1	168.0
06/2002	79	176.6	193.5	45.8	224	170.1	88.6	223.7	95	236.4	117.2	83.9	243	86.0	63.5	243.0	208	146.4	88.4	278.1
07/2002	143	61.5	63.1	68.8	178	41.6	319.9	178.3	140	53.4	93.0	90.5	270	31.8	211.5	270.3	222	43.0	222.0	254.4
08/2002	144	30.8	90.9	100.4	177	21.2	320.1	177.4	191	54.2	101.8	225.2	263	27.4	254.2	263.4	164	30.1	235.7	232.2
09/2002	119	21.1	90.9	99.4	74	3.2	320.1	73.6	105	11.9	101.8	54.2	60	5.4	254.2	60.3	71	0.8	235.7	90.1
10/2002	199	66.1	99.0	118.3	6	31.9	167.1	5.5	58	30.0	96.4	58.6	0	24.1	105.0	0.0	13	38.6	135.6	0.0
11/2002	50	174.7	123.8	28.2	0	77.7	13.5	0	9	181.2	71.6	2	0	178.0	3.9	0.0	0	135.3	15.4	0.0
12/2002	152	252.1	39.1	152	29	38.1	2.1	29	106	268.1	14.5	96.4	27	43.8	1.7	26.6	32	65.1	2.1	37.8
01/2003	55	202.3	168.5	62.2	0	197.8	41.4	0	42	271.4	120.9	99.5	27	127.2	36.7	26.8	22	248.0	67.7	17.6
02/2003	23	138.6	1.3	2.1	25	227.4	3.7	24.9	19	161.0	1.9	22.5	6	273.8	0.0	5.6	11	251.6	0.0	63.5
03/2003	155	93.9	1.4	96.6	50	310.1	1.7	49.9	115	155.7	2.1	62	82	326.2	0.0	82.5	71	242.5	0.1	76.4
04/2003	245	95.5	38.9	96.1	56	216.5	9.2	55.6	219	114.9	30.3	131.3	142	229.1	14.8	141.7	109	191.2	17.6	122.9
05/2003	203	2.2	176.5	113.5	2	0.0	103.2	1.9	112	0.0	147.5	66.6	18	0.0	95.7	18.2	16	0.0	124.6	144.9
06/2003	222	3.9	217.8	160.2	188	1.1	170.8	188.3	173	5.9	225.5	186.7	189	0.3	125.0	188.8	199	0.8	175.3	196.9
07/2003	171	37.9	113.0	63.6	289	9.5	322.7	288.5	191	31.4	130.8	198.1	333	7.8	158.9	332.8	274	8.9	181.4	369.4
08/2003	320	241.2	162.9	256.9	265	112.8	286.1	264.6	246	254.6	145.5	262.6	200	107.4	246.8	199.5	178	130.1	216.9	218.1
09/2003	167	165.1	134.7	106.4	139	164.9	320.1	138.5	110	209.5	153.1	36.2	112	122.8	227.2	112.4	71	215.0	200.5	202.7
10/2003	146	103.6	98.3	115.2	19	353.7	272.8	19.1	71	100.4	159.3	62.4	21	184.6	183.6	21.2	22	177.5	197.3	25.3
11/2003	69	130.0	320.5	30.7	0	295.2	154.5	0	43	140.9	201.4	40.3	14	317.4	78.0	14.0	16	270.0	113.1	10.1
12/2003	40	79.5	74.7	36.2	15	248.3	51.3	14.6	47	106.5	67.6	86	32	282.3	40.0	31.9	34	202.4	48.3	9.3
01/2004	124	123.3	24.7	54.7	7	178.1	21.3	7.2	87	237.7	22.4	55.4	55	151.7	13.2	55.0	35	295.0	11.2	46.3
02/2004	42	176.6	103.3	50.6	30	170.1	21.0	30.2	59	236.4	108.6	52.5	34	86.0	51.9	33.6	28	146.4	48.1	9.9
03/2004	61	61.5	21.7	10.7	18	41.6	11.6	18.3	54	53.4	43.9	41	49	31.8	14.9	48.7	37	43.0	22.6	30.1
04/2004	321	30.8	66.5	309.2	41	21.2	52.4	41	220	54.2	50.9	277.8	94	27.4	47.7	93.5	86	30.1	49.3	97.7
05/2004	248	21.1	270.2	97.4	31	3.2	92.5	31.2	117	11.9	214.5	106	49	5.4	88.9	49.1	47	0.8	101.9	88.5
06/2004	83	66.1	135.5	31.2	228	31.9	100.0	228.2	96	30.0	124.6	103.3	216	24.1	40.7	215.5	170	38.6	77.3	207.5
07/2004	123	174.7	74.1	100.6	289	77.7	304.2	288.7	162	181.2	92.7	185.2	282	178.0	180.7	282.0	234	135.3	200.5	162.9

08/2004	161	252.1	103.7	106.1	183	38.1	340.0	183.2	159	268.1	139.7	159.3	234	43.8	258.1	233.6	237	65.1	246.0	204.3
09/2004	155	202.3	129.2	94.7	164	197.8	335.0	163.7	144	271.4	147.8	63.6	172	127.2	287.9	171.8	141	248.0	271.3	160.0
10/2004	95	138.6	115.1	62.7	47	227.4	195.1	46.9	135	161.0	134.5	93	39	273.8	109.3	38.8	70	251.6	164.7	3.3
11/2004	178	93.9	97.9	131	0	310.1	72.5	0	45	155.7	96.1	39.2	8	326.2	46.6	8.2	11	242.5	82.3	6.3
12/2004	45	95.5	191.3	48.6	14	216.5	15.8	14.4	22	114.9	79.4	27.7	0	229.1	4.0	0.0	8	191.2	12.8	10.3
01/2005	49	2.2	57.1	59.4	0	0.0	15.5	0	33	0.0	44.6	8.2	63	0.0	13.9	63.3	44	0.0	31.4	44.7
02/2005	21	3.9	83.3	37.5	0	1.1	19.7	0	17	5.9	57.5	30.7	0	0.3	32.8	0.0	3	0.8	22.1	4.4
03/2005	223	37.9	6.1	76.6	78	9.5	2.7	78.4	135	31.4	12.1	186.9	75	7.8	3.5	74.7	116	8.9	3.1	93.9
04/2005	256	241.2	336.5	159.2	36	112.8	169.1	35.5	187	254.6	203.0	208.4	105	107.4	133.3	105.3	78	130.1	167.0	97.4
05/2005	387	165.1	206.2	485.1	69	164.9	67.6	69.1	279	209.5	156.5	323.2	70	122.8	90.1	70.3	99	215.0	130.6	10.3
06/2005	105	103.6	314.6	155.9	264	353.7	120.5	264	112	100.4	354.4	108.4	188	184.6	152.2	187.7	187	177.5	143.2	173.9
07/2005	147	130.0	106.6	28	185	295.2	310.8	185.2	198	140.9	125.7	241.7	230	317.4	175.5	230.2	254	270.0	215.0	240.5
08/2005	90	79.5	134.8	112.1	208	248.3	282.6	208	165	106.5	157.3	134.5	255	282.3	242.9	254.8	168	202.4	247.6	211.6
09/2005	229	123.3	128.4	104.4	159	178.1	335.6	159	204	237.7	130.3	151.5	157	151.7	267.3	157.3	176	295.0	301.6	239.1
10/2005	148	176.6	160.5	180.5	37	170.1	160.7	36.8	107	236.4	147.8	107.2	50	86.0	141.3	49.9	110	146.4	186.0	38.6
11/2005	101	61.5	122.2	62.1	81	41.6	68.6	80.8	105	53.4	94.5	113.5	16	31.8	45.4	16.4	22	43.0	59.9	34.2
12/2005	4	30.8	60.5	0	0	21.2	27.4	0	7	54.2	69.8	5	0	27.4	5.4	0.0	1	30.1	17.5	0.0
01/2006	19	21.1	5.2	1.3	0	3.2	0.6	0	11	11.9	2.5	4.4	2	5.4	0.0	2.1	3	0.8	0.7	4.4
02/2006	77	66.1	7.3	138.3	5	31.9	1.6	4.5	50	30.0	10.4	25	59	24.1	1.6	59.0	29	38.6	3.7	25.4
03/2006	247	174.7	102.6	126.9	52	77.7	31.7	52.4	152	181.2	87.4	125.5	91	178.0	74.8	91.3	78	135.3	54.5	83.2
04/2006	228	252.1	230.9	128.5	66	38.1	104.5	66.4	216	268.1	197.3	222.7	91	43.8	124.0	90.9	85	65.1	121.9	131.0
05/2006	228	202.3	160.2	113.8	125	197.8	70.0	125.1	141	271.4	210.0	142.6	102	127.2	85.0	102.0	114	248.0	117.5	100.3
06/2006	129	138.6	192.7	9	256	227.4	204.6	256.1	116	161.0	185.5	101.7	214	273.8	108.7	214.2	164	251.6	213.3	120.0
07/2006	123	93.9	80.6	9.7	233	310.1	362.3	232.9	171	155.7	148.2	136.7	303	326.2	284.1	302.6	253	242.5	365.8	163.6
08/2006	168	95.5	178.1	110.5	412	216.5	362.6	411.8	257	114.9	182.5	258.6	325	229.1	349.3	324.6	248	191.2	391.6	234.7
09/2006	126	2.2	147.8	27	206	0.0	264.4	205.8	82	0.0	165.8	62.1	175	0.0	278.0	174.6	158	0.0	238.3	174.0
10/2006	277	3.9	95.8	113.7	92	1.1	253.5	91.9	210	5.9	104.2	133.4	21	0.3	164.8	20.9	58	0.8	156.3	52.3
11/2006	142	37.9	239.6	32.8	22	9.5	158.4	22.2	45	31.4	180.0	37.6	18	7.8	76.0	17.8	21	8.9	119.6	35.5
12/2006	156	241.2	149.1	129.6	41	112.8	23.7	40.8	87	254.6	70.5	120.9	0	107.4	18.7	0.0	9	130.1	44.2	4.7
01/2007	115	165.1	163.1	38.8	9	164.9	33.8	8.7	46	209.5	108.0	74.1	22	122.8	21.0	21.6	41	215.0	40.9	42.3
02/2007	76	103.6	59.6	21	21	353.7	11.0	20.8	48	100.4	47.3	35.1	53	184.6	25.0	52.6	32	177.5	59.2	58.3

03/2007	134	130.0	89.8	50.6	14	295.2	75.7	14.4	83	140.9	71.9	91.2	21	317.4	38.2	21.1	36	270.0	62.1	34.9
04/2007	260	79.5	114.9	233.5	31	248.3	49.1	30.6	136	106.5	143.9	186.4	24	282.3	53.3	24.0	31	202.4	85.9	52.8
05/2007	293	123.3	236.9	139.4	190	178.1	84.0	190.2	213	237.7	164.3	225	155	151.7	69.9	154.5	138	295.0	85.4	122.5
06/2007	229	176.6	221.4	129.1	411	170.1	226.2	410.7	231	236.4	228.3	269	226	86.0	132.9	225.8	183	146.4	183.2	189.3
07/2007	221	61.5	118.2	144.8	200	41.6	288.0	199.8	214	53.4	122.4	215.8	249	31.8	191.7	248.7	246	43.0	229.4	220.1
08/2007	233	30.8	119.4	91.3	227	21.2	315.3	227	210	54.2	203.6	244.6	236	27.4	286.4	236.1	209	30.1	348.3	216.6
09/2007	274	21.1	101.8	106.7	213	3.2	286.7	213.1	233	11.9	162.8	242.2	177	5.4	241.8	177.4	151	0.8	253.9	137.2
10/2007	136	66.1	172.7	66.8	102	31.9	229.3	102	60	30.0	235.0	23.2	8	24.1	181.9	8.4	35	38.6	232.6	27.2
11/2007	95	174.7	106.7	50.6	0	77.7	48.7	0	21	181.2	53.3	15	0	178.0	32.1	0.0	1	135.3	47.3	0.0
12/2007	4	252.1	64.4	0	0	38.1	13.5	0	5	268.1	27.7	0	0	43.8	0.2	0.0	0	65.1	1.3	0.0
01/2008	25	202.3	3.8	2	24	197.8	0.7	24.4	16	271.4	1.2	6.1	0	127.2	0.0	0.0	5	248.0	0.0	0.0
02/2008	21	138.6	27.6	11	2	227.4	11.1	1.6	15	161.0	14.6	15.1	1	273.8	10.4	1.1	1	251.6	17.4	8.4
03/2008	72	93.9	19.5	71.4	4	310.1	5.2	4	39	155.7	9.2	10.9	5	326.2	8.7	5.4	6	242.5	10.3	7.9
04/2008	193	95.5	68.4	129.2	35	216.5	9.7	35.4	107	114.9	40.7	86.7	43	229.1	15.3	43.3	46	191.2	27.3	95.4
05/2008	195	2.2	191.8	96.5	291	0.0	69.0	290.9	156	0.0	147.2	136.5	127	0.0	34.1	127.3	190	0.0	65.5	248.8
06/2008	127	3.9	249.8	142.9	368	1.1	357.0	368.1	132	5.9	162.8	134.6	178	0.3	179.7	177.6	167	0.8	260.7	189.9
07/2008	189	37.9	156.9	73.3	248	9.5	312.2	247.5	255	31.4	172.7	225.4	326	7.8	195.8	326.2	317	8.9	248.1	287.8
08/2008	264	241.2	129.7	206.2	163	112.8	294.3	163	203	254.6	156.9	241.5	263	107.4	298.5	262.8	244	130.1	292.8	239.9
09/2008	254	165.1	133.3	123.9	177	164.9	256.3	176.7	155	209.5	200.1	241.2	160	122.8	258.2	159.6	161	215.0	239.1	83.5
10/2008	250	103.6	190.3	174.3	83	353.7	189.7	82.7	205	100.4	165.6	206.8	51	184.6	160.8	50.6	83	177.5	161.6	52.0
11/2008	132	130.0	143.1	51.4	69	295.2	122.1	69.5	116	140.9	142.3	131.6	88	317.4	67.6	88.3	79	270.0	107.7	67.5
12/2008	14	79.5	123.3	7.2	12	248.3	64.2	11.7	14	106.5	95.5	0	0	282.3	60.7	0.0	4	202.4	68.0	0.0
01/2009	41	123.3	10.6	10.2	333	178.1	5.5	335.6	85	237.7	13.2	13.5	17	151.7	2.4	16.7	65	295.0	2.8	25.8
02/2009	29	176.6	46.5	4.3	29	170.1	17.4	29.2	21	236.4	42.6	21.3	2	86.0	44.1	1.6	8	146.4	70.6	37.1
03/2009	101	61.5	29.9	51.7	34	41.6	24.1	33.6	48	53.4	26.9	29.2	43	31.8	18.6	42.8	68	43.0	30.3	7.2
04/2009	171	30.8	106.1	193.6	45	21.2	42.3	44.6	90	54.2	66.9	128.9	38	27.4	33.1	37.9	90	30.1	58.9	30.1
05/2009	158	21.1	305.1	141.6	30	3.2	107.3	30.1	106	11.9	119.0	125	64	5.4	44.5	64.4	51	0.8	105.7	57.6
06/2009	148	66.1	156.3	121.4	230	31.9	83.5	229.6	112	30.0	171.6	60.6	78	24.1	113.3	77.9	116	38.6	152.8	157.0
07/2009	74	174.7	50.9	113.6	247	77.7	253.4	246.6	133	181.2	57.3	85.4	234	178.0	111.4	234.1	213	135.3	162.3	240.1
08/2009	112	252.1	76.3	79.7	289	38.1	256.8	289.4	161	268.1	110.4	122.3	290	43.8	216.8	290.4	189	65.1	204.9	187.8
09/2009	159	202.3	106.5	119.7	177	197.8	281.9	176.6	134	271.4	145.4	148.9	107	127.2	224.7	107.2	147	248.0	248.6	108.6

10/2009	243	138.6	142.6	121.6	26	227.4	150.9	26.2	135	161.0	114.5	146.3	84	273.8	125.7	83.9	199	251.6	161.0	108.1
11/2009	81	93.9	177.4	49.7	56	310.1	142.1	56.6	49	155.7	138.6	45.5	0	326.2	65.0	0.0	9	242.5	113.1	1.4
12/2009	91	95.5	177.4	147	0	216.5	142.1	0	81	114.9	138.6	164	22	229.1	65.0	21.6	25	191.2	113.1	18.5
01/2010	36	2.2	105.1	38.3	26	0.0	22.9	26.2	28	0.0	93.3	16.2	9	0.0	36.3	8.7	10	0.0	48.0	37.7
02/2010	114	3.9	57.2	45.1	34	1.1	20.4	33.9	75	5.9	25.1	97.1	49	0.3	11.4	48.7	44	0.8	17.2	76.1
03/2010	292	37.9	100.2	217.2	15	9.5	104.7	14.8	141	31.4	92.2	144.7	28	7.8	204.9	28.1	70	8.9	120.5	40.8
04/2010	289	241.2	140.7	207.8	50	112.8	25.7	50.2	220	254.6	101.7	189.4	88	107.4	51.4	88.3	86	130.1	58.8	103.8
05/2010	307	165.1	214.0	245.9	208	164.9	52.0	208	249	209.5	235.4	280.8	134	122.8	89.3	133.8	141	215.0	119.2	157.8
06/2010	187	103.6	163.1	147.3	263	353.7	254.3	262.9	192	100.4	196.0	199.3	229	184.6	192.1	228.9	219	177.5	195.3	266.5
07/2010	150	130.0	140.3	134.4	286	295.2	324.2	285.6	155	140.9	177.9	112.9	307	317.4	288.7	306.7	215	270.0	343.7	221.1
08/2010	159	79.5	109.3	67.8	101	248.3	250.5	100.6	136	106.5	124.5	97.4	359	282.3	233.9	359.1	211	202.4	219.3	226.3
09/2010	196	123.3	93.5	114.9	124	178.1	179.0	123.9	167	237.7	95.3	130.7	148	151.7	199.9	147.8	124	295.0	206.8	121.8
10/2010	146	176.6	110.2	105	84	170.1	178.7	83.9	105	236.4	120.9	34.2	0	86.0	159.1	0.0	18	146.4	176.7	43.4
11/2010	28	61.5	125.9	26.3	57	41.6	70.5	56.6	26	53.4	97.8	18.7	5	31.8	20.5	5.4	12	43.0	55.5	5.1
12/2010	32	30.8	34.0	10	0	21.2	44.4	0	21	54.2	29.3	19.8	28	27.4	19.0	28.2	22	30.1	21.7	36.5
01/2011	13	21.1	16.6	15.1	28	3.2	11.3	27.8	15	11.9	11.3	4.5	5	5.4	10.4	5.3	10	0.8	10.7	11.8
02/2011	29	66.1	11.9	3.2	29	31.9	27.6	29.2	28	30.0	8.8	9.5	1	24.1	12.2	1.2	5	38.6	17.1	0.0
03/2011	67	174.7	86.6	70	11	77.7	31.0	10.6	31	181.2	57.3	43.2	36	178.0	33.6	35.7	32	135.3	49.0	55.2
04/2011	201	252.1	167.5	175.9	75	38.1	59.8	74.6	128	268.1	90.3	68.4	65	43.8	36.1	65.3	74	65.1	56.6	25.4
05/2011	316	202.3	204.5	220.5	229	197.8	190.8	228.8	276	271.4	169.1	270.8	132	127.2	87.8	132.2	189	248.0	148.5	130.5
06/2011	148	138.6	146.9	72.6	223	227.4	302.6	222.6	132	161.0	130.3	115.4	189	273.8	244.8	188.9	202	251.6	230.2	165.6
07/2011	184	93.9	141.4	87.8	222	310.1	223.7	222.2	167	155.7	232.1	202.8	235	326.2	236.1	234.7	234	242.5	264.4	138.0
08/2011	192	95.5	215.8	116.6	270	216.5	299.6	270.3	242	114.9	243.1	201.9	284	229.1	239.7	283.7	188	191.2	243.4	229.0
09/2011	291	2.2	246.9	103.8	17	0.0	173.4	17.3	153	0.0	272.9	106.6	159	0.0	178.9	158.8	102	0.0	236.4	117.5
10/2011	102	3.9	72.7	121.5	17	1.1	21.7	17.3	80	5.9	58.8	25.2	0	0.3	0.9	0.0	3	0.8	0.7	44.0
11/2011	231	37.9	209.6	252.2	37	9.5	96.0	36.5	135	31.4	123.6	138.4	30	7.8	56.7	30.0	48	8.9	105.3	18.0
12/2011	19	241.2	3.5	7.1	0	112.8	0.4	0	6	254.6	0.2	10.5	0	107.4	0.0	0.0	1	130.1	0.1	0.0
01/2012	13	165.1	7.9	0	0	164.9	2.0	0	9	209.5	3.1	1.2	0	122.8	3.5	0.0	3	215.0	15.4	0.0
02/2012	11	103.6	9.8	0	0	353.7	0.0	0	6	100.4	8.5	28.7	0	184.6	3.1	0.0	4	177.5	3.8	0.0
03/2012	61	130.0	89.8	35.7	33	295.2	58.7	33	41	140.9	30.0	10.1	33	317.4	67.9	33.3	36	270.0	149.2	44.0
04/2012	390	79.5	319.6	259.3	13	248.3	62.1	12.9	252	106.5	177.4	199.2	78	282.3	120.3	78.4	67	202.4	168.8	92.0

05/2012	201	123.3	206.3	74.4	35	178.1	273.1	34.9	116	237.7	339.0	139.3	61	151.7	297.3	60.6	75	295.0	252.5	143.0
06/2012	168	176.6	106.3	54.2	217	170.1	156.2	216.9	156	236.4	197.3	89	174	86.0	99.1	173.7	178	146.4	113.7	124.5
07/2012	313	61.5	142.7	138.2	188	41.6	236.6	188.3	263	53.4	142.9	314.3	187	31.8	156.4	186.8	228	43.0	182.4	165.8
08/2012	192	30.8	129.5	152.7	308	21.2	233.2	308	177	54.2	173.2	246.7	196	27.4	198.2	195.6	177	30.1	174.0	169.8
09/2012	326	21.1	217.5	123.7	187	3.2	230.2	187.4	160	11.9	236.6	135.8	216	5.4	289.4	215.6	169	0.8	289.5	125.8
10/2012	144	66.1	83.3	91	9	31.9	15.8	8.5	56	30.0	21.7	26.8	2	24.1	3.2	1.8	6	38.6	7.7	82.4
11/2012	114	174.7	83.4	47.7	21	77.7	18.3	21.4	61	181.2	111.9	85.7	3	178.0	19.8	3.0	8	135.3	12.7	59.8
12/2012	46	252.1	86.9	38.2	29	38.1	16.8	29.3	30	268.1	35.4	17.2	6	43.8	10.8	6.2	8	65.1	19.9	31.5
01/2013	93	202.3	40.2	25.7	21	197.8	10.3	20.6	60	271.4	63.8	47.4	2	127.2	9.2	1.9	12	248.0	12.1	26.0
02/2013	28	138.6	23.4	27.3	0	227.4	4.8	0	21	161.0	19.9	7.5	7	273.8	11.0	6.7	7	251.6	15.7	27.6
03/2013	180	93.9	129.2	76.2	24	310.1	34.8	23.7	133	155.7	110.7	76.2	79	326.2	50.2	79.4	57	242.5	61.1	75.1
04/2013	370	95.5	202.5	131.3	6	216.5	36.0	5.8	203	114.9	241.1	342.8	111	229.1	81.4	110.7	102	191.2	118.5	128.1
05/2013	191	2.2	175.1	144.8	122	0.0	264.9	121.7	142	0.0	188.8	80.8	112	0.0	143.1	112.0	96	0.0	265.8	143.0
06/2013	223	3.9	114.8	124.5	160	1.1	236.9	159.5	198	5.9	157.9	159.1	158	0.3	206.5	158.0	150	0.8	233.6	105.1
07/2013	194	37.9	110.2	121.3	179	9.5	267.7	178.7	317	31.4	169.0	252.8	203	7.8	221.0	203.2	200	8.9	234.3	166.4
08/2013	170	241.2	130.0	76.9	365	112.8	235.6	364.6	280	254.6	186.7	232.9	285	107.4	259.7	285.2	226	130.1	235.6	84.0
09/2013	237	165.1	103.5	124.9	128	164.9	160.1	128	155	209.5	143.9	145.1	155	122.8	143.7	155.4	161	215.0	158.8	125.4
10/2013	286	103.6	210.5	92.5	71	353.7	97.1	70.7	238	100.4	162.9	77.5	118	184.6	77.2	117.9	151	177.5	131.4	82.5
11/2013	189	130.0	98.2	139.5	24	295.2	33.3	24.1	87	140.9	87.0	44.8	27	317.4	22.5	26.6	27	270.0	40.0	19.0
12/2013	5	79.5	10.4	43.6	0	248.3	0.9	0	4	106.5	5.0	0	0	282.3	0.2	0.0	0	202.4	0.2	31.5
01/2014	15	123.3	13.6	3	0	178.1	6.0	0	14	237.7	12.7	33.9	11	151.7	5.8	11.1	16	295.0	7.6	26.2
02/2014	79	176.6	41.2	57.8	3	170.1	12.3	2.5	42	236.4	27.1	50	5	86.0	36.2	4.8	7	146.4	26.3	27.8
03/2014	218	61.5	97.9	77.3	27	41.6	52.9	26.8	134	53.4	85.2	127.3	49	31.8	55.7	49.4	59	43.0	74.0	75.5
04/2014	205	30.8	210.2	130.8	145	21.2	177.8	144.7	131	54.2	186.6	90.1	39	27.4	105.9	39.0	72	30.1	207.0	37.0
05/2014	361	21.1	242.3	145.1	223	3.2	246.9	222.9	284	11.9	268.1	237.1	179	5.4	150.5	179.1	155	0.8	229.0	143.0
06/2014	152	66.1	155.0	77	195	31.9	214.3	180	127	30.0	180.8	132.9	138	24.1	187.3	137.9	125	38.6	245.1	115.0
07/2014	135	174.7	119.1	159.1	83	77.7	222.0	82.5	166	181.2	152.6	198.8	262	178.0	205.9	262.2	270	135.3	232.8	165.8
08/2014	172	252.1	161.6	130.3	150	38.1	252.1	149.9	247	268.1	166.7	229	197	43.8	250.3	197.4	164	65.1	233.6	169.2
09/2014	232	202.3	156.3	87.9	127	197.8	214.3	126.5	135	271.4	211.5	179.2	128	127.2	154.7	128.5	139	248.0	163.6	181.8
10/2014	221	138.6	192.5	236.9	57	227.4	117.0	57.1	184	161.0	168.3	307.7	94	273.8	82.1	94.3	155	251.6	138.3	82.4
11/2014	85	93.9	98.2	70.8	6	310.1	33.3	6	47	155.7	87.0	111.2	14	326.2	22.5	14.5	12	242.5	40.0	0.0

12/2014	20	95.5	9.4	33.1	0	216.5	5.2	0	16	114.9	13.7	8.7	6	229.1	2.8	5.7	4	191.2	5.4	31.4
01/2015	27	2.2	7.2	0	0	0.0	3.4	0	25	0.0	6.1	0.6	0	0.0	3.0	0.0	5	0.0	3.1	26.0
02/2015	37	3.9	22.0	23	0	1.1	2.5	0	18	5.9	5.7	6.2	30	0.3	11.9	30.0	9	0.8	9.4	0.0
03/2015	132	37.9	92.3	64.4	22	9.5	38.6	22.1	86	31.4	96.1	40.2	40	7.8	68.7	40.5	55	8.9	69.1	51.0
04/2015	236	241.2	138.4	168.7	8	112.8	12.0	8.4	104	254.6	54.0	122.9	11	107.4	13.4	11.1	32	130.1	51.7	20.5
05/2015	296	165.1	266.1	144.8	173	164.9	167.2	172.7	183	209.5	196.4	192.4	155	122.8	125.1	154.7	161	215.0	212.0	165.0
06/2015	248	103.6	147.0	65.4	161	353.7	193.1	160.7	220	100.4	195.4	161	197	184.6	175.6	197.5	191	177.5	206.0	159.5
07/2015	179	130.0	140.2	57.3	180	295.2	290.1	180	227	140.9	124.0	135.5	231	317.4	248.0	230.8	230	270.0	377.2	129.5
08/2015	92	79.5	105.0	135.7	245	248.3	263.9	244.9	119	106.5	114.7	77.8	197	282.3	254.6	196.9	168	202.4	212.2	117.5
09/2015	176	123.3	127.2	130.5	126	178.1	209.4	125.9	117	237.7	170.6	79.4	140	151.7	168.6	140.1	190	295.0	209.8	39.5
10/2015	342	176.6	291.8	243.6	53	170.1	44.3	53.3	175	236.4	137.9	58.3	0	86.0	29.9	0.2	16	146.4	41.0	2.5
11/2015	186	61.5	110.2	163.5	25	41.6	53.4	24.8	86	53.4	147.6	37.5	3	31.8	6.0	3.1	17	43.0	74.7	36.5
12/2015	20	30.8	60.1	41	27	21.2	25.8	26.7	18	54.2	33.5	22.1	23	27.4	15.6	23.4	25	30.1	27.2	31.6
01/2016	29	21.1	30.4	14.1	0	3.2	13.8	0	27	11.9	34.7	51.7	22	5.4	47.4	22.3	22	0.8	32.8	4.0
02/2016	52	66.1	67.6	4	7	31.9	24.1	7	32	30.0	58.1	6.9	0	24.1	34.3	0.0	2	38.6	37.7	4.5
03/2016	84	174.7	135.3	122.3	14	77.7	64.7	13.5	60	181.2	108.2	110.6	63	178.0	59.7	62.9	80	135.3	103.7	64.5
04/2016	331	252.1	411.7	392.8	29	38.1	59.0	29.3	216	268.1	264.6	198.2	215	43.8	104.0	215.2	145	65.1	102.2	115.5
05/2016	271	202.3	188.1	181.2	171	197.8	323.7	171.3	152	271.4	180.0	220.7	159	127.2	239.7	159.1	169	248.0	299.4	143.2
06/2016	157	138.6	79.6	67.4	135	227.4	301.0	135.4	142	161.0	84.8	150.3	148	273.8	177.6	148.4	128	251.6	162.1	109.5
07/2016	79	93.9	66.9	158.5	178	310.1	224.4	177.7	123	155.7	88.5	92.4	143	326.2	201.4	143.3	154	242.5	240.5	131.0
08/2016	129	95.5	150.4	58.3	191	216.5	287.9	190.6	131	114.9	175.3	89.2	315	229.1	240.2	314.8	238	191.2	333.2	97.5
09/2016	98	2.2	105.8	38.9	78	0.0	236.2	77.6	65	0.0	110.7	129.6	152	0.0	188.2	152.4	134	0.0	193.1	46.0
10/2016	189	3.9	141.1	158.5	82	1.1	81.3	81.7	207	5.9	156.7	69.6	40	0.3	70.7	40.5	142	0.8	95.9	17.0
11/2016	141	37.9	106.9	79.2	9	9.5	4.2	8.8	76	31.4	84.5	50.6	25	7.8	5.2	25.6	17	8.9	4.1	58.9
12/2016	22	241.2	16.5	12.2	0	112.8	1.5	0	20	254.6	11.8	21.6	16	107.4	1.8	15.9	19	130.1	2.2	30.7
01/2017	12	165.1	5.8	0	0	164.9	2.2	0	7	209.5	5.5	0	21	122.8	1.3	20.9	15	215.0	0.9	0.0
02/2017	58	103.6	95.7	50.3	28	353.7	47.8	27.8	47	100.4	106.5	68.4	29	184.6	48.3	29.2	45	177.5	92.3	8.5
03/2017	119	130.0	148.4	30.5	77	295.2	35.1	76.6	69	140.9	106.5	24.1	29	317.4	58.3	29.1	43	270.0	90.7	74.8
04/2017	237	79.5	215.9	135.6	131	248.3	83.9	131.3	103	106.5	99.7	51.5	28	282.3	40.7	28.3	46	202.4	70.9	126.5
05/2017	356	123.3	300.3	145.1	148	178.1	237.7	148	220	237.7	206.4	182.5	164	151.7	175.8	164.5	123	295.0	206.5	69.4
06/2017	92	176.6	61.0	138.1	157	170.1	194.6	156.6	91	236.4	63.9	56.8	162	86.0	190.4	162.1	147	146.4	213.4	128.5

07/2017	200	61.5	91.9	114.3	339	41.6	274.3	177.7	192	53.4	110.3	221	204	31.8	239.1	204.0	194	43.0	217.0	165.2
08/2017	183	30.8	111.7	136.8	278	21.2	214.6	190.6	219	54.2	164.2	97.8	210	27.4	236.2	210.1	171	30.1	213.2	168.3
09/2017	273	21.1	244.2	230.7	201	3.2	214.1	138.2	178	11.9	315.3	144.2	152	5.4	386.4	151.7	145	0.8	212.7	125.0
10/2017	247	66.1	185.7	189.7	83	31.9	78.4	81.7	235	30.0	168.7	58.5	40	24.1	46.5	39.9	115	38.6	86.2	81.3
11/2017	99	174.7	50.7	29.4	26	77.7	6.9	11.2	52	181.2	58.9	14.7	25	178.0	9.6	25.7	34	135.3	7.8	58.9
12/2017	2	252.1	0.2	0	5	38.1	0.4	0	5	268.1	0.8	21.9	0	43.8	0.1	0.0	1	65.1	0.1	30.9
01/2018	15	202.3	6.8	0	15	197.8	7.6	0	10	271.4	9.7	0	21	127.2	7.4	21.5	17	248.0	15.7	25.7
02/2018	116	138.6	114.2	63.7	34	227.4	42.4	0	69	161.0	93.3	57.1	30	273.8	45.1	30.0	20	251.6	48.3	27.1
03/2018	113	93.9	65.0	26.3	50	310.1	41.2	57.1	101	155.7	66.6	84.8	77	326.2	36.4	77.5	87	242.5	47.8	74.8
04/2018	342	95.5	278.8	263.4	76	216.5	59.7	12.7	241	114.9	263.8	344.3	104	229.1	74.7	104.1	122	191.2	104.6	126.5
05/2018	320	2.2	257.6	134.2	112	0.0	179.1	232.2	224	0.0	249.1	148	130	0.0	134.8	129.6	154	0.0	184.5	142.7
06/2018	204	3.9	133.8	138	193	1.1	192.9	177.1	184	5.9	195.7	291.3	280	0.3	267.7	280.0	218	0.8	323.7	142.9
07/2018	69	37.9	122.1	158.2	273	9.5	318.5	157.2	75	31.4	166.1	102.6	342	7.8	269.6	342.5	324	8.9	262.5	165.2
08/2018	200	241.2	135.2	162.9	211	112.8	307.1	82.1	181	254.6	177.4	275.4	202	107.4	268.7	235.9	181	130.1	268.8	168.3
09/2018	168	165.1	132.4	14	114	164.9	223.9	26.7	95	209.5	139.1	23.6	50	122.8	159.9	90.9	53	215.0	179.5	125.0
10/2018	137	103.6	137.8	105.2	46	353.7	94.3	126	126	100.4	97.0	48.1	33	184.6	61.5	22.3	118	177.5	108.5	81.3
11/2018	127	130.0	126.6	60.7	53	295.2	63.2	53.9	103	140.9	121.9	172.1	26	317.4	63.6	133.0	33	270.0	51.5	58.9
12/2018	18	79.5	30.6	32.8	12	248.3	11.9	27.7	10	106.5	16.6	3.7	7	282.3	2.8	0.0	7	202.4	7.5	31.5
01/2019	17	123.3	9.5	25	10	178.1	0.4	0	11	237.7	5.1	0	3	151.7	0.0	0.0	3	295.0	0.6	25.9
02/2019	41	176.6	35.7	27.7	39	170.1	28.8	27.5	21	236.4	33.1	29.1	38	86.0	20.0	28.9	32	146.4	35.4	27.3
03/2019	109	61.5	80.6	75.8	96	41.6	55.8	76.4	72	53.4	62.1	76.3	42	31.8	33.9	74.6	75	43.0	65.7	75.2
04/2019	243	30.8	248.3	134	119	21.2	174.3	130.1	215	54.2	198.0	126.3	162	27.4	175.0	103.9	140	30.1	240.3	126.0
05/2019	432	21.1	210.8	145	103	3.2	165.6	148.8	263	11.9	163.9	148	105	5.4	116.1	128.5	107	0.8	154.0	142.9
06/2019	252	66.1	249.0	138.1	232	31.9	374.3	156.8	196	30.0	288.9	152.6	152	24.1	424.2	158.0	155	38.6	374.5	142.9
07/2019	238	174.7	179.5	158.2	287	77.7	213.9	177.5	252	181.2	190.3	197.9	193	178.0	211.5	212.3	207	135.3	206.5	165.8
08/2019	181	252.1	133.4	162.9	234	38.1	271.3	189.5	234	268.1	172.9	205.2	249	43.8	266.0	213.7	229	65.1	257.7	168.6
09/2019	139	202.3	140.6	123	169	197.8	228.2	137.1	84	271.4	128.4	142.2	179	127.2	214.5	151.4	118	248.0	176.8	124.6
10/2019	265	138.6	193.8	88.3	114	227.4	56.2	82.2	195	161.0	143.9	58.3	37	273.8	31.5	38.8	51	251.6	47.3	81.5
11/2019	198	93.9	83.6	60.7	86	310.1	77.1	53.9	95	155.7	88.9	39.6	22	326.2	44.2	29.2	23	242.5	65.5	59.2
12/2019	47	95.5	80.0	32.8	10	216.5	8.6	27.7	27	114.9	58.6	21.7	11	229.1	6.8	14.5	10	191.2	8.1	31.4