ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

Process Based Understanding of Drought in the Upper Blue Nile Basin Ethiopia

A thesis Submitted to the School of Graduate Studies of Addis Ababa University in partial fulfillment for the degree of Masters of Science in Civil Engineering (Hydraulics Engineering)

By:-

Endalew Ashagrie Fenta

Advisor: -

Dr. Semu A Moges and Dr. Dereje Hailu

Addis Ababa

Ethiopia

December, 2016

ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF GRADUATE STUDIES

Process Based Understanding of Drought in the Upper Blue Nile Basin, Ethiopia

By:-

Endalew Ashagrie Fenta

Approval by Board of Examiners

_______________________________ ______________

Chairman (department of graduate committee) signature

_______________________________ ______________

Advisor Signature

_______________________________ ______________

Internal Examiner Signature

_______________________________ ______________

External Examiner Signature

DECLARATION

I, the undersigned hereby declare that this thesis entitled: **Process Based Understanding of Drought in the Upper Blue Nile Basin, Ethiopia** is my original work performed under the supervision of Dr. Semu A Moges and Dr. Dereje Hailu, has not been presented as a thesis for a degree program in any other university and all sources of materials used for the thesis are duly acknowledged.

Name: ____________________

Signature: ____________________

Place: _______________________

Date of submission: -------------------

This thesis has been submitted for examination with our approval as university Advisor.

Dr:-____________________

Signature:-______________

ACKNOWLEDGEMENTS

I would like to express my wholehearted gratitude to my advisors, **Dr. Semu Ayalew Moges**, for his priceless support in supervising my work and providing me with important reference materials, for his invaluable guidance, constructive comments and his encouragement from early stage of my study. I am very grateful to **Dr. Dereje Hailu** and express my heart-felt appreciation for his unreserved support in guiding me to find out research problem and to help me to join **eartH2Obserb** project.

My sincere appreciation goes to **Mr. Haileyesus** and **Mr. Dejene Sahlu** for their appreciable support in providing ECMWF ERA Interim datasets and Bias corrected ECMWF ERA Interim datasets respectively and for their support on the concept of MATLAB. I would like also to thank Ministry of Water Resource and National Meteorological Service Agency for their cooperation in availing the necessary metrological data.

Finally, I owe whatever I have accomplished to God without whom I could accomplish nothing.

ABSTRACT

Drought poses immense impacts on economic activities, human lives and the environment. The main objective of this study is to characterize the drought condition of the (UBNB) by applying Standardized Precipitation Index (SPI) and Soil Moisture Deficit Index (SMDI). Drought indices have been derived from actual precipitation, ECMWF precipitation and soil moisture product and simulated using MATLAB 2015a. Comparison of datasets shows ECMWF precipitation product underestimate 45% the whole data and 20% of the data was overestimated from actual precipitation. SPI showed too much fluctuation between drought and normal conditions at shorter time scales (SPI-3 and SPI-6) and there are an increasing in the duration and magnitude of drought with timescale. SPI using ECMWF product exhibit low results in terms of coefficient of determination (R^2) and more than 50% of percentage deviations were under scanty range compared with SPI using actual precipitation product. SPI shows ECMWF product has lower tendency to capturing severe drought events. However, the chronic drought events i.e.1984/85, 1995/96, 2003/04 and 2009/10 have been characterized and captured well by SMDI and events were occurred less frequently with longer duration. Hence, SMDI shows a good correspondence with extent of historical drought events and better to capture drought events than the SPI and ECMWF product needs further correction before implement the data for drought analysis. The drought event during years 1984/85 was the most critical drought years in the basin with more than 57% of the total basin area under extreme drought and more than 32% of the total basin area under severe drought. So, it recommended to conduct further bias correction for all rainfall season and to evaluate other ECMWF product like temperature for its effectiveness.

(Key words: **Drought, Drought index, ECMWF, Grid, Upper Blue Nile Basin)**

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURE

ACRONYMS AND ABBREVIATIONS

AET: - Actual Evapotranspiration

BCM: - Billions Cubic Meter

CDF: - Cumulative Distribution Function

CFSR; - Climate Forecast System Reanalysis

DEM: - Digital Elevation Model

ECMWF: - European Centre for Medium-Range Weather Forecasts

ET: - Evapotranspiration

ETDI: - Evapotranspiration Deficit Index

GTS: - Global Telecommunications System

MATLAB: - Matrix Laboratory

NCEP; - National Centers for Environment Prediction

NMA: - National Meteorological Agency

NWP: - Numerical Weather Prediction

PDF: - Probability Distribution Function

SD: - Soil Water Deficit

SMC: - Soil Moisture Content

SMDI: - Soil Moisture Drought Index

SSFI: - Standardized Stream Flow Index

SPI: - Standardized Drought Index

UBNB: - Upper Blue Nile Basin

USAID: - U.S. Agency for International Development

1. Introduction

1.1. Background

Drought is considered as a deficiency of rainfall or increase in evapotranspiration over a prolonged period of time. Drought is one of the major natural hazards that bring about billions of dollars in loss to the farming community around the world every year. Globally, 22% of the economic damage caused by natural disasters and 33% of the damage in terms of the number of persons affected can be attributed to drought (Keshavarz et al., 2013). In spite of the economic and the social impact of drought, it is the least understood of all natural hazards due to the complex nature, the difficulty in identifying their inception and their end and varying effects of droughts on different economic and social sectors (Wilhite, 2000).

Agriculture is often the first sector to be affected by the onset of drought due to dependence on water resources and soil moisture reserves during various stages of crop growth. The impacts of drought are more severe in Sub-Saharan Africa, where rain-fed agriculture comprises 95% of all agriculture. This dependence of rain-fed agriculture leaves Sub -Saharan Africa vulnerable to the impacts of drought (Husak et al., 2013). Ethiopia is one of the Sub-Sahara African countries highly prone to different hazards. However, drought has remained the leading cause of disaster and human suffering in Ethiopia in terms of frequency, area coverage and the number of people affected (Sara. A, 2010).

The drought characteristics should provide information about drought vulnerability, spatial and temporal aspect of the drought, as well as water deficit volume during drought events (Rahel S. T. 2007). Drought monitoring is of critical importance for risk assessment and decision making, as well as for taking prompt and effective actions to reduce the effects of droughts. This could be achieved by developing different drought indices that are capable of characterizing drought at different spatial and temporal scale. Developing and selecting the best drought indices among the available for drought monitoring, forecasting and early warning systems is indispensable.

Most commonly used drought indices are mainly based on precipitation and /or temperature datasets because of these meteorological variables are readily available for most parts of the world (Rahel S. T. 2007). However, the amount of available soil moisture at the root zone is a more critical factor for crop growth than the actual amount of precipitation deficit or excess. Hence, the development of a reliable drought index for agriculture requires proper consideration of vegetation type, crop growth and root development, soil properties, antecedent soil moisture condition, evapotranspiration and temperature.

Conventional methods of drought assessment which rely on the availability of weather data from metrological station are tedious and time consuming and most of these data are often incomplete and limited in the basin (Beyene E. G., 2007). In contrast, in recent years, several global reanalysis datasets with high spatial and temporal resolution are consistently available to compensate for the lack of direct observations in the globe. The European Centre for Medium-Range Weather Forecasts (ECMWF) is one of globally available reanalysis datasets and it provides two widely used reanalysis datasets: the 40-yr ECMWF Re-Analysis (ERA-40), and the interim ECMWF Re-Analysis (ERA-Interim) (Xinghua B. & Fuqing. 2012). In this study ECMWF (ERA-Interim) reanalysis datasets are evaluated based on Drought Index as criteria.

1.2. Droughts in Ethiopia

Ethiopia's weather and climate are extremely variable both temporally and spatially. The heavy dependence of the population on rain-fed agriculture has made the people and the country's economy extremely vulnerable to the impacts of droughts. Drought has long been associated with Ethiopia with records indicating such conditions as far back as 250 BC (Rahel S. T. 2007). The first well documented drought and famine crisis in Ethiopia happened in the years 1973-1975 (Glantz 1996). Moreover, the frequency of drought has been increasing more recently. In the 1970s and 1980s, droughts typically occurred, on average, once per decade; presently, droughts are anticipated to occur about once in every three years (USAID, 2011).

Ethiopia experienced its worst drought in the year 2016 due to existing periodical El Niño, leaving 10.1 million people food insecure and estimated 2.1millions children in need of treatment for severe acute malnutrition (SNOPSIS, 2016). To make matters worse, the weather phenomenon also brings heavy flood to some areas of the country. Almost all part of upper Blue Nile basin facing a severe drought resulting from the failure of the rainy season due to existing periodical El Niño (UNICEF 2015). Number of population affected by recent drought in Ethiopia is summarized in Figure.1.1.

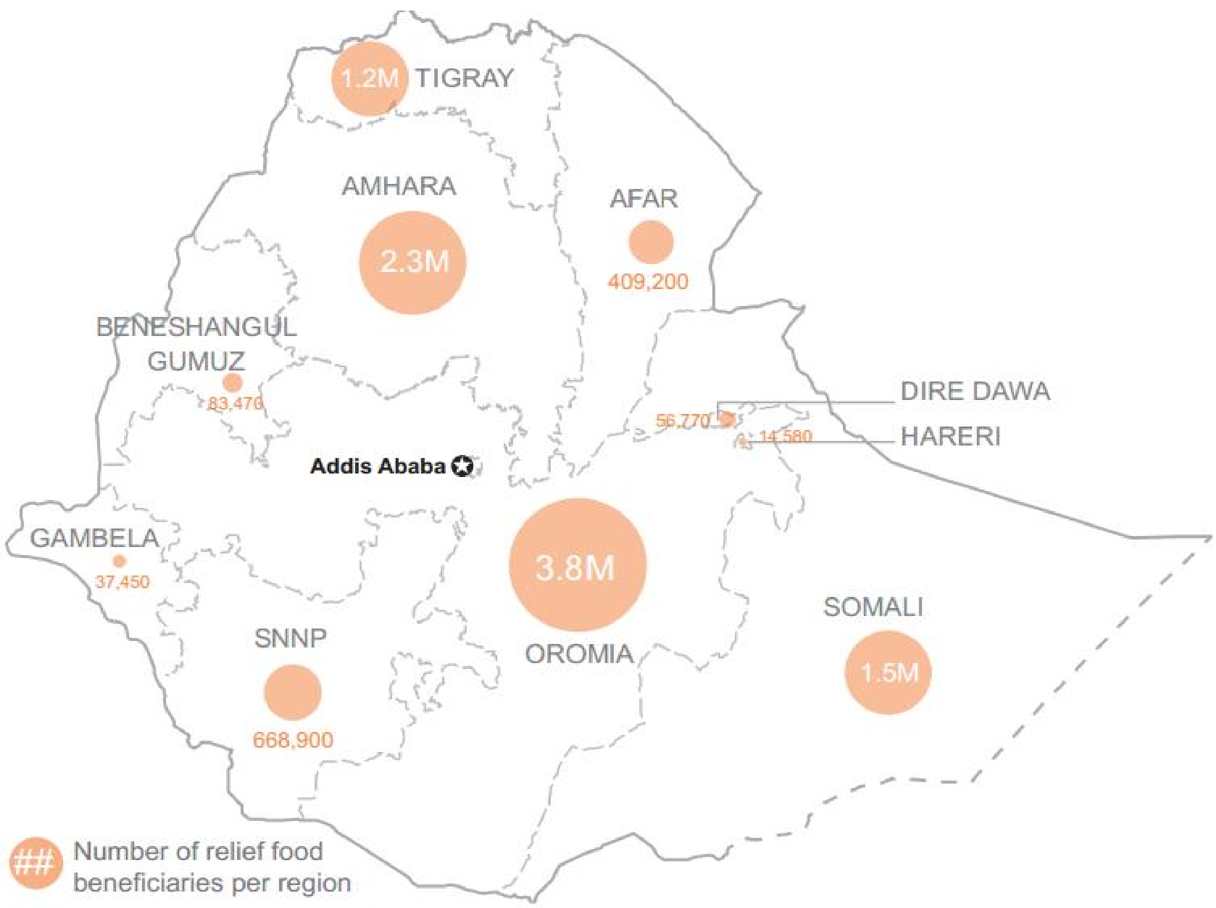


Figure 1-1:- Number of people Affected by Recent Drought 2015/16

[Source SYNOPSIS, 2016 Central Statistical Agency Projection, Ethiopia]

1.3. Statement of the Problem

Ethiopia has experienced four major droughts since 1970s. The drought of the early 1970s was responsible for 200,000 deaths in Ethiopia (Boken, 2005) and was soon followed by another drought from 1983-1985 that was responsible for between 400,000 and 1 million deaths (Belayneh, A. et.al., 2012) and a total number of 13.5 million populations potentially affected, (ECA 2005). The year 2009/10 is also 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). Although the famine caused by the drought of 1984–85 remains well known to the world community, less serious, but nonetheless significant droughts occurred in the years 1987/88, 1991/92, 1993/94, 1999, and 2002 (Edossa et al., 2010).

Most part of Upper Blue Nile basin often faces drought disaster; even though areas received enough total rainfall in a year. Previous studies on metrological indices show that there was no extreme drought in the basin even during the chronic drought years (Mosaad K. 2015). Accordingly, drought indices only based on precipitation and /or temperature datasets may lead to wrong conclusion. Hence, the development of a reliable drought index requires proper consideration of vegetation type, crop growth and root development, soil properties, antecedent soil moisture condition, evapotranspiration, and temperature.

Drought` assessment which rely on the availability of weather data from Ethiopian metrological station are tedious and time consuming and most of these data are often incomplete and limited. In addition, drought indices recommend having around 30 to 60 years records. The minimum 30 years of data or less will have shortens the sample size and weakens the confidence (Guttman, 1994, 1999). In order to overcome this problem several global reanalysis datasets are consistently available in the globe. But, before directly use this globally available data; evaluation based on different parameters like drought indices is mandatory.

1.4. Research Objective

The general objective of this research is to analyze drought characteristics in UBN basin using meteorological and agricultural related indices based on ECMWF, bias corrected ECMWF and observed precipitation datasets.

The specific objectives are to:

- To compute drought characteristics using soil moisture drought index (SMDI) and standardized precipitation index (SPI) in the upper Blue Nile basin based on reanalysis and observed data sets.
- To analysis drought indices on the basis of the characteristics explained by the intensity, severity and duration of droughts.
- To understand drought indices during the chronic drought years of 1984/85, 1995/96, 2003/04 and 2009/10.

1.5. Research Questions

- Can globally available reanalysis precipitation and soil moisture products help to characterize the drought condition of the Upper Blue Nile basin?
- How does the drought index such as SPI-3, SPI-6, SPI-12 and SMDI correlate?
- Which drought index is appropriate to explain drought in UBN basin better?

2. Literature Review

2.1. Drought Definition and Classification

There is no clear definition of drought; it only depends on the context and regions. (B. Narasimhan 2004). The primary cause of any drought is a deficiency in rainfall and in particular the timing, distribution, frequency and intensity of this deficiency in relation to the existing water storage, demand, and use. This deficit can result in an unavailability of water essential for the functioning of a natural ecosystem and/or indispensable for a certain human activities. Generally drought is an insidious natural hazard characterized by lower than expected or lower than normal precipitation that, when extended over a season or longer period of time (B. Narasimhan 2004). Figure 2.1 shows that propagation of drought though the hydrological cycle.

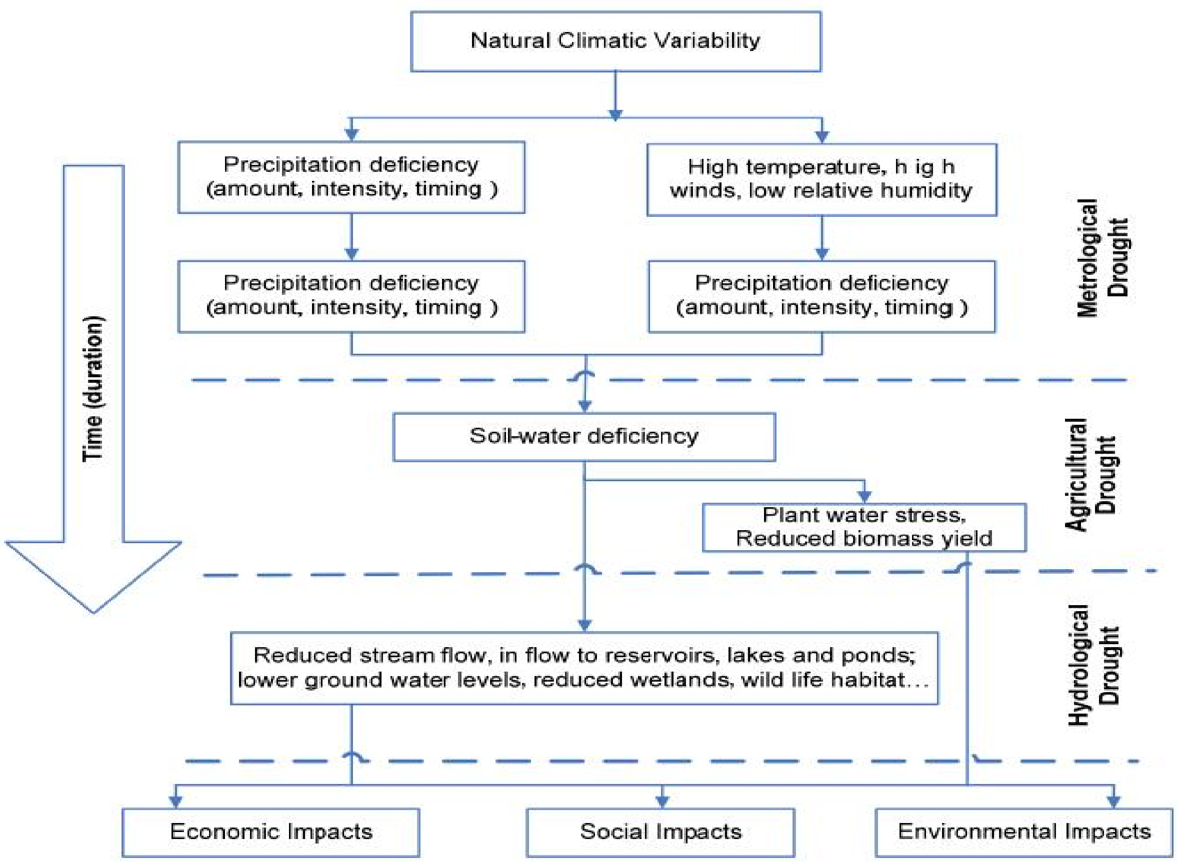


Figure 2-1:- Propagation of Drought through the Hydrological Cycle

[Source: National Drought Mitigation Centre, University of Nebraska-Lincoln, USA]

As shown in Figure 2-1 drought has been categorized as, **Meteorological**: - a measure of departure of precipitation from normal. It basically originates from a deficiency of precipitation and is focused on the physical characteristics of drought, rather than on the impacts associated with shortage of precipitation in a region. **Agricultural**:- refers to a situation where the amount of moisture in the soil no longer meets the needs of a particular crop. It is more closely associated with the deficiencies in the soil moisture than precipitation deficiencies. Because of this fact, agricultural drought lags the occurrence of meteorological drought. **Hydrological**:- It is best defined by deficiencies in surface and subsurface water supplies, which lead to a lack of water availability to meet normal and specific demands; and **Socio economic**: refers to the situation that occurs when physical water shortages begin to affect people (Adane, A. A. (2009).

2.2. Drought Indices

Drought indices are quantitative indicators, used to identify, characterize and analyze drought events with relative accuracy and objectivity (McKee et al., 1995). A drought index integrates various hydrological and meteorological parameters like rainfall, temperature, evapotranspiration (ET), runoff and other water supply indicators into a single number and gives a comprehensive picture for decision-making. There are different drought indices extensively used for water resources management, drought monitoring and forecasting (Rahel S. T, 2007).

Drought indices are also categories as: **Meteorological**: - typical: SPI – Standardized Precipitation Index (McKee et al. 1992), Drought Severity Index DSI (Bryant et al. 1992) etc. **Agricultural**: - typical: CMI – Crop Moisture Index (Palmer 1968), Evapotranspiration Deficit Index ETDI (Narasimhan and Srinivasan 2005), Soil Moisture Drought Index SMDI (Hollinger et al. 1993) etc and **Hydrological:** - Palmer Hydrological Drought Index PHDI (Palmer 1965), Surface Water Supply Index SWSI (Shafer and Dezman1982) etc.

Choosing appropriate drought index for the basin depends on available information, drought specific, specific boundary conditions, field of application and spatial scales (continental, national, regional ...) etc. If the existing drought index fails to detect droughts, their severity or insufficient description of spatiotemporal development for the basin; developing the new drought index is mandatory. In this case new applications require, new source of data available, new methodology developed for better tailored drought indices.

2.2.1. Parameters' Use to Characterized the Drought

Droughts are fundamentally characterized in three dimensions: **severity**, **duration**, and **spatial distribution**. Additional characteristics include: frequency, magnitude, predictability, rate of onset, and timing. The drought characteristics are summarized graphically on figure 2.2.

Duration (D): vary between a Weeks's up to a few years because of drought's dynamic nature. It is a duration or run-length from beginning to end of the drought

Magnitude (M): The accumulated deficit of water (e.g., precipitation, soil moisture, or runoff) below some threshold during a drought period.

Mean Intensity: The ratio of drought magnitude to its duration.

Severity(S): Two usages are provided for drought severity: the degree of the precipitation deficit (i.e., magnitude), or the degree of impacts resultant from the deficit (Wilhite, 2004). Equation 2.1 is used to calculate Severity.

$$S = -(\sum_{j=1}^{x} SPI_{i.j}) \qquad 2—1$$

Where j starts with the first month of a drought and continues to increase until the end of the drought (x) for each time scales.

Geographic extent: The areal coverage of the drought which is variable during the event. This area can cover one or several pixels (cells), watersheds or regions.

Frequency (return period): The frequency or return period of a drought is defined as the average time between drought events that have a severity that is equal to or greater than a threshold.

Statistical properties of the drought: **Drought Duration (D_i)**, **Severity(S), And Peak Intensity (*M_{min}*)**:- are summarized in figure 2.2.

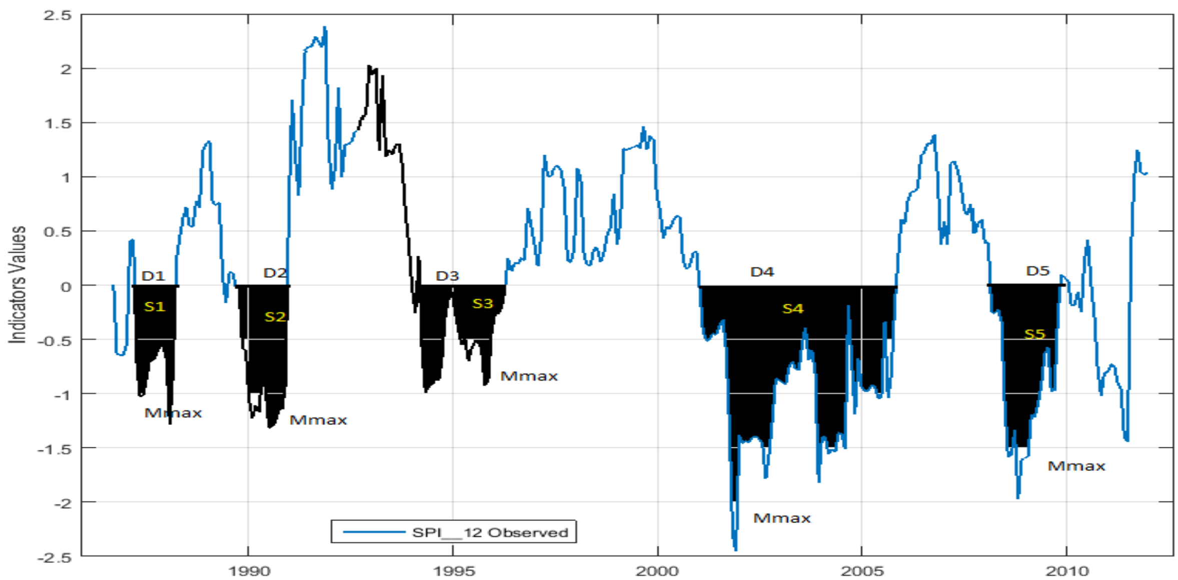


Figure 2-1:- Parameters' use to of Characteristics Drought

2.2.2. Standardized Precipitation Index (SPI)

The SPI (McKee and others, 1993, 1995) is a powerful, flexible index that is simple to calculate. In fact, precipitation is the only required input parameter. In addition, it is just as effective in analyzing wet periods/cycles as it is in analyzing dry periods/cycles. Ideally, this drought index does recommend having around 30 to 60 years of data. The minimum 30 years of data (or less) will have shortens the sample size and weakens the confidence; with 50 to 60 years or more being optimal and preferred (Guttman, 1994, 1999).

The SPI calculation for any location is based on the long-term precipitation record for a desired period. This long-term record is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee, 1997). Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation. Because the SPI is normalized, wetter and drier climates can be represented in the same way; thus, wet periods can also be monitored using the

SPI. Calculating the standardized precipitation index (SPI) summarized below in Figure 2.3.

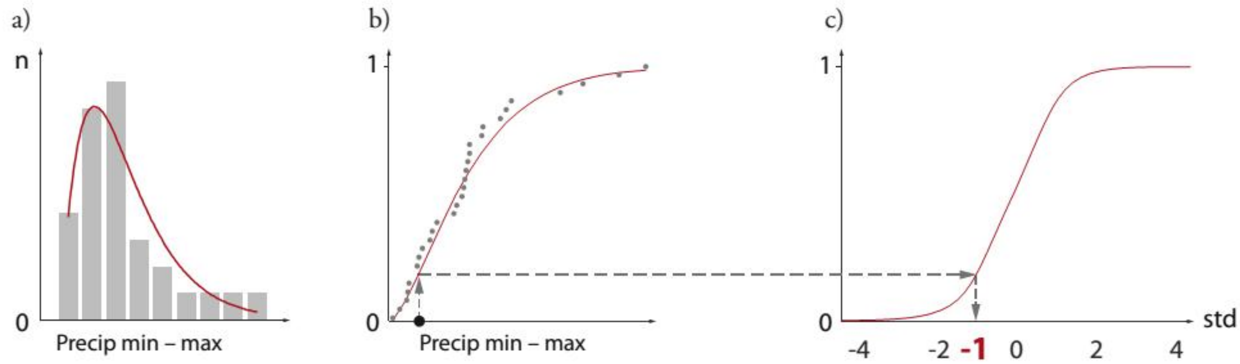


Figure 2-2:- Calculating the Standardized Precipitation Index (SPI)

a) Is a bar histogram of a sample distribution of monthly precipitation, with the number of occurrences in each of 9 equally spaced precipitation classes. The red curve is the gamma probability distribution function (PDF) fitted to these data. b) shows the empirical cumulative probability distribution of the same data (markers), with the corresponding cumulative distribution function (CDF) of the fitted gamma function (red curve). c) Shows the CDF of the standard normal distribution. As indicated by the arrows in b) and c), the SPI of a specific precipitation value may be found graphically by locating the gamma CDF value corresponding to this precipitation, and go to the same level of the normal CDF (horizontal arrow). The SPI is then the standard deviation of the normal distribution at this level, found at the horizontal axis. This is equivalent to fitting a gamma function to the data, and then assumes that the SPI describing them is normally distributed.' (Guttman, 1994, 1999).The detail calculation description of the index will be discussed in (section 4.2.2)

The SPI was designed to quantify the precipitation deficit for multiple timescales. These timescales reflect the impact of drought on the availability of the different water resources. McKee and others (1993) originally calculated the SPI for 1, 3, 6, 12, 24 and 48-month timescales. Meteorological and soil moisture conditions respond to precipitation anomalies on relatively short timescales, for example 1-6 months, whereas stream flow, reservoirs, and groundwater respond to longer-term precipitation anomalies of the order of 6 months up to 24 months or longer. (WMO User Guide, 2012)

2.2.2.1. 1-Month SPI

A 1-month SPI map is very similar to a map displaying the percentage of normal precipitation for a 30-day period. In fact, the derived SPI is a more accurate representation of monthly precipitation because the distribution has been normalized. For example, a 1-month SPI at the end of November compares the 1-month precipitation total for November in that particular year with the November precipitation totals of all the years on record. (WMO User Guide, 2012)

Interpretation of the 1-month SPI may be misleading unless climatology is understood. In regions where rainfall is normally low during a month, large negative or positive SPIs may result even though the departure from the mean is relatively small. The 1-month SPI can also be misleading with precipitation values less than the normal in regions with a small normal precipitation total for a month.

2.2.2.2. 3-Month SPI

The 3-month SPI provides a comparison of the precipitation over a specific 3-month period with the precipitation totals from the same 3-month period for all the years included in the historical record. In other words, a 3-month SPI at the end of February compares the December–January– February precipitation total in that particular year with the December–February precipitation totals of all the years on record for that location. (WMO User Guide, 2012)

2.2.2.3. 6-Month SPI

The 6-month SPI compares the precipitation for that period with the same 6-month period over the historical record. For example, a 6-month SPI at the end of September compares the precipitation total for the April–September period with all the past totals for that same period. (WMO User Guide, 2012)

The 6-month SPI indicates seasonal to medium-term trends in precipitation and is still considered to be more sensitive to conditions at this scale than the Palmer

Index. A 6-month SPI can be very effective in showing the precipitation over distinct seasons. For example, a 6-month SPI at the end of March would give a very good indication of the amount of precipitation that has fallen during the very important wet season period from October through March for certain Mediterranean locales.

2.2.2.4. 12-Months SPI

The SPI at these timescales reflects long-term precipitation patterns. A 12-month SPI is a comparison of the precipitation for 12 consecutive months with that recorded in the same 12 consecutive months in all previous years of available data. Because these timescales are the cumulative result of shorter periods that may be above or below normal, the longer SPIs tend to gravitate toward zero unless a distinctive wet or dry trend is taking place.

2.2.3. Soil Moisture Deficit Index (SMDI)

Soil Moisture Deficit Index (SMDI) developed based on weekly soil moisture deficit. SMDI was computed at four different levels, using soil water available in the entire soil profile, then soil water available at the top two feet, four feet, and six feet. This was done because the potential of the crop to extract water from depths varies during different stages of the crop growth and also by crop type. Weekly values are calculated for different soil layers and depths. Weekly values reflect short-term dry conditions, which is very helpful during plant growth phases. (Narasimhan et al. 2004). Since SMDI is used in this study detail description of the index will be discussed in (section 4.2.3.)

2.2.4. Standardized Stream Flow Index (SSFI)

Standardized Stream flow Index (SSFI) McKee *et al.* (1993) developed a standardizing procedure for evaluating precipitation departures (e.g., SPI) using a PDF. A similar approach to SPI was used to develop the Standardized Stream flow Index (SSFI). Rather than computing SSFI on a monthly time step, it is computed on a daily time step using rolling cumulative flows for a variety of time scales.

2.3. Global Reanalysis Datasets

The basic idea of reanalysis is to use a general circulation model coupled with an assimilation system that is kept constant for the whole analyzed period. The output atmospheric fields are consequently free of secular changes that may result from changes in the physics of the model or in the way observations are treated (Dee et al. 2011). Reanalysis are particularly well suited for the detection of long-term changes or oscillations in the atmosphere and have become widely used among the community for such studies (K.I.Hadgos. and S.Hagemann, 2011).

In recent years, several global reanalysis datasets with high spatial and temporal resolution have been used to compensate for the lack of direct observations in the globe. The National Centers for Environment Prediction (NCEP) and the European Centre for Medium-Range Weather Forecasts (ECMWF) provide four widely used reanalysis datasets: the NCEP–National Center for Atmospheric Research (NCAR) Reanalysis Project (NNRP), the NCEP Climate Forecast System Reanalysis (CFSR), the 40-yr ECMWF Re-Analysis (ERA-40), and the interim ECMWF Re-Analysis (ERA-Interim) (Hodges et al. 2011). Given the inherent uncertainties in the forecast model, input data, and data assimilation, it is essential to assess the quality of these reanalysis and the reliability of their use in evaluating variations in weather and climate and/or as surrogates of observations to be assimilated into climate models.

2.3.1. ECMWF Interim Reanalysis

The ECMWF is an intergovernmental organization supported by more than 30 States. It provides weather services with medium-range forecasts of global weather to 15 days ahead as well as with monthly and seasonal forecasts (Dee et al. 2011). ECMWF's computer system at its headquarters in Reading, United Kingdom, is one of the largest for meteorology worldwide and contains the world's largest archive of numerical weather prediction data and become an important source of data for research. It is used extensively by the centre's staff and by scientists from all over the world for a wide variety of studies and applications (Pesonen, O., and Raoult, B., 1999)

Currently ECMWF is producing its 3 rd generation reanalysis, ERA-Interim, which benefits from the analysis and model developments since ERA-40, in particular in the assimilation of satellite radiances. The goal of the ERA-Interim project was to improve upon ECMWF's previous reanalysis, ERA-40, in advance of their planned next-generation reanalysis (Dee et al. 2011). Through three decades of Numerical Weather Prediction (NWP) development and feedback from the scientific community reanalysis have achieved partly the qualities required for climate change studies. The ERA-Interim system is described in detail by Dee et al. (2011), and the data sets provided by ECMWF from the ERA-I archive are described by Berrisford et al. (2009). For this study the new Re-analysis product available at ECMWF called ERA-Interim of daily soil moisture available in root one, monthly precipitation with 0.5 degree spatial resolutions from 1979 to 2012 G.C is used to compute the drought indices.

2.4. Review of Previous Studies

Early studies by Rahel (2007) were developed an agricultural drought indices by using advanced distributed parameter hydrologic model SWAT (Soil and Water Assessment Tool) across the Upper Blue Nile basin of Ethiopia. Two drought indices, the soil moisture deficit index (SMDI) and evapotranspiration deficit index (ETDI), were developed in this study based on soil moisture deficits and evapotranspiration, respectively. Analysis of the data showed that SMDI compared well in six zones of Amhara region during the months of critical crop growth stages. However, selected drought indices are at the same category and used observed data to develop indices.

In addition Yared A.et al (2015) was developed a paper on Inter-comparison of the performance of five drought indices to assess and characterize historic drought events across the Upper Blue Nile basin of Ethiopia. In this study Standardized Precipitation Evaporation Index, Evapotranspiration Deficit Index, Soil Moisture Deficit Index, Aggregate Drought Index, and Standard Runoff-discharge Index was assessed to characterize the historic drought events in the basin. It concludes that a "hybrid" approach using multiple drought indices better to characterize and understand drought conditions in the region.

Mosaad Khadr and Andreas Schlenkhoff (2015) also conducted journal on analysis of spatial and temporal variability of meteorological drought vulnerability in the Blue Nile River Basin. In this study, spatial and temporal dimensions of meteorological drought in Blue Nile basin were investigated from vulnerability concept. The standardized precipitation index (SPI) was computed at multiple-time steps and the Mann – Kendall test was applied on monthly SPI time series for trend detection. Results indicate that droughts randomly affect the region and several drought events contain mild, moderate severe, and extreme droughts were observed during the long rainy season (June to September) and the short rainy season flow (March to May) as well. As it shown in the result there was no severe drought in some area even if in well known historical drought events in the area.

Researches focused on systematic evaluation of the quality of globally available reanalysis ECMWF data sets based on draught characteristics on the basin is hardly available in the literature. The main objective of this study is to examine European center for medium-range weather forecast (ECMWF) reanalysis datasets for characterize the drought condition of the (UBNB) by applies two drought indices, Standardized Precipitation Index (SPI) and Soil Moisture Deficit Index (SMDI).

3. Material and Description of Study Area

3.1. Description of Study Area

3.1.1. Location

The study area, Upper Blue Nile river basin, is known at Abbay in Ethiopia, located in the centre and west of Ethiopia. It lies approximately between latitude 7^0 45' and 12^0 45'N, and 34^0 05' and $39^0$45'E, being generally rectangular in shape, and extending about 400 km from north to south, and about 550 km from east to west as shown in Figure 3.1. It is the largest in terms of volume of discharge, second largest in terms of area in the country (Habte A, Cullmann, J. and Horlacher H (2007).

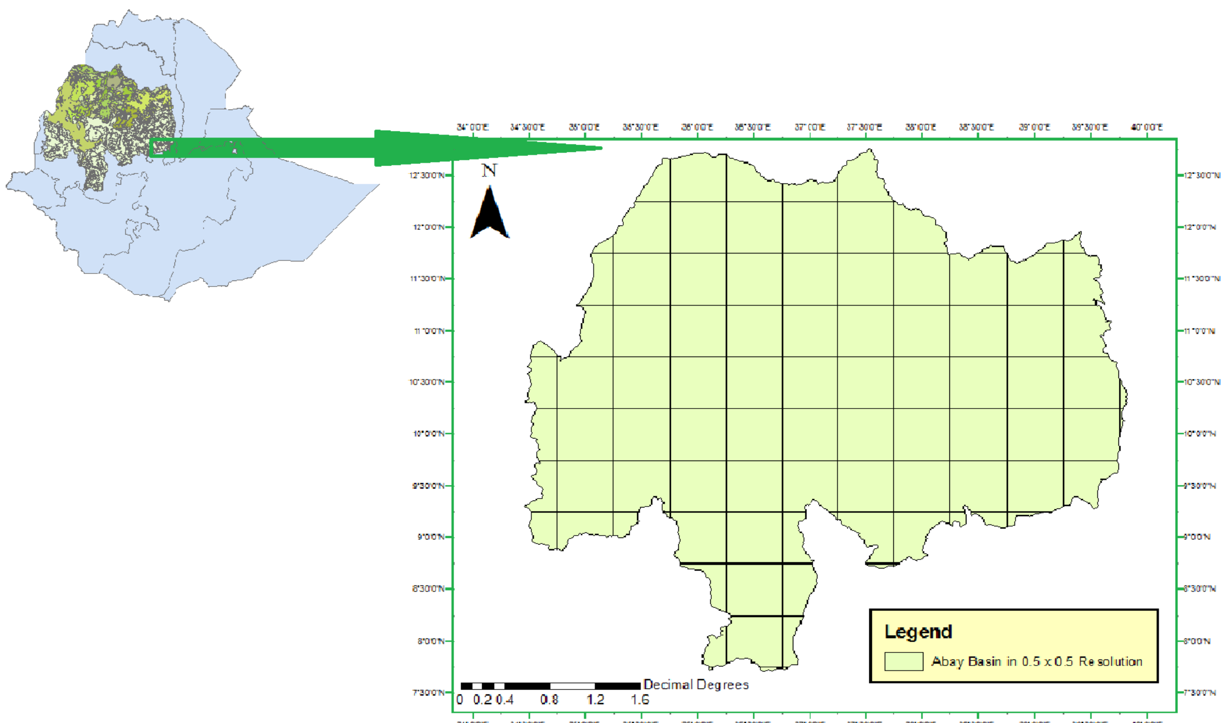


Figure 3-1:- Location Map and Gridded (0.5^0 * 0.5^0) Abay Basin

3.1.2. Climate

The climate of UBN basin is dominated by an altitude ranging from 590 meters to more than 4000 meters. The influence of this factor determines the rich variety of local climates ranging from hot to desert-like climate along the Sudan boarder with mean temperature of the coldest month above 18°c, to temperate on the high plateau, and cold on the mountain peaks, with mean temperature of the warmest month below 10°C. But the annual rainfall varies between about 800mm to 2,220 mm with a mean of about 1420mm (Master Plan of BNRB – Main Report, 1999). The traditional classification of climate in the basin uses elevation as a controlling factor and recognized the following three regions:

1. The *Kolla* zone below 1800m has mean annual temperatures in the range 20-28°C
2. The *Woina Dega* zone between 1800-2400m has mean annual temperatures in the range 16-20°C; and
3. The *Dega* zone above 2400 has mean annual temperatures in the range 6-16°C

3.1.3. Hydrology and Size of the Basin

As indicated from the Master Plan of BNRB – Main Report, (1999) UBN basin accounts for almost 17.1% of Ethiopia's land area, about 50% of its total average annual runoff and 25 % of its population. The UBNB Rivers has an average annual runoff of about 50 BCM. The rivers of the UBNB contribute on the average about 62% of the average Nile total at Aswan Dam (Dereje, 2006).

Most of the rain occurs in a few months, primarily from June through September. There is a very strong influence of the topography on storms during this period, and there is a significant correlation of rainfall with topography as a result. The Blue Nile and its tributaries are all rise on the Ethiopian plateau at an elevation of 2,000 meters (Dereje, 2007).

3.1.4. DEM (Digital Elevation Model)

The digital elevation model used in this study has a 1km resolution as shown in Figure 3.2. It is obtained from a previous study on Blue Nile basin (Monica H., 2006). The DEM of Upper Blue Nile basin shows the source of the Blue Nile, the Lake Tana, located in the northwestern portion of the Ethiopian highlands at 1800m. The eastern part of the basin, where elevation rises above 2500m, is highly susceptible to land slide, erosion. This is true to some extent in the southeast and northeast part. The drainage area of this basin is around 175,000 km2 in Ethiopia then flows to lower elevations towards Khartoum when it merges with the White Nile form the Nile River (Dereje, 2007).

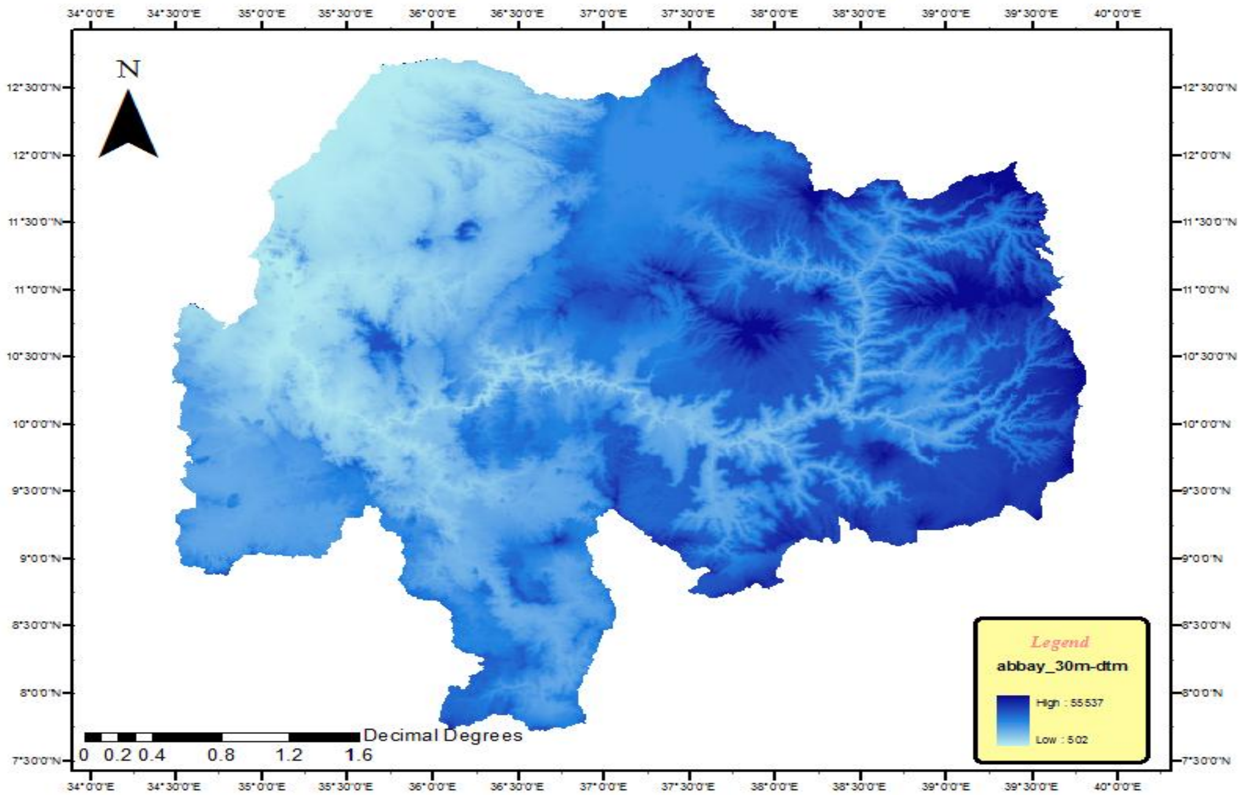


Figure 3-2:- Digital Elevation Model for UBN Basin

3.2. Data Collection

3.2.1. Observed Metrological Data

A comprehensive review of existing data about soil moisture, daily precipitation, topographic map, land use pattern, agricultural practice and socio economic data in the area and related works was conducted at the beginning stage of the study and some description maps of the study area directly adopted form previous similar works. Additionally daily precipitation data were collected from the National Meteorological Agency (NMA) of Ethiopia and called observed precipitation data. Seventeen metrological stations with in eleven grids are selected for detail analysis in this study based on; available periods of records for 1986 to 2012, spatially distribution over the basin and percentage of missing records. Selected stations are shown in the Figure 3.3.

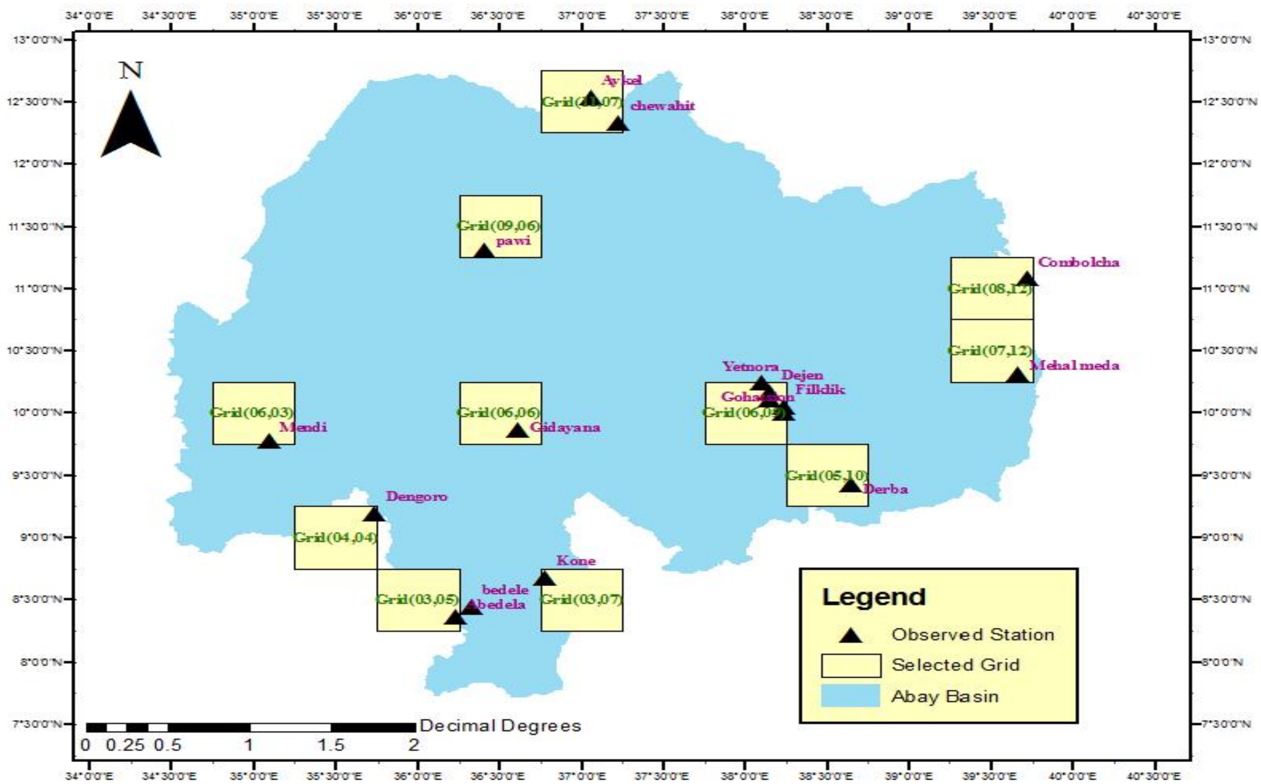


Figure 3-3:- Location of Selected Grid and Observed Station

3.2.2. ECMWF Interim Reanalysis (ERA-Interim)

The ECMWF archive contains all observational data acquired in real time from the world meteorological organization's Global Telecommunications System (GTS) since the beginning of daily operations in 1979. ERA-Interim is the latest ECMWF global atmospheric reanalysis from 1979 to the present (Dee et al. 2011). For this study the newly Re-analysis product of ECMWF datasets called ERA-Interim can be downloaded from the ECMWF Public Datasets web interface and it is available at *http://apps.ecmwf.int/datasets.* Daily soil moisture available in root zone and Daily precipitation with 0.5 degree spatial resolutions from 1979 to 2012 G.C is used to analyze drought characteristics.

ERA-Interim is a global atmospheric reanalysis from1979, continuously updated in real time. Data may be requested on grids much coarser than 0.125º or 13.5 km. For this study data with 0.5º resolution grid points is selected. Clear procedures used to retrieving data from the data server are:-

- ✓ Create an account and login into ECMWF Public Datasets web interface,
- ✓ Select a date in the interval, data type and resolution,
- ✓ Open the downloaded “net cdf” file using Arch GIS 10.2 and convert in to raster data.
- ✓ From the raster datasets find the value for each grid by selecting the longitudinal and latitudinal coordinate.
- ✓ Finally, convert the whole data in to “dot mat” file and simulated in to MATLAB.

3.2.3. Bias Corrected ECMWF Interim Datasets

Dejen.sahalu, et.al, 2015 has examined the error characteristics of satellite based precipitation estimation (ECMWF Interim Datasets) with the view to improve the reliability of wet season (June to September) rainfall dataset over the Blue Nile Basin. Since both researches are a part of the ongoing eart**H2O**bserve project and the corrected output data (Bias Corrected ECMWF) of ECMWF interim product has used as an input for this research. Accordingly the bias ratio for long-term mean of corrected and uncorrected ECMWF datasets with long-term mean of observed data are present graphically as shown in Figure. 3.4.

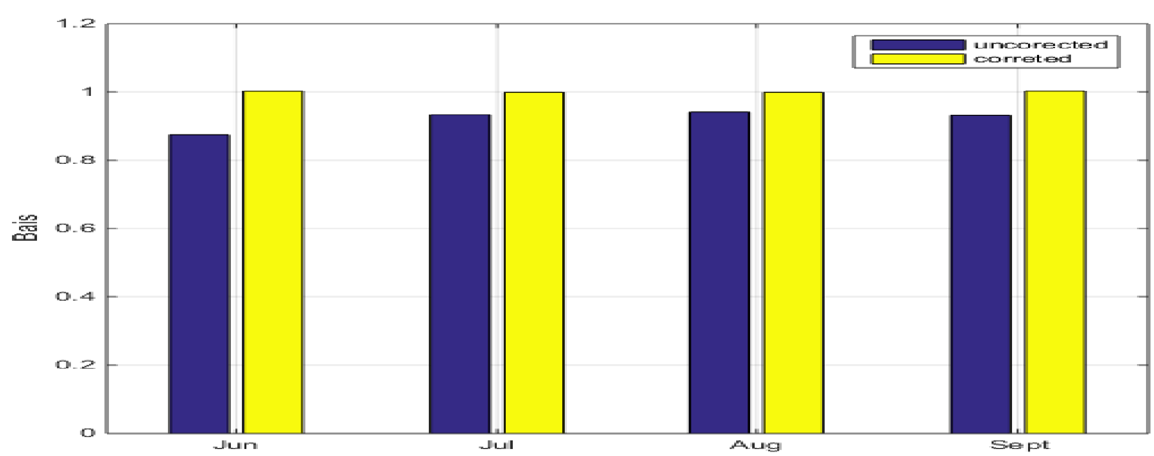


Figure 3-4;-Bias Ratio of Corrected and uncorrected ECMWF datasets

(Dejen.sahalu, et.al, 2015)

4. Data Analysis and Methods

4.1. Meteorological Data Analysis

To receive a correct result, it is essential to devote careful screening and quality checks for all data before use in any hydrological analysis. The quality of the input data has been checked based on comparison graphs of neighboring stations, Visual inspection and double mass analyses. Those methods also have been used to detect outliers and any possible outliers in these stations were not identified. Table 4.1 and 4.2 shows the description of selected station and selected grids for gird based and regional analysis respectively.

Table 4-1:-Basic information of selected Rainfall Stations for Detail Analysis

No	Grid	Station Name	Longitude	Latitude	Zone	Period of Records
1	Grid(03,05)	Abedela	36.233	8.367	Illubabor	1986-2015
2	Grid(03,07)	Kone	36.783	8.683	West Wellega	1986-2015
3	Grid(04,04)	Dengoro	35.733	9.200	East Wellega	1986-2015
4	Grid(05,10)	Derba	38.651	9.426	North Shoa	1986-2015
5	Grid(06,03)	Mendi	35.100	9.783	West Wellega	1986-2015
6	Grid(06,06)	Gidayana	36.617	9.867	West Wellega	1986-2015
7	Grid(06,09)	Gohatsion	38.147	10.329	East Gojjam	1986-2015
		Yetnora	38.108	10.245	East Gojjam	1986-2015
		Dejen	38.151	10.171	East Gojjam	1986-2015
		Abay sheleko	38.157	10.113	East Gojjam	1986-2015
		Filklik	38.243	10.053	North Shoa	1986-2015
8	Grid(07,12)	Mehal meda	39.660	10.315	West Wellega	1986-2015
9	Grid(08,12)	Combolcha	39.718	11.084	South Wollo	1986-2015
10	Grid(09,06)	Pawi	36.410	11.312	Metekel	1986-2015
11	Grid(11,07)	Chewahit	37.228	12.335	North Gondar	1986-2015
		Aykel	37.059	12.540	North Gondar	1986-2015

Table 4-2:- Selected Grid for Regional Analysis

Selected station for Regional Analysis				
Southern Part of the basin	Western Part of the basin	Central Part of the basin	Eastern Part of the basin	Northern Part of the basin
ECMWF Data sets at				
Grid (02,6)	Grid (05,3)	Grid (06,6)	Grid (06,11)	Grid (10,5)
Grid (03,5)	Grid (05,4)	Grid (06,7)	Grid (06,12)	Grid (10,6)
Grid (03,6)	Grid (06,3)	Grid (06,8)	Grid (07,11)	Grid (10,7)
Grid (03,7)	Grid (06,4)	Grid (07,6)	Grid (07,12)	Grid (10,8)
Grid (04,5)	Grid (07,3)	Grid (07,7)	Grid (08,11)	Grid (11,5)
Grid (04,6)	Grid (07,4)	Grid (07,8)	Grid (08,12)	Grid (11,6)
Grid (04,7)	Grid (08,4)	Grid (08,7)	Grid (09,11)	Grid (11,7)
		Grid (08,8)	Grid (09,12)	Grid (11,8)

4.1.1. Handling Missing Values

Stations with missing data were filled by simple linear interpolation and normal ratio method recommended by Linsley et al. (1988). Using this method, rain depths for missing data are estimated from observations at three stations as close to and as evenly spaced around the station with missing record as possible. Large data gaps e.g. for the duration of one year and above, were excluded from the analysis. Normal Ratio Method is applied when average value of rainfall for the neighboring station differ by more than 10% of average value of rainfall for the station in question for recording period. Normal ratio method is expressed by the following Equation 4.1.

$$Px = 1/3(P1\frac{Nx}{N1} + P2\frac{Nx}{N1} + P3\frac{Nx}{N3}) \quad 4\text{—}1$$

Where,

Px = Missing value of precipitation to be computed.

Nx = Average value of rainfall for the station in question for recording period.

*N*1… N3, = Average value of rainfall for the neighboring station.

*P*1....*P3* = Rainfall of neighboring station during missing period

4.1.2. Double Mass Analysis

Double mass curve technique is used to test the consistency of observed rainfall record. The procedure is that accumulated rainfall at the gauge station whose record is in doubt is plotted as ordinate versus the average concurrent accumulated average rainfall of nearby stations whose rainfall data are reliable. For example the consistency of precipitation records at Dejen were checked using a double mass analysis against neighboring precipitation stations at Yetnora, Abay Sheleko, Filklik & Gohatsion. As shown in figure 4.1. So that, the precipitation data for all selected stations were consistent.

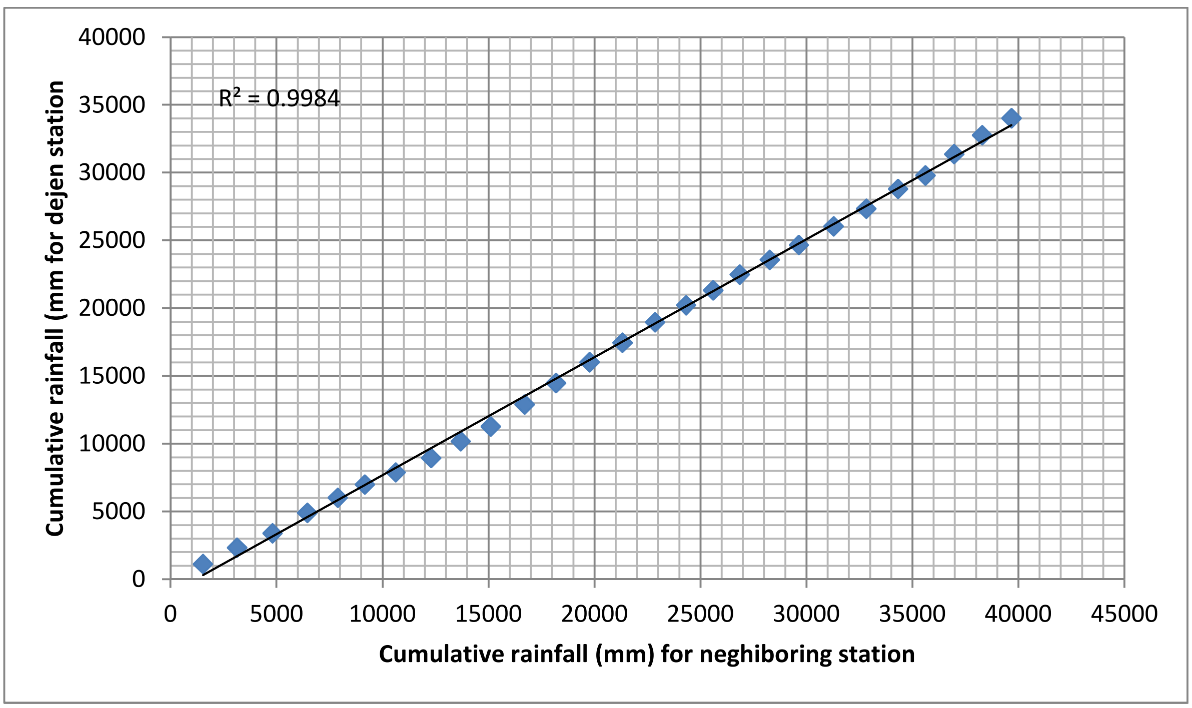


Figure 4-1:- Double Mass Curve for Grid (06, 09) at Dejen Station

4.2. Developing SPI and SMDI

4.2.1. MATLAB Simulation Software

The name MATLAB stands for Matrix Laboratory. It is an interactive package for numerical analysis, matrix computation, control system design and linear system analysis and design. MATLAB 2015a was used to simulate the daily soil moisture and monthly precipitation data sets of different type.

4.2.2. Standardized Precipitation Index (SPI)

McKee et al. (1993) developed the Standardized Precipitation Index (SPI) for the purpose of defining and monitoring drought. The nature of the SPI allows an analyst to determine the rarity of a drought or an anomalously wet event at a particular time scale for any location in the world that has a precipitation record.

Computation of the SPI involves fitting a gamma probability density function to a given frequency distribution of precipitation totals for a station. The gamma distribution is defined by its frequency or probability density function:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} X^{\alpha-1} e^{-x/\beta} \qquad 4\text{—}2$$

Where:

α > 0 α is a shape parameter

β> 0 β is a scale parameter

X > 0 x is the precipitation amount

$$\Gamma(\alpha) = \int_0^{\infty} y^{\alpha-1} e^{-y} dy \qquad 4\text{—}3$$

Γ (α) is the gamma function

The alpha and beta parameters of the gamma probability density function are estimated for each station, for each time scale of interest (1, months, 3 months, 12 months, 48 months, etc.), and for each month of the year.

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right) \qquad 4\text{—}$$

4

$$\beta = \frac{\overline{X}}{\alpha}$$

Where:

$$A = \ln(\overline{x}) - \frac{\sum \ln(x)}{n}$$

n = number of precipitation observations

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station in question. The cumulative probability is given by:

$$G(x) = \int_0^x g(x)dx = \frac{1}{\beta^{\alpha}\Gamma(\alpha)}\int_0^x x^{\alpha-1}e^{-x/\beta}dx \qquad 4—5$$

Since the gamma function is undefined for x=0 and a precipitation distribution may contain zeros, the cumulative probability becomes:

$$H(x) = q + (1-q)G(x) \qquad 4—6$$

Where q is the probability of a zero, if m is the number of zeros in a precipitation time series, Thom (1966) states that q can be estimated by m/n.

The cumulative probability, H(x), is then transformed to the standard normal random variable Z with mean zero and variance of one, which is the value of the SPI. Since it would be cumbersome to produce these types of figures for all stations at all time scales and for each month of the year, the Z or SPI value is more easily obtained computationally using an approximation provided by Abramowitz and Stegun (1965) that converts cumulative probability to the standard normal random variable Z:

$$Z = SPI = -\left(t - \frac{c_o + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad \text{For } 0 < H(x) <= 0.5 \qquad 4—7$$

$$Z = SPI = +\left(t - \frac{c_o + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3}\right) \quad \text{For } 0.5 < H(x) < 1.0 \qquad 4—8$$

Where:

$$t = \sqrt{\ln\left(\frac{1}{(H(x))^2}\right)} \quad \text{For } 0 < H(x) <= 0.5$$

$$t = \sqrt{\ln\left(\frac{1}{(1.0 - H(x))^2}\right)} \quad \text{For } 0.5 < H(x) < 1.0$$

$c_o = 2.515517$, $c_1 = 0.802853$, $c_2 = 0.010328$, $d_1 = 1.432788$, $d_2 = 0.189296$, $d_3 = 0.001308$

Conceptually, the SPI represents a z-score, or the number of standard deviations above or below that an event is from the mean.

There are many classifications used by different authors. Originally McKee et al. (1993) distinguished 4 categories of drought: mild, moderate, severe and extreme, with the threshold value of SPI for the mild drought category equal to SPI = 0 (Table. 4.3).

Table 4-3:- Classification of the SPI values and its drought category

(Leszek Ł. Bogdan 2014)

SPI	**Classification**	**Probability (%)**
2.00 >	Extremely wet	2.3
1.50 to 1.99	Very wet	4.4
1.00 to 1.49	Moderately wet	9.2
0 to 0.99	Mildly wet	34.1
0 to -0.99	Mild drought	34.1
-1 to -1.49	Moderate drought	9.2
-1.50 to -1.99	Severe drought	4.4
-2.00 <	Extreme drought	2.3

4.2.3. Soil Moisture Drought Index (SMDI)

The MATLAB was run on a monthly time step using the ECMWF data from 01/01/1979 to 31/12/2012. The monthly model output of available soil water in the root zone was averaged over a month period by taking the available soil water at the beginning of the month and at the end of the month. The soil moisture deficit index has been calculated using the formula explained by Narasimhan et al. (2004).

The total available water present along the entire soil profile at the end of each month for each grid was analyzed to determine the long term median, maximum and minimum available soil water for each. Using this long-term monthly median soil water, the soil moisture deficit ratio was scaled between long-term monthly maximum and minimum available soil water in the soil profile.

$$SD_{i,j} = \frac{SW_{i,j} - MSW_j}{MSW_j - minSW_j} * 100 \quad \text{If } SW_{i,j} <= MSW_j \qquad 4\text{—}9$$

$$SD_{i,j} = \frac{SW_{i,j} - MSW_j}{maxSW_j - MSW_j} * 100 \quad \text{If } SW_{i,j} > MSW_j \qquad 4\text{—}10$$

Where:

$SD_{i,j}$ = Soil water deficit (%),

$SW_{i,j}$ = Mean monthly soil water available in the soil profile (mm),

MSW_j = Long-term median available soil water in the soil profile (mm),

$maxSW_j$ = Long-term maximum available soil water in the soil profile (mm)

$minSW_j$ = Long-term minimum available soil water in the soil profile (mm)

(Where i = 1979 to 2012 and j = 1 to 12 months)

The soil moisture deficit ratio during a given month represents how dry the soil profile is when compared to long-term median, minimum and maximum available soil water. The cumulative soil moisture deficit during each month $(\sum_t^n SD_t)$ will give a measure of the rate at which the drought is progressing. As the limit of SD values were between –100 and + 100, the worst drought can be represented by a straight line with the equation

$$\sum_t^n SD_t = -100t - 100 \qquad 4\text{—}11$$

Where, t is the time in months. If this line defines the worst drought (i.e., to get the drought index in range – 4 to +4), then SMDI for any given month can be calculated by:

$$SMDI_j = \frac{\sum_{t=1}^{j} SDt}{25t + 25} \qquad 4—12$$

In order to take in to account the accumulated dry values to determine drought severity, the drought index was calculated on an incremental basis as suggested by Palmer (1965).

$$SMDI_j = SDMI_{j-1} + \Delta SMDI_j \qquad 4—13$$

To evaluate the contribution of each month to drought severity, set i=1 and t=1and we have:

$$SMDI_1 = \frac{SD_1}{50}, \qquad 4—14$$

Since this is the initial month:

$$SMDI_1 = SDMI_0 = SMDI_1 = \frac{SD_1}{50}, \qquad 4—15$$

A drought will not continue in the extreme category if subsequent months are normal or near normal. Therefore the rate at which SD must increase in order to maintain a constant value of SMDI depends on the value of SMDI to be maintained. For this reason, additional term must be added to equation 4.5 for all the months following an initial dry month:

$$\Delta SMDI_j = \frac{SD_j}{50} + cSMDI_{j-1} \qquad 4—16$$

Solving equation 5 for c by assuming SMDI is – 4 during subsequent time steps, and then SDi should be –100:

$$\Delta SMDI_j = \frac{-100}{50} + c(-4)\,\&\, c = -0.5 \qquad 4—17$$

Drought severity in any given month is given by:

$$SMDI_j = 0.5SMDI_{j-1} + \frac{SD_j}{50} \qquad 4—18$$

Based on SMDI severity classification the newly developed indices were classified in to nine categories as shown in Table 4.4.

Table 4-4:- SMDI Severity Classifications

SMDI	**Drought Category**
3 to 4	Very wet
2 to 2.99	Moderately wet
1 to 1.99	Slightly wet
0.5 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.5 to -0.99	Incipient dry spell
-1 to -1.99	Mild drought
-2 to -2.99	Moderate drought
-3 to -4	Severe drought

5. Result and Discussion

5.1. Comparison of Datasets

5.1.1. Histogram for Monthly and Annually Cycle of Datasets

Comparison of datasets was undertaken in terms of histogram of monthly precipitation and annual cycle of precipitation as described figure 5-1 to figure5.3. According to histogram of monthly precipitation analysis ECMWF data sets overestimates for grid (07, 12), grid (08, 12) and grid (11, 07). In contrast, to rest of selected grid ECMWF data sets underestimate the historical monthly precipitation. The biggest differences were observed in the Abdela station at grid (03, 05) and Derba station at grid (05, 10). For Abdela station ECMWF underestimate of historical monthly precipitation of June for 34 years reached 4500 mm and in Derba station ECMWF overestimate of historical monthly precipitation of July for 34 years reached 3800 mm. The data sets in grid (06, 09) relatively agree in the terms of intensity of historical monthly precipitation and trend of monthly cycle related to other grid.

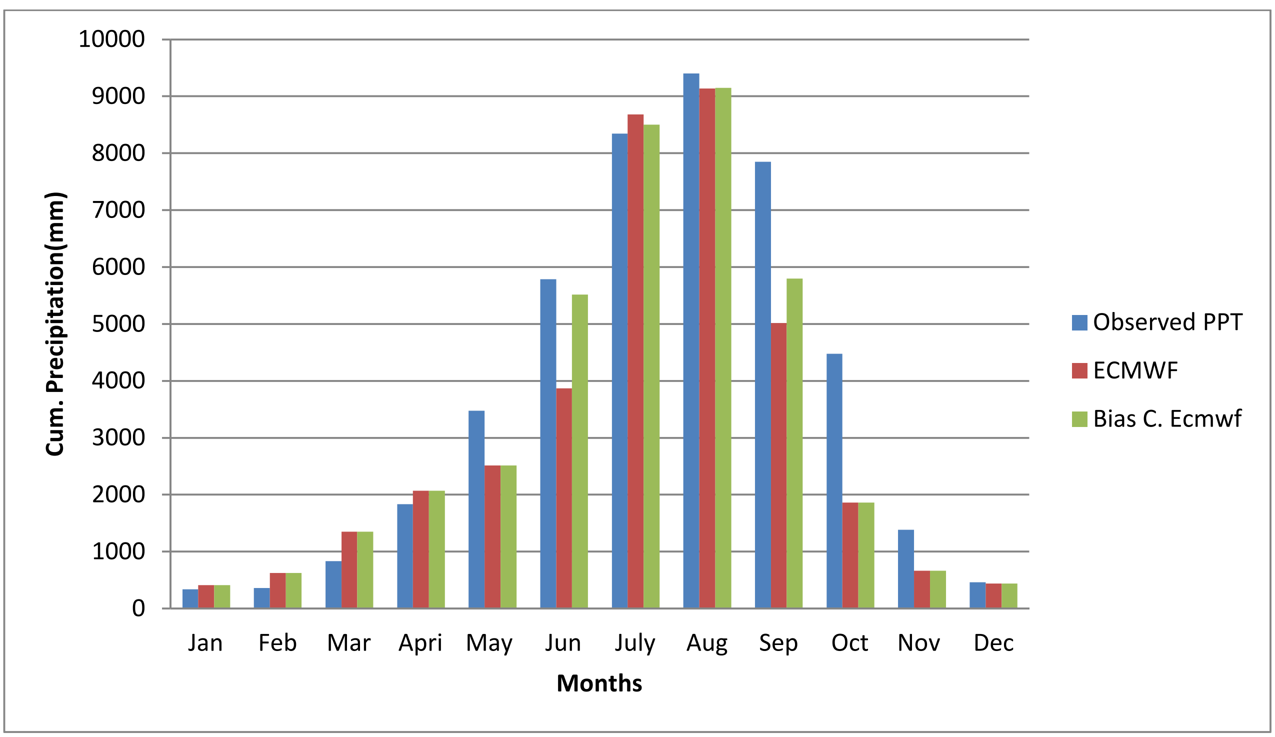


Figure 5-1:- Histograms of Monthly Precipitation for the Grid (06, 09)

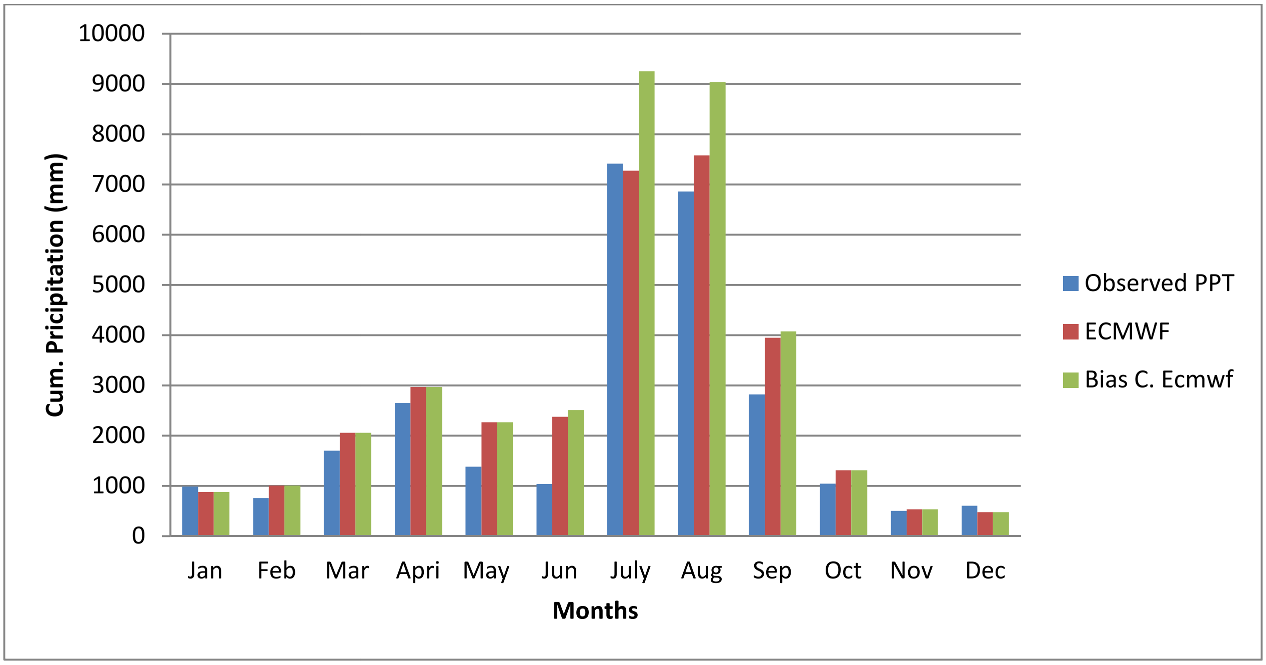


Figure 5-2; - Histograms of Monthly Precipitation for the grid (08, 12)

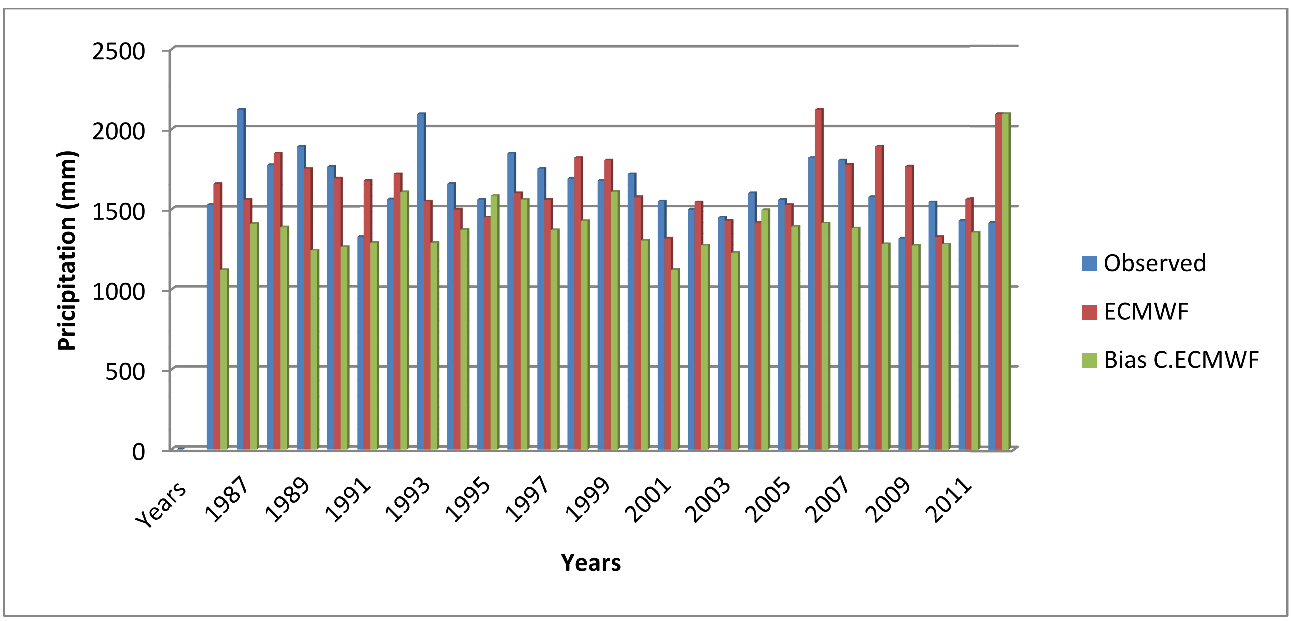


Figure 5-3:- Annual precipitation cycle for the grid (06, 09).

Both historical plot shows there is an overall agreement between the ECMWF and observed precipitation data sets with respect to the trend of historical monthly rainfall. This is true even for the Mehal Meda and Combolcha station that represent grid (07, 12) and grid (08, 12) respectively which are characterized by two rainy seasons (Figure. 5.2.).

5.1.2. Correlation between Datasets

The coefficient of determination (R^2) measures the degree of correlation among the observed and predicted values. Higher value of R^2 (with 1 being the highest possible value) shows better the performance of the datasets. The coefficient of determination R^2 between ECMWF, bias corrected ECMWF and observed precipitation was presented in Table 5.1 and shown in Figure 5.4 and 5.5.for selected grid. For grid (05, 10) the correlation coefficient was very low. But ninety percent of the observed datasets had a high correlation (R^2 greater than 50%) with that of ECMWF data sets. This shows that there is a good piecewise linear correlation between the datasets with respect to tread.

Table 5-1:- Coefficient of Determination R2 between Datasets

	Coefficient of determination R^2 for Grid										
Data Sets B/n	(03,05)	(03,07)	(04,04)	(05,10)	(06,03)	(06,06)	(06,09)	(07,12)	(08,12)	(09,06)	(11,07)
ECMWF Vs Observed	0.636	0.585	0.733	0.267	0.717	0.537	0.845	0.794	0.773	0.677	0.740
ECMWF Vs Bias Corrected ECMWF	0.836	0.829	0.895	0.862	0.976	0.978	0.947	0.964	0.928	0.911	0.804
Bias Corrected ECMWF Vs Observed	0.73	0.682	0.744	0.353	0.733	0.537	0.886	0.826	0.824	0.678	0.765

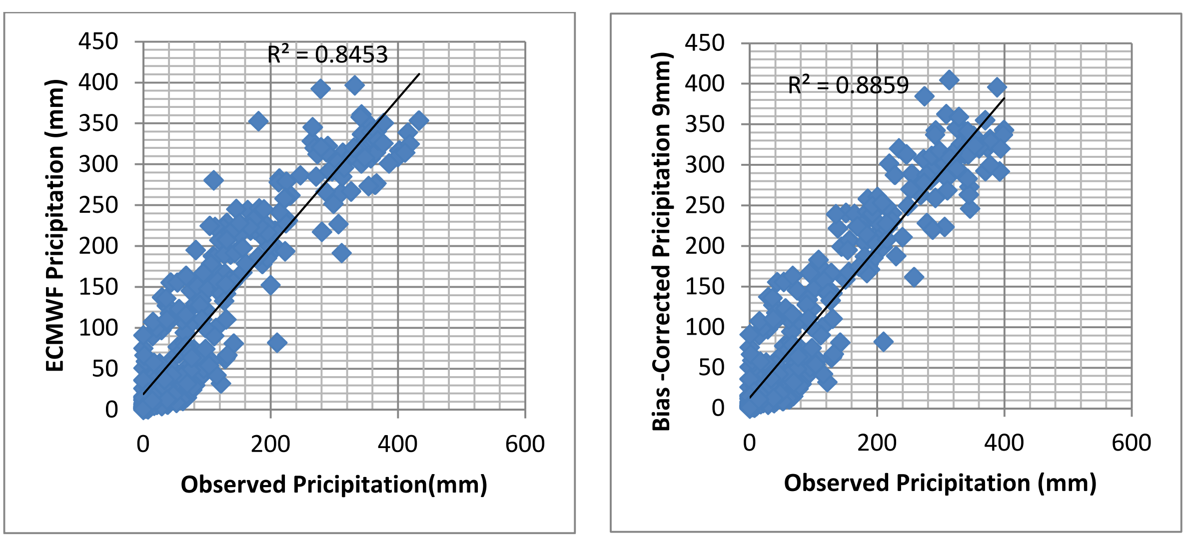


Figure 5-4; - Coefficient of Determination R2 between Dataset for Grid (06, 09)

As shown in the table 5.1 of coefficient of determination (R^2) for bias corrected ECMWF datasets with observed precipitation almost the same value with ECMWF datasets. This is due to bias correction was undertake only for main rainy season (June to September).

5.1.3. Percentage Deviation

Deviation of rainfall from normal is the most commonly used indicator for drought monitoring and shows the quantitative difference between datasets. On the basis of percentage deviations, four categories are used for monitoring and evaluating the rainfall patterns i.e. ±20% deviation as "**Normal**", −20 to −60% deviation as "**Deficit**", less than −60% deviation as "**Scanty**" and greater than 20% deviation as "**Excess**". (M. Naresh Kumar, et.al 2009).

Percentage deviation is presented on table 5.2 and values are expressed in terms percentage. It shows quantitative difference between estimated datasets with observed datasets. For all station the percentage deviation under normal rage was very low and it shows that estimated ECMWD datasets value was not able to capture the observed precipitation. For example, percentage deviation of normal range for grid (03, 05) and grid (04, 04) has smaller value that is 4.10 and 3.28 percents respectively. As shown in table 5.2 percentages for excess range was higher up to 80.74 % for grid (03, 06) and it indicate ECMWF under estimate 80.74 % of the data for grid (03, 06).

Table 5-2:- percentage deviation b/n monthly row data's for selected grid

Categories	Selected Grid										
	(03,05)	**(03,07)**	**(04,04)**	**(05,10)**	**(06,03)**	**(06,06)**	**(06,09)**	**(07,12)**	**(08,12)**	**(09,06)**	**(11,07)**
	Observed Vs ECMWF										
Excess	80.74	69.78	82.79	42.86	71.70	47.97	43.17	10.10	17.89	25.50	10.68
Normal	14.34	16.91	8.20	13.57	12.83	17.91	29.52	19.16	33.33	15.89	20.71
Deficit	4.10	7.55	3.28	17.86	7.17	14.53	26.43	29.27	23.86	16.89	22.65
Scanty	0.82	5.76	5.74	25.71	8.30	19.59	0.88	41.46	24.91	41.72	45.95

	Observed Vs Bias Corrected ECMWF										
Excess	72.54	64.39	72.95	38.57	67.17	48.65	37.00	8.01	15.44	26.16	11.65
Normal	20.49	21.94	16.80	14.29	15.85	16.55	25.99	16.03	29.47	16.23	19.42
Deficit	6.15	8.27	4.10	19.64	8.68	14.53	36.12	31.36	30.88	16.23	23.62
Scanty	0.82	5.40	6.15	27.50	8.30	20.27	0.88	44.60	24.21	41.39	45.31

Accordingly, ECMWF has a tendency to underestimate the precipitation in all selected station except in Kombocha, Aykel, Pawi and Mehal Meda" station at grid (07, 12), (11, 07), (09, 06), and (08, 12) respectively. In general ECMWF has underestimate 45% the whole data and 20.4% of the data was overestimated. Bias corrected ECMWF datasets also has reduced percentage of underestimated in to 42% and percentage of overestimation has 20% of the whole data. This result shows the bias correction was focused only on underestimated precipitation amount of main rainy season (June to September) and it was very closer with original ECMWF in percentage deviation. Hence, the bias corrected ECMWF datasets almost the same with that of the original ECMWF datasets.

Grid (06, 09) was best gauged grid that has five metrological stations and has the lowest dispersion in terms of historical monthly rainfall. In addition this grid shows larger value for coefficient of determination. This shows that the density of rain gauges and its location relatively to grid plays a significant role in determining the agreement between data sets.

5.2. Evaluation of ECMWF Datasets and Drought Indices

5.2.1. ECMWF datasets under grid based Analysis

A drought event begins when the indices' values become continuously negative and ends when the indices' values become continuously positive. In the following sections, the two drought indices are analyzed separately to evaluate the performance of ECMWF datasets.

5.2.1.1. Soil Moisture Drought Index (SMDI)

The SMDI time series plots extracted at grid (06, 03) and grid (11, 07) are presented in Figure.5.5 and 5.6. As shown in figure the historic drought years 1984/85 and 2003/04 are well captured. In contrast the drought year 1995/96 and 2009/10 for presented station show that drought has captured but not severe drought. SMDI shows that in addition to the four recorded historical drought there was severe drought condition in the year 1993/94 for some grids like grid (03, 05), grid (03, 07), grid (09, 06), and grid (11, 07) as shown in the appendices. But it indicates less severe than drought condition during 1983/84 and 2003/04.

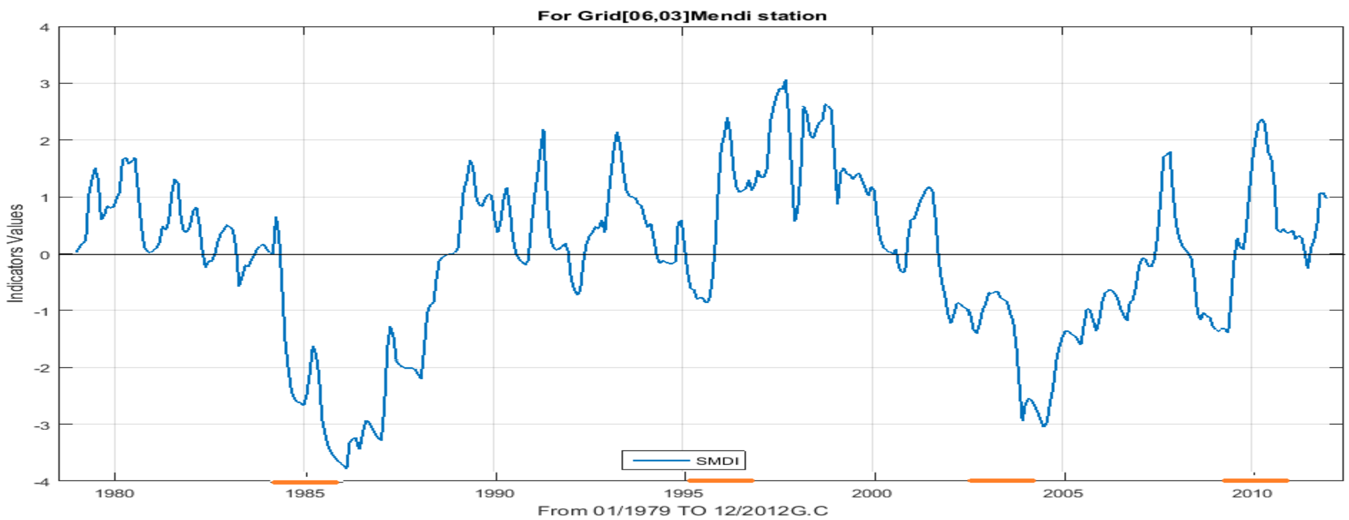


Figure 5-5:- Time series SMDI indicator value for Grid (06, 03)

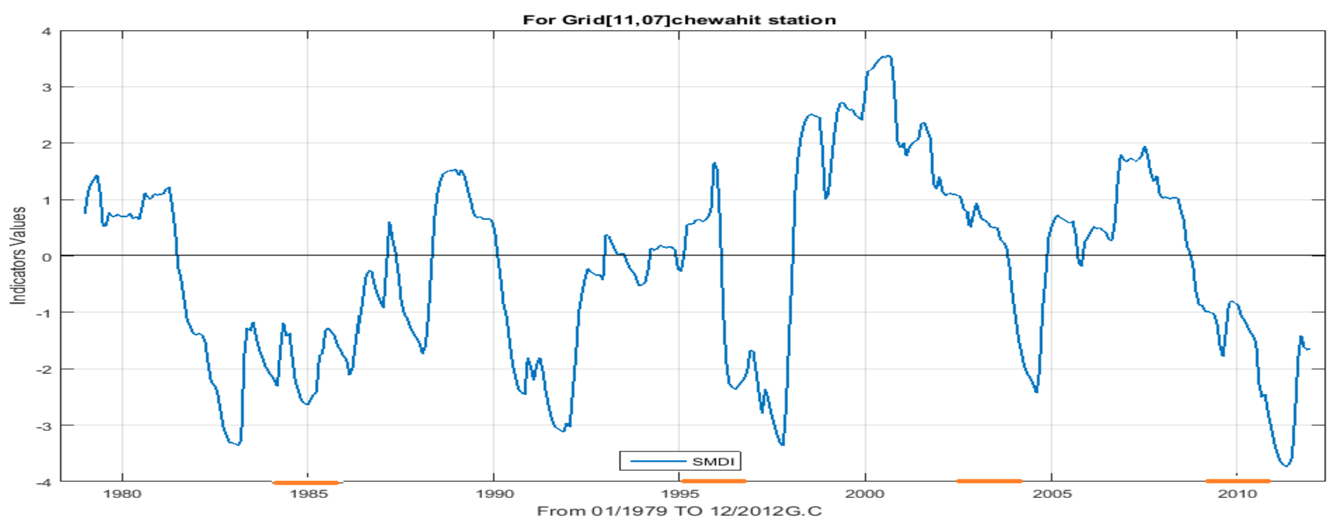


Figure 5-6: - Time series SMDI indicator value for Grid (11, 07)

All plots of SMDI shows that drought events occurred less frequently but their duration was long and historical drought events in UBN basin was vary in severity range with spatial extent and most of historical drought event is not uniformly affect all area of the basin. Relatively during chronic drought year 1984/85 most part of the basin was severe drought at the same time.

Drought events are characterized due to severity, duration and intensity of the drought. According to time series SMDI indicator value ECMWF Soil moisture product has a good agreement with the time and severity of historical chronic drought years.

2.2.1.2. Standardized Precipitation Index (SPI)

Since the *SPI* in a 1- month time scale highly fluctuates between positive and negative values, detection of the start and end of a drought event is improper. Therefore, in this paper the *SPI* with a 3, 6 and 12-month time scale were used to identify drought events. In addition, analyses of SPI indicator value were compute for all type of data sets that is observed, ECMWF and bias corrected ECMWF. Figure 5.7 and 5.8 shows the time series SPI indicator value for each time scale using observed precipitation data sets. The available period of records of observed precipitation was from 1886-2012 and the historical drought event for 1984/85 was not assessed using observed datasets.

SPI time series plot using observed precipitation data sets captured chronic drought year 2003/04 and 2009/10 with lower severity range for each station but for the drought year 1995/96 was not significantly affect for most of the gird. Only those grids like grid (03, 05), grid (03, 07), grid (05, 10) and grid (11, 07) has captured with moderate drought range. This shows the basin was received enough precipitation amounts per each month for each station even for known historical drought event. SPI time series plot using observed shows there was unrecorded drought events occurred for some grid that is in year 1992/93. In similar to SMDI, all SPI indices' also shows drought in UBN basin is vary with spatial extent and most of historical drought event is not uniformly affect the basin.

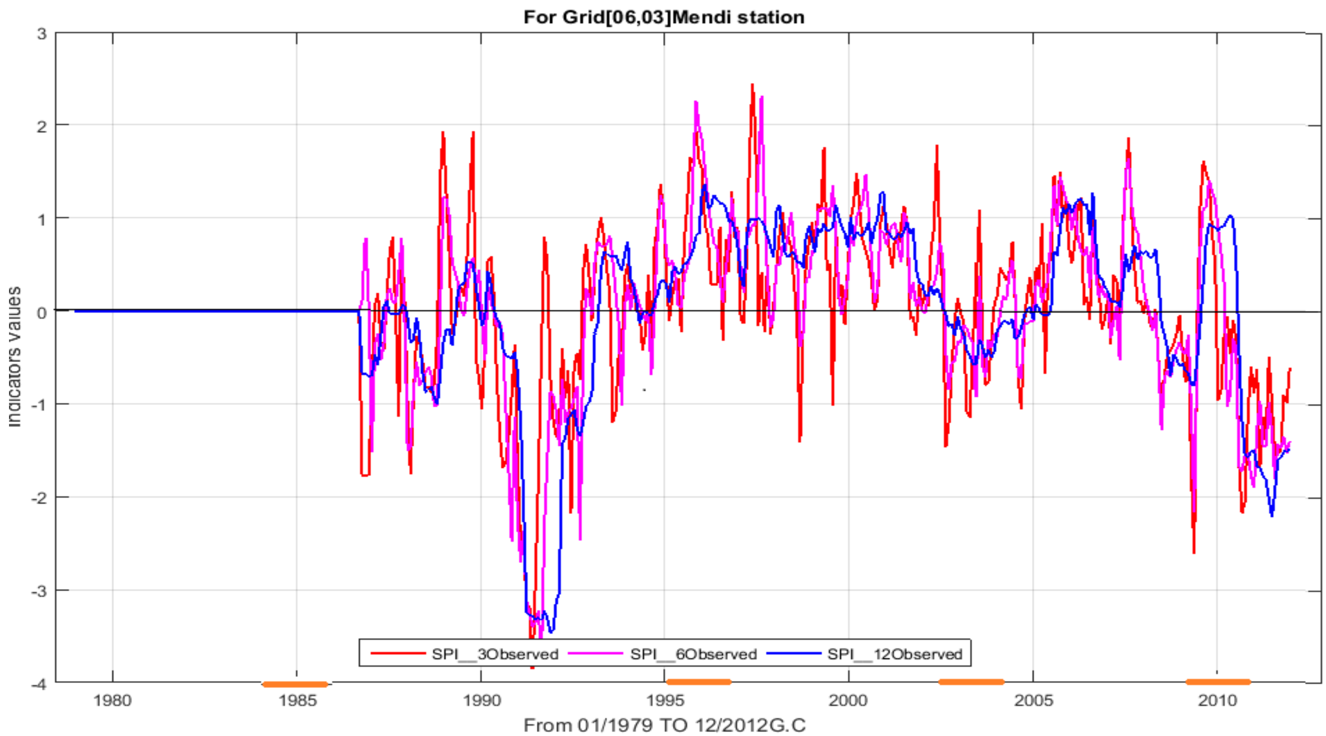


Figure 5-7:- Time series of 3, 9, and 12 - Months SPI _Observed for grid (06, 03)

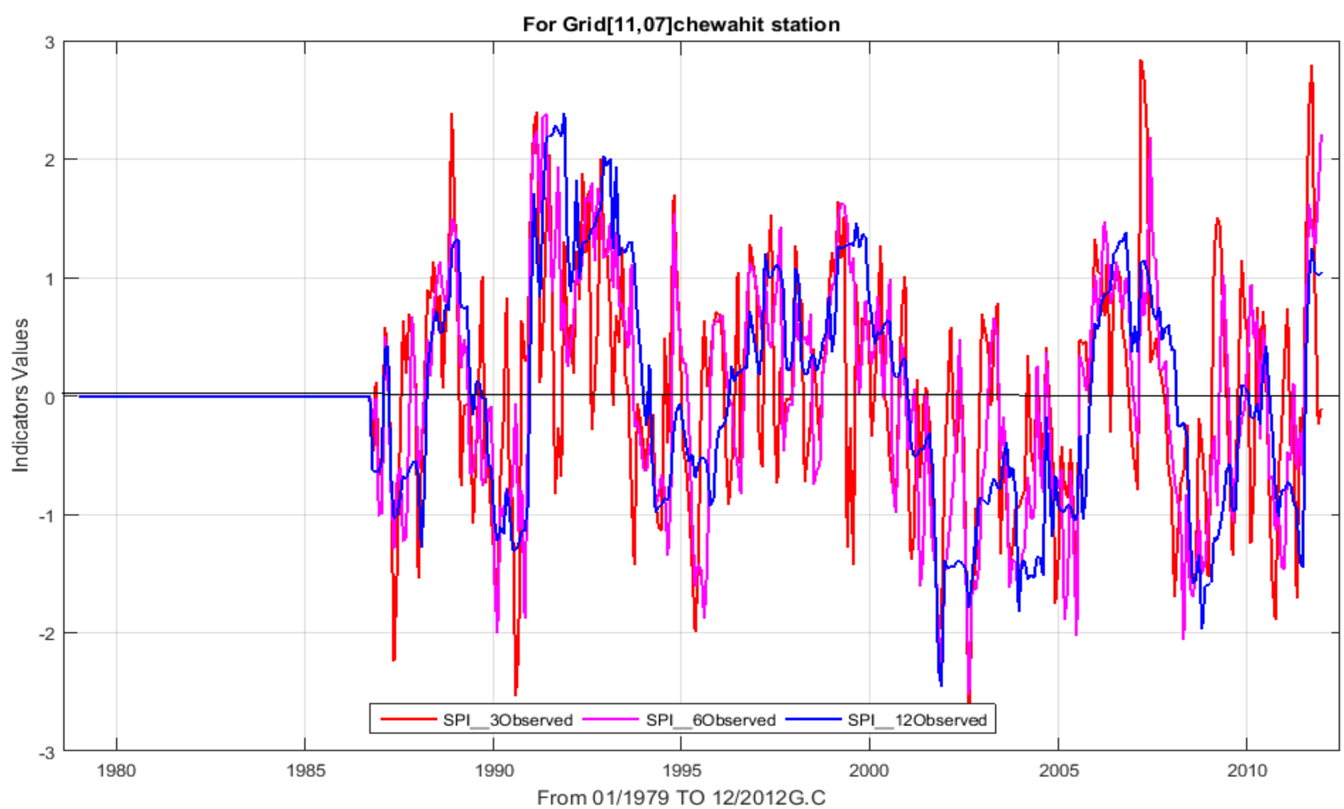


Figure 5-8;-Time series of 3, 9, and 12 - Months SPI _Observed for grid (11, 07)

Figure 5.9 and 5.10 present the time series SPI indicator value for each time scale using ECMWF data sets. SPI indicators value for ECMWF data sets shown that all grid captured drought year 2003/2004 with less severe range and for drought year of 1984/1985 was captured with all grids with severe drought except at grid (03, 05) and grid (03, 07). On the other hand for drought year 2009/2010, almost all grids didn't capture the drought event except grid (06, 09) and grid (06, 06).

Time series SPI indicator value plot shows drought event happened frequently with moderate drought range and it can't captured historical drought event well. Small variation of precipitation datasets will change the drought condition frequently this is due to there is no large difference in received precipitation amount during the study period even during chronic drought events. In similar to SMDI and SPI with observed the plot shows drought in UBN basin is vary with spatial extent and most of historical drought event is not uniformly affect the basin.

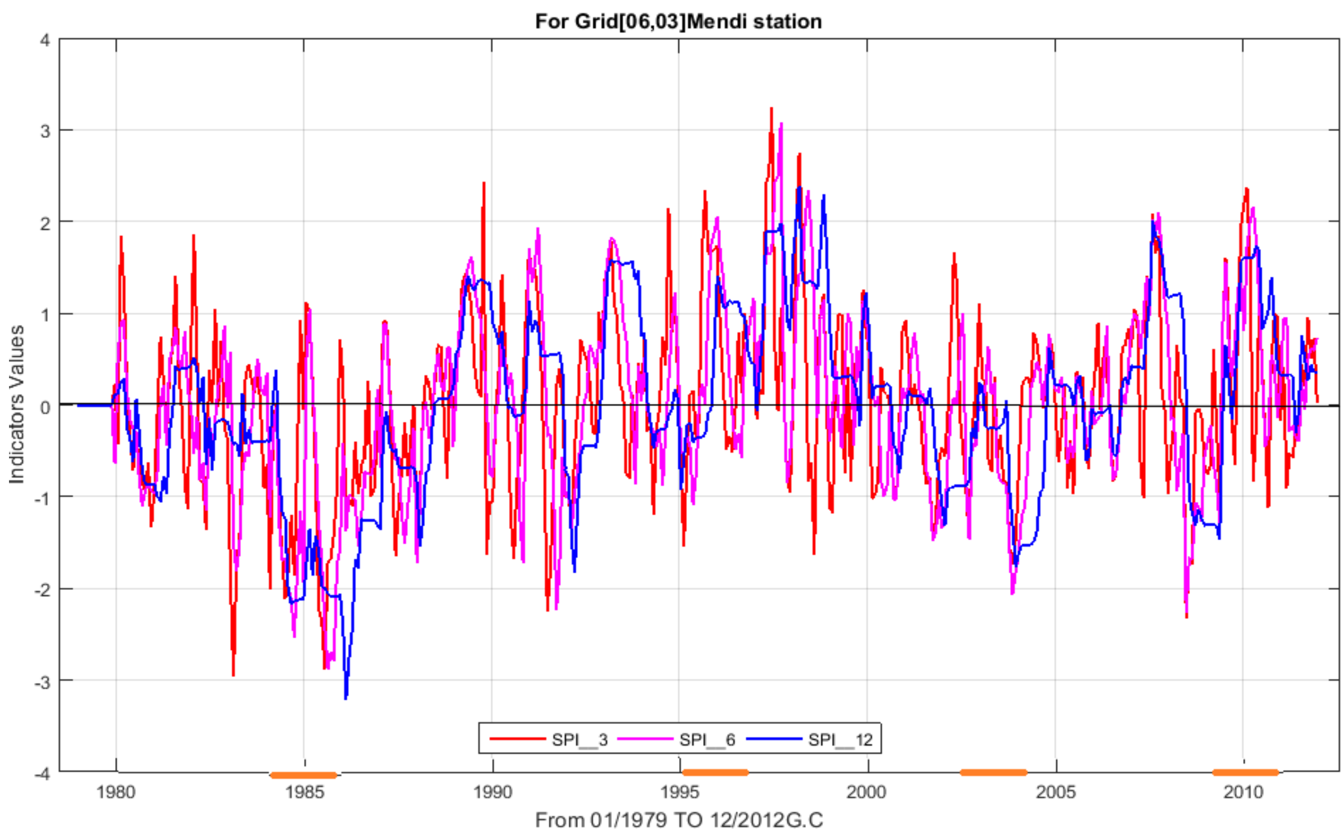


Figure 5-9:-Time series of 3, 9, and 12 - Months SPI _ECMWF for grid (06, 03)

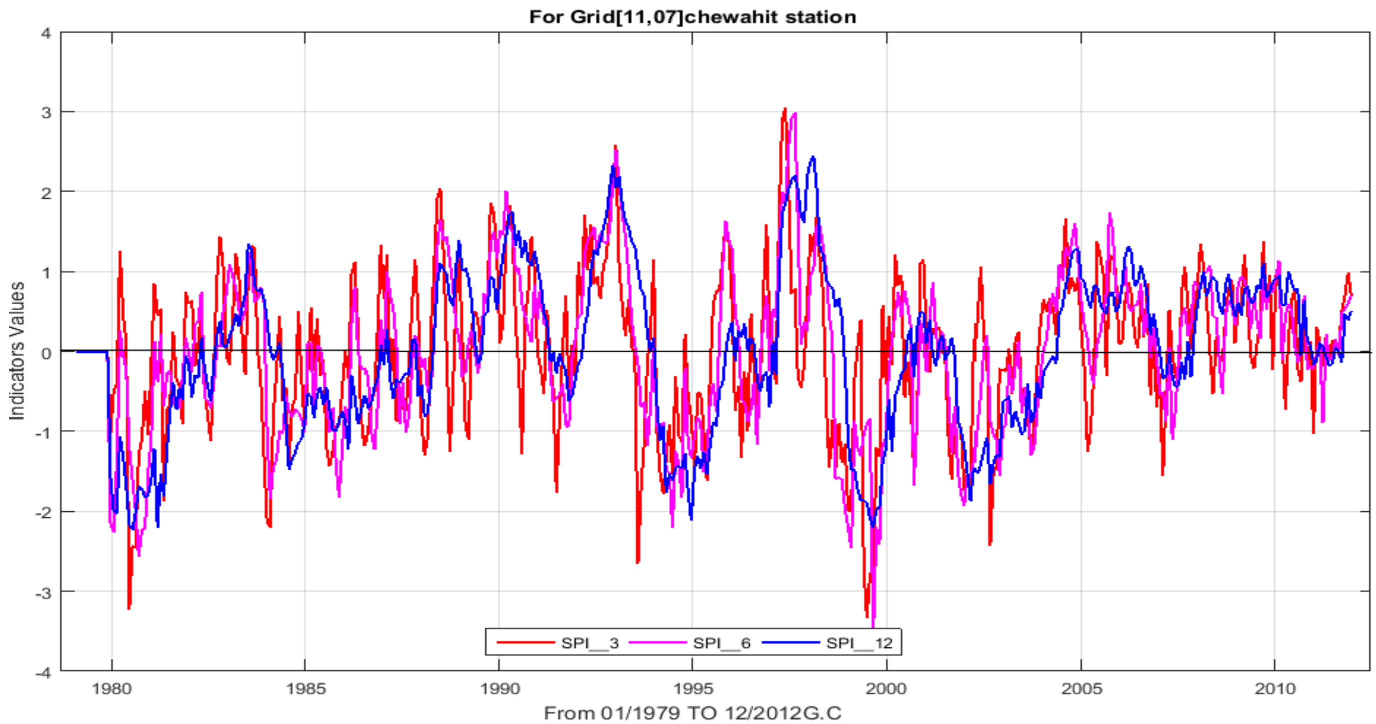


Figure 5-10:- Time series of 3, 9, and 12 - Months SPI _ECMWF for grid (11, 07)

In order to evaluate and compare dataset's response for historical chronic drought events SPI indicator for 6 and 12 months time scale was used as shown in figure 5.11 to 5.14. Time series SPI indicators values for different datasets was respond differently. Since we use different datasets the nature of indicators value was under different drought severity range. For some station this different was highly significant at SPI-12 time series plot for example at grid (06, 07) the SPI indicator value during 1992 to 1994 shows positive value for ECMWF product and larger negative value for observed precipitation product.

According to the combined time series plot for all datasets shows historical drought event was not well captured due to all data sets. The period of record for observed precipitation is short and it will affect the probability to capture severe drought. Even if the period of records for observed precipitation was shorter than the ECMWF it was better to characterized and captured historical drought events.

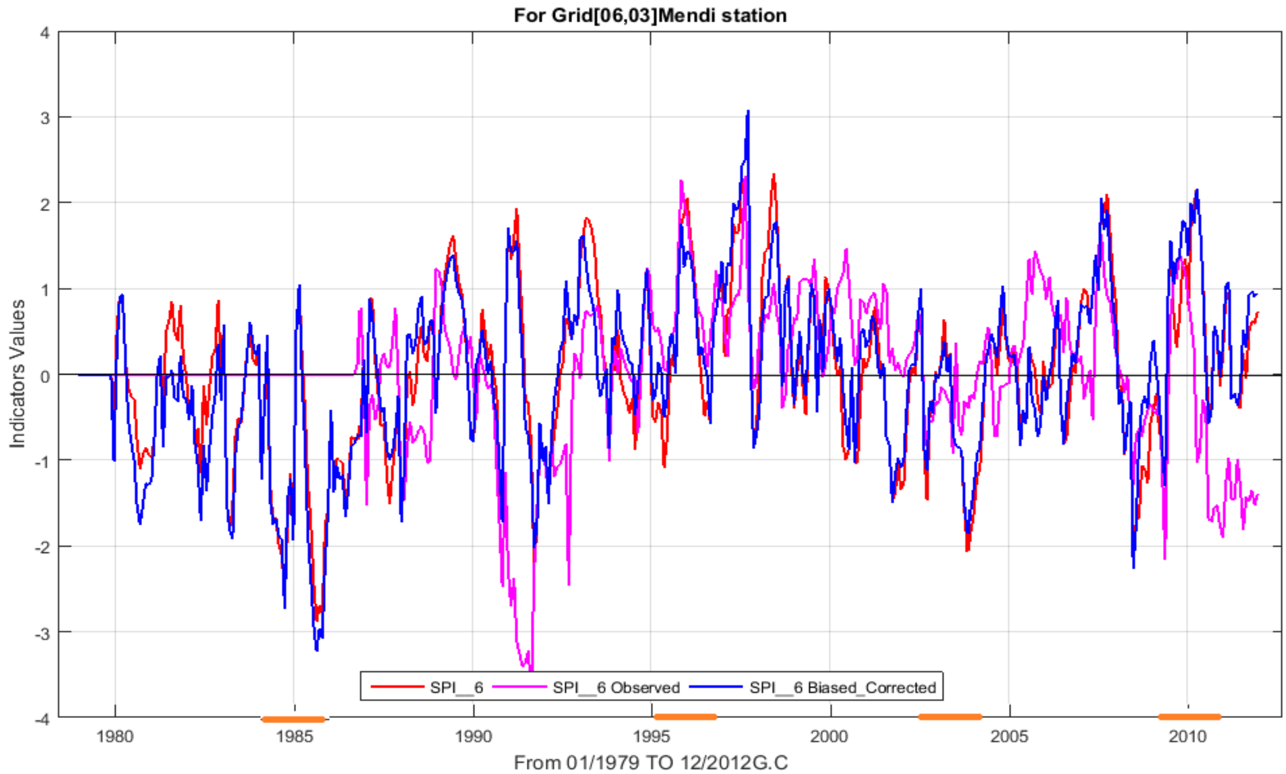


Figure 5-11:-SPI_6, SPI_6 Observed, and SPI_6 Bias Corrected for grid (06, 03)

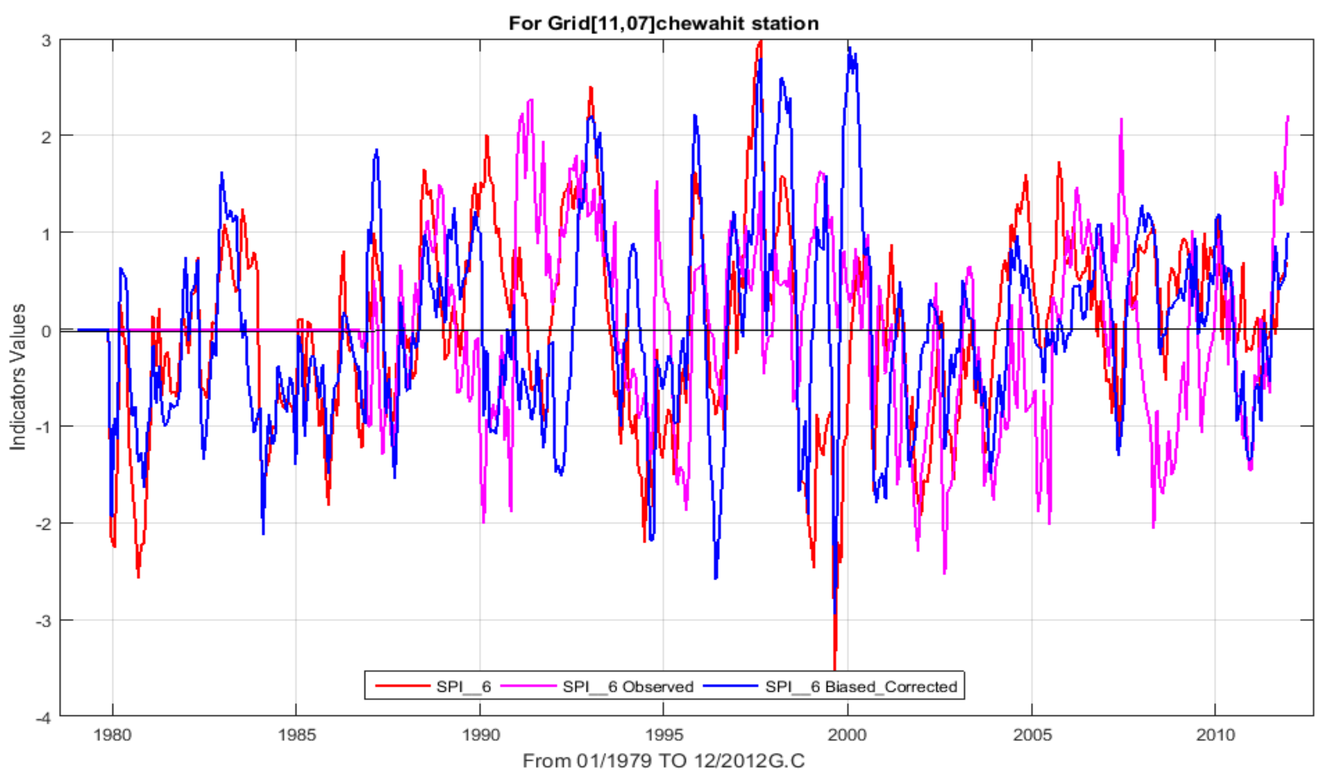


Figure 5-12:-SPI_6, SPI_6 Observed, and SPI_6 Bias-Corrected for grid (11, 07)

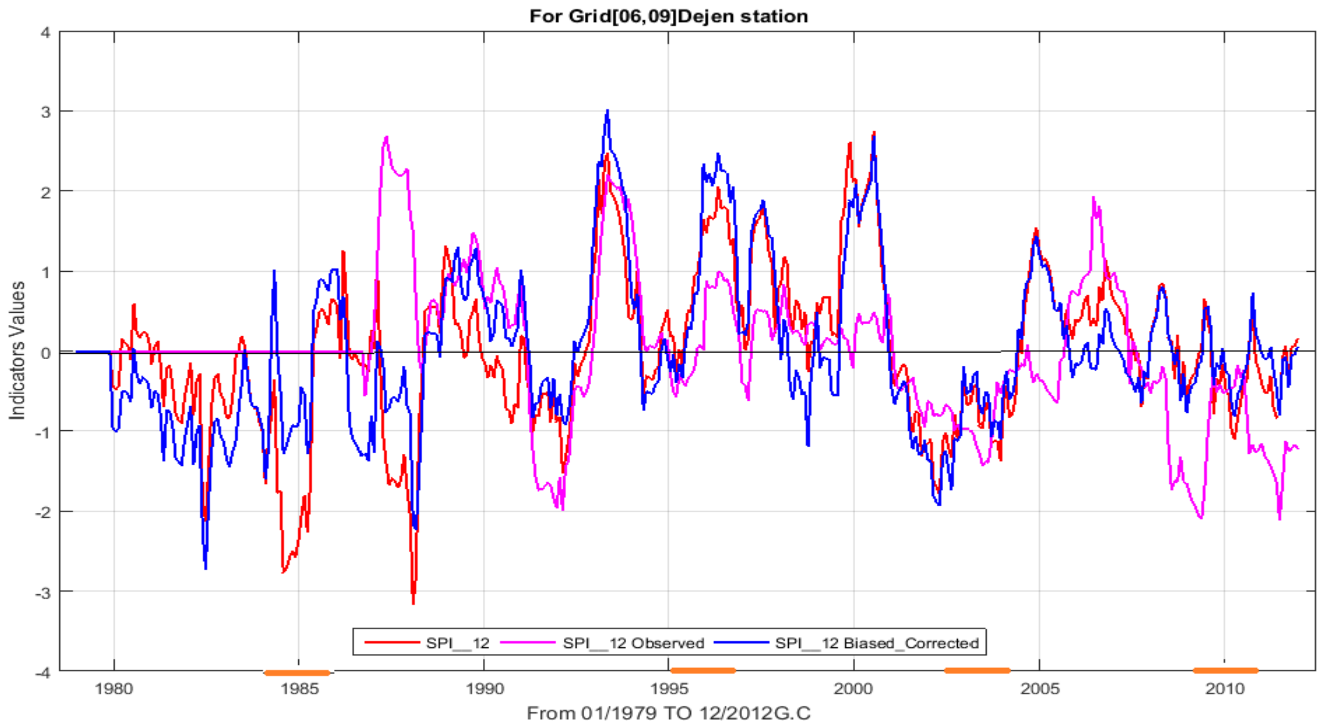


Figure 5-13:-SPI-12, SPI_12 Observed, & SPI_12 Bias Corrected grid (6, 7)

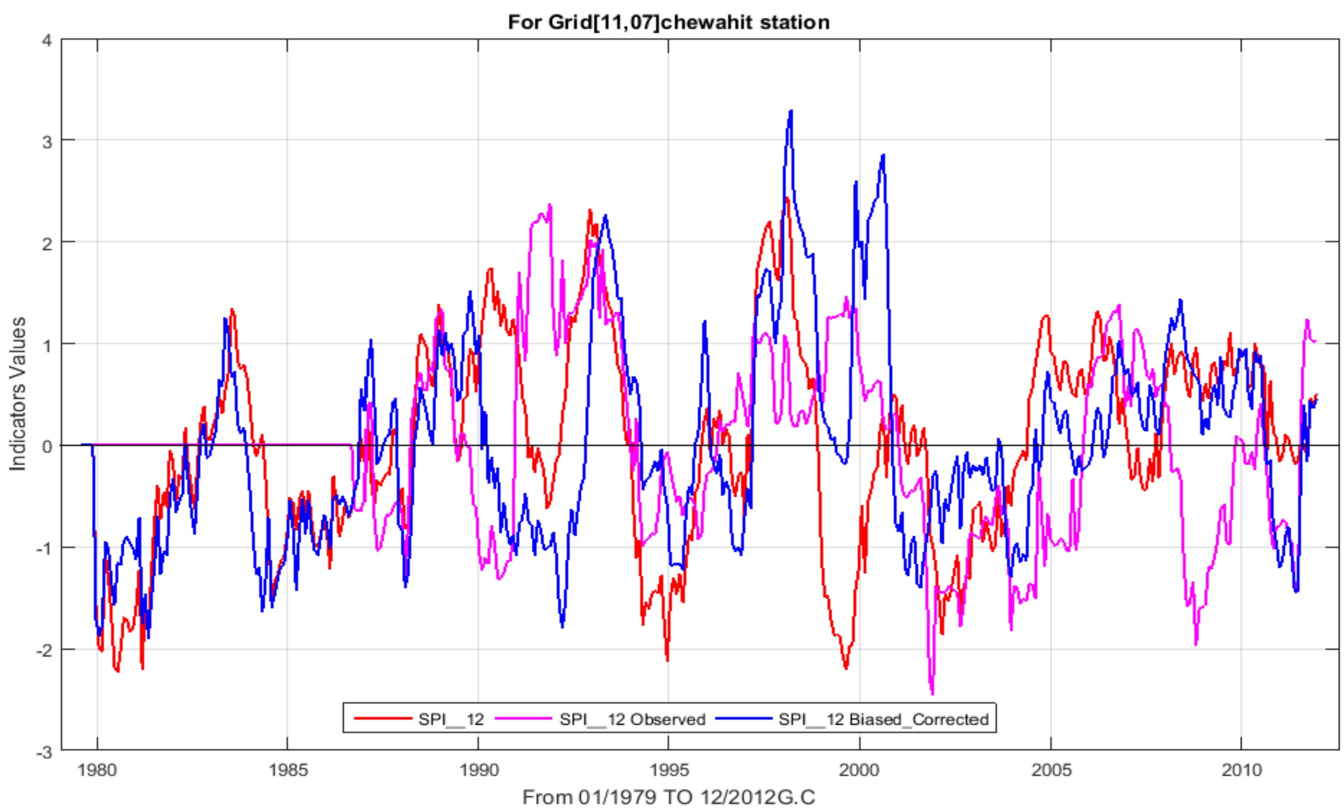


Figure 5-14; -SPI_12, SPI_12 Observed, & SPI_12 Bias Corrected grid (11, 7)

5.2.1.3 Evaluation of ECMWF Reanalysis Product using Drought Indices

Evaluation of ECMWF reanalysis product is done by compare time series drought indicators values of both ECMWF datasets with that of observed SPI indicators value by using values of drought characteristics, coefficient of determination and percentage deviation.

Average drought characteristics for each datasets and for each time scale are summarized on Table: - 5.3. Average was taken for all selected grid and compare its value with the same time scale but different datasets. According to the table SPI using observed dataset shows it was a longest with respect to duration at all time scale and more severe drought event at all time scale during historical drought events. Hence, drought event using observed precipitation datasets was better performance to capture the drought events.

Table 5-3:- SPI Average drought parameters for all station

Drought Characteristics	ECMWF Dataset			Bias Corrected ECMWF Dataset			Observed Dataset		
	SPI_3	SPI_6	SPI_12	SPI_3	SPI_6	SPI_12	SPI_3	SPI_6	SPI_12
Mean Intensity M	-0.89	-0.86	-0.70	-0.84	-0.77	-0.64	-0.91	-0.86	-0.77
Duration D (months)	5.85	10.52	18.24	5.88	9.58	19.44	8.42	14.21	27.02
Severity, S	-5.25	-9.54	-15.12	-4.97	-7.93	-14.37	-7.83	-12.24	-22.40
Maximum Intensity, M_{max}	-1.75	-1.74	-1.25	-1.53	-1.54	-1.21	-1.73	-1.73	-1.51

Coefficients of determination Table 5.4 and Figure 5.5 present the performance of SPI using ECMWF with respect to SPI using observed precipitation. Coefficient of determination (R2) for all SPI time series indicator values exhibit low results in terms of R^2. Indeed the best SPI time series indicator value is between observed and bias corrected ECMWF datasets has R^2 of 0.4497. A possible explanation for the low correlation between reanalysis product and observed SPI values is the low level of autocorrelation within the data set. As shown in the table 5.4 for each station autocorrelation between SPI using bias corrected ECMWF data sets and observed data sets is slightly better that autocorrelation between SPI using ECMWF data sets and observed data sets.

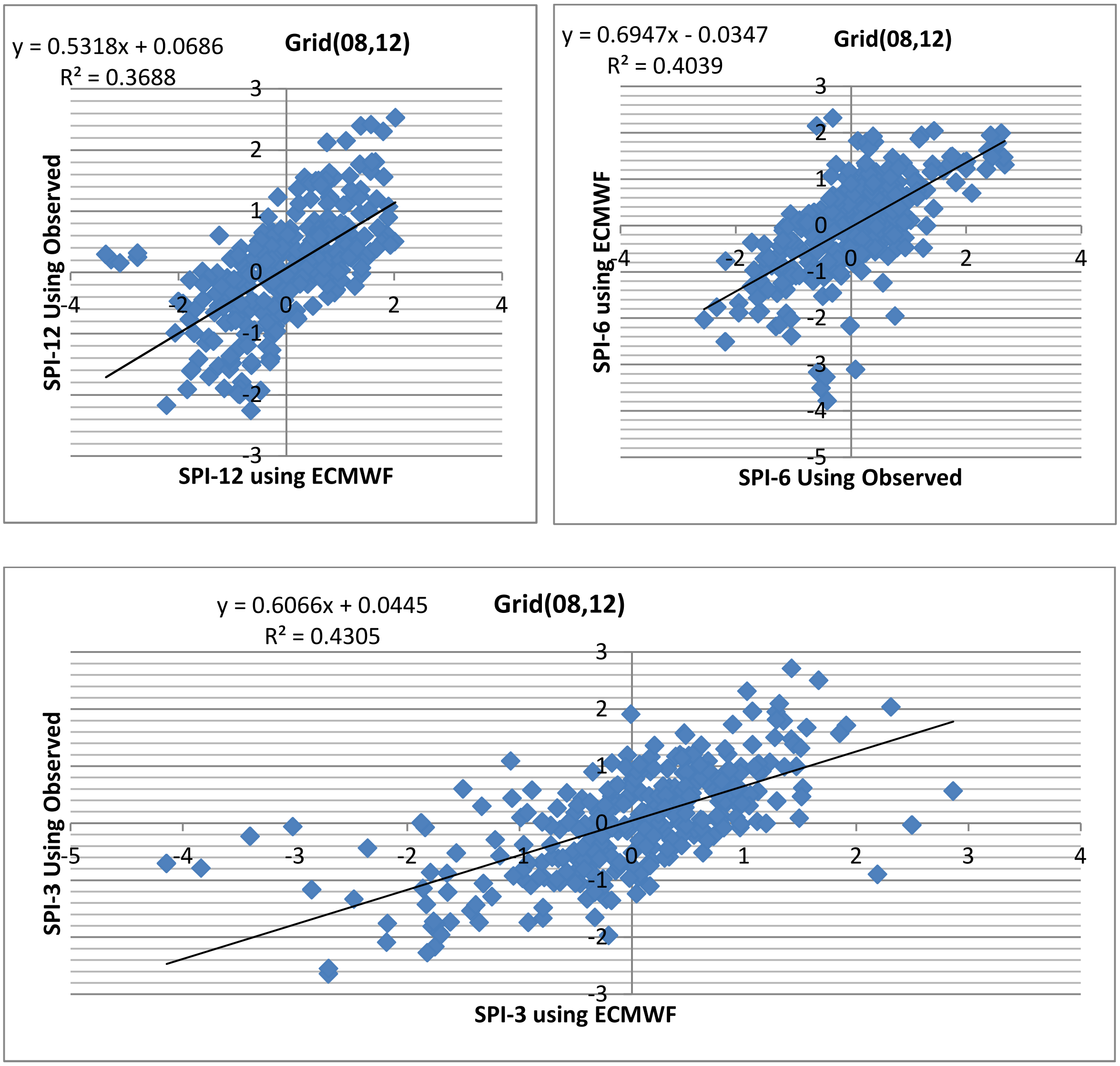


Figure 5-15:- Coefficient of determination (R2) of SPI for Grid (08, 12)

Percentage deviation of SPI indicators values of two reanalysis product with that of indicators value observed precipitation for 6 and 12-month timescale are summered at table 5.5. Percentage deviation analysis was focused on understanding which reanalysis product is better to close with observed. Accordingly, percentage deviation with normal range is higher in bias corrected reanalysis data than uncorrected. As shown in the table 5.5 percentage deviation for scanty range has greater than 50 percent of the indicator value for almost all grids at all time scale.

This means SPI for reanalysis data sets has larger in magnitude and it reduced a probability of capturing severe drought.

Table 5-4:- Correlations between SPI-Indicators vaues for different Dat sets

Data Sets B/n	Performance Evaluation R^2 for Grid										
	(03,05)	(03,07)	(04,04)	(05,10)	(06,03)	(06,06)	(06,09)	(07,12)	(08,12)	(09,06)	(11,07)
	SPI-3										
ECMWF Data Sets Vs Observed	0.06	0.09	0.09	0.01	0.14	0.04	0.17	0.35	0.43	0.04	0.08
Bias Corrected ECMWF Data Sets Vs Observed	0.01	0.07	0.09	0.07	0.15	0.04	0.22	0.35	0.46	0.04	0.1
	SPI-6										
ECMWF Data Sets Vs Observed	0.03	0.061	0.069	0.01	0.094	0.049	0.142	0.27	0.404	0.011	0.05
Bias Corrected ECMWF Data Sets Vs Observed	0.04	0.016	0.083	0.05	0.099	0.056	0.208	0.3	0.501	0.018	0.09
	SPI-12										
ECMWF Data Sets Vs Observed	0.01	0.06	0.02	0.02	0.08	0.01	0.1	0.14	0.37	0	0.04
Bias Corrected ECMWF Data Sets Vs Observed	0.01	2E-04	0.03	0.01	0.099	0.016	0.171	0.2	0.497	0.012	0.08

Accordingly, SPI with observed precipitation data sets was better due to all values of drought characteristics during historical drought event. SPI with observed precipitation datasets is longest duration, better to capture more severe drought and less frequently vary from drought events. In addition, bias corrected ECMWF datasets was good performance under all performance evaluation criteria than original reanalysis data sets. Even if bias corrected data sets better to understand the drought than ECMWF data, it is still poor to characterized drought than observed datasets. So there must be use a bias model in order to correct and use globally available ECMWF reanalysis product (ERA-Interim) of precipitation data to understand the drought condition of the Upper Blue Nile basin.

Table 5-5; - Percentage of Deviation between SPI Indicators Value for different datasets

%age of Deviations		Grid					
		(05,10)	(06,03)	(06,06)	(08,12)	(09,06)	(11,07)
SPI-6 Observed Vs SPI-6 ECMWF	Excess	21.22	27.01	23.47	27.97	20.26	24.76
	Normal	5.79	9.65	9.00	12.86	6.43	9.65
	Deficit	8.36	11.25	13.18	16.40	7.72	14.15
	Scanty	64.63	52.09	54.34	42.77	65.59	51.45
SPI-6 Observed Vs SPI-6 Bias - corrected-- ECMWF	Excess	20.90	25.40	28.62	27.97	19.94	29.26
	Normal	11.25	9.97	9.00	17.68	7.40	9.65
	Deficit	11.25	12.54	10.93	17.68	10.93	11.90
	Scanty	56.59	52.09	51.45	36.66	61.74	49.20
SPI-12 Observed Vs SPI-12 ECMWF	Excess	22.51	21.5434	23.151	36.6559	23.1511	23.1511
	Normal	6.752	6.10932	11.576	11.5756	0.32154	11.254
	Deficit	6.431	18.328	14.469	14.4695	8.68167	16.3987
	Scanty	64.31	54.0193	50.804	37.299	67.8457	49.1961
SPI-12 Observed Vs SPI-12 Bias - corrected- ECMWF	Excess	27.65	24.1158	24.759	34.4051	20.9003	31.8328
	Normal	12.86	9.32476	9.0032	20.5788	8.68167	7.3955
	Deficit	6.752	22.1865	12.219	15.7556	12.5402	13.1833
	Scanty	52.73	44.373	54.019	29.2605	57.8778	47.5884

5.2.2. Performance of Drought Indices

Comparison of agricultural drought index (SMDI) with that of metrological drought index (SPI) based of drought characteristics may lead to wrong conclusion. It is because of different nature severity classification. For example when SMDI value for a month is negative two point five (-2.5), the severity range is moderately drought. In contrast if it is SPI value the severity range is extreme drought. In this work comparison was made on extent historical drought events, severity range by considering its difference and percentage of probability of capturing extreme drought for the selected grid by considering severity range.

5.2.2.1. Performance of Indices during Historical Drought Events

In this section, the performance of the SMDI and SPI with different time scale has been assessed during the chronic drought years of 1984/85, 1995/96, 2003/04 and 2009/10. Figure 5.16 and 5.17 shows the evolution of drought characteristics by SPI and SMDI with different data sets with the same time scale for selected grid. Figure 5.16 and 5.17 shows SPI drought's characteristics with shorter time scale change frequently with time and at longer time scales droughts become less frequent but their duration larger. Small rainfall amounts within a 3 and 6-month time scale a drought year can potentially change the index value from drought to normal and/or wet conditions. For example, there is a possibility of a normal 3-month period occurring in the longer-term drought year of 1983/84. Such fluctuations have not been observed in 12-month SPI.

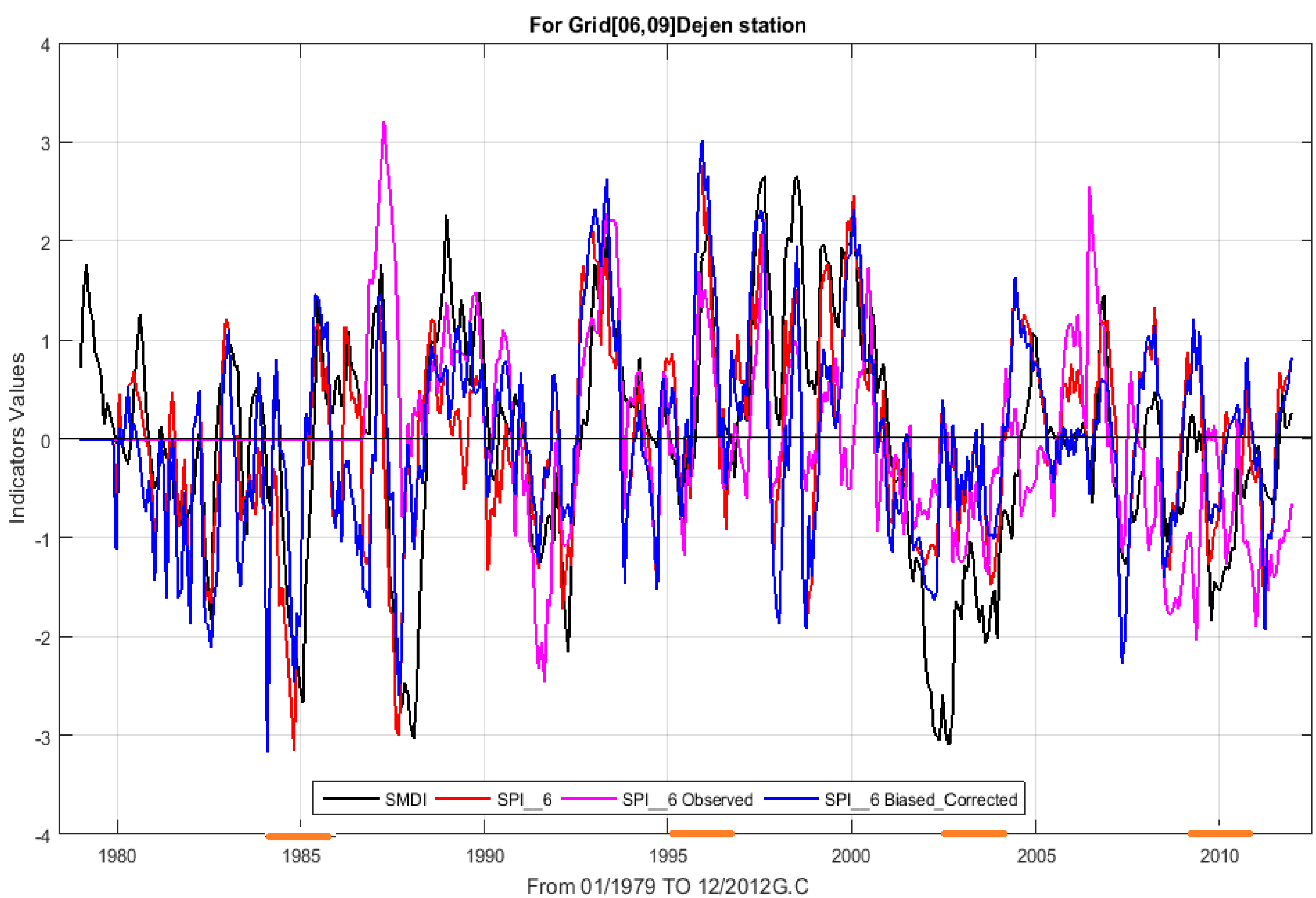


Figure 5-16:- SMDI, SPI_6, SPI_6 Observed, & SPI_6 bias corrected grid (6, 7)

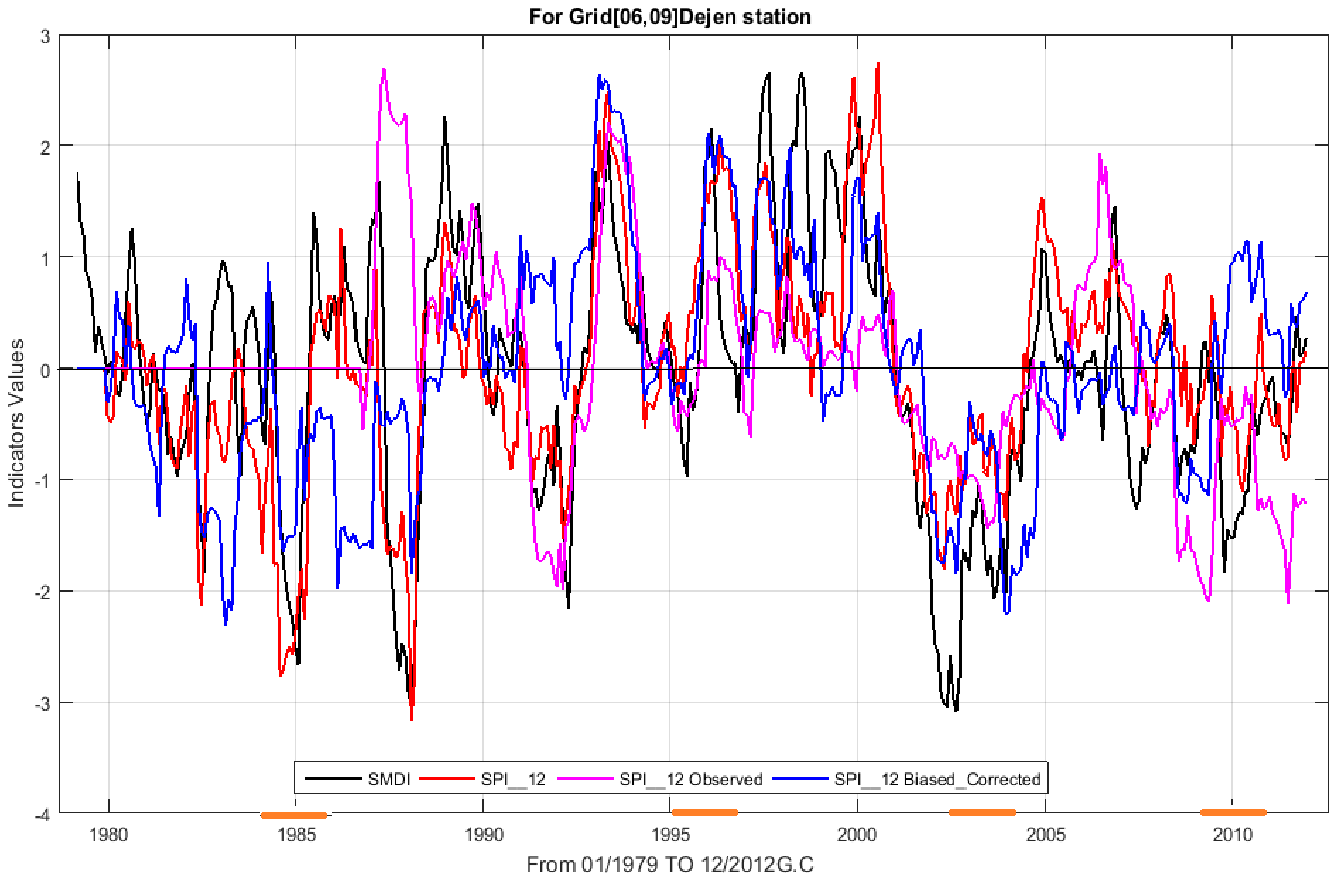


Figure 5-17:- SMDI, SPI_12, SPI_12 Observed, & SPI_12 Bias Corrected Grid (6, 7)

The time series plot shows visual comparison of drought indicator is difficult because of their difference with drought event is insignificant. Hence, drought characteristics were used to compare and contrast the severity rank of historical drought events. Table 5.6 shows the details of the historical drought events as characterized in severity, duration and intensity for grid (08, 12) and table 5.8 shows the summery for minimum and maximum drought characteristics for each grid for each different index.

According to table 5, 6 and 5.8 shows that there is an increasing in the duration and magnitude of meteorological droughts with timescale for all data sets. For SPI-3 and SPI-6 their duration and severity (magnitude) has shorter and smaller respectively than SPI-12. So, it is important to have a drought index for longer time scales as, SPI-12. SMDI has longest duration from all categories of SPI and larger value for magnitude of drought. Overall, dry periods measured with SMDI more persistent if compared with the other estimations. Even if, the magnitude of the SMDI indicator sometimes smaller with respect to the other indicators; SMDI shows a good correspondence with extent historical drought events for selected grid.

Table 5.7 presents the ranking of the historic drought years based on drought severity, duration, and mean and maximum drought intensities as indicated table 5.6 drought indices. Accordingly, among all of historical drought event 1984/85 drought event has higher mean intensity on grid (03,05), grid (05,10), grid (06,03), grid (07,12), grid (06,09), grid (06,06), and grid (08,12), and longest duration in grid (04,04), grid (05,10), grid (06,03) and grid (07,12). In addition, 1884/85 was more severe than other drought event on grid (04, 04) grid (05, 10), grid (06, 03), grid (06, 09), and grid (07, 12). The same thing happened in maximum intensity as criteria. On grid (05, 10), grid (06, 03), grid (06, 03), grid (06, 09), grid (07, 12) and grid (08, 12) has larger value for 1984/85 drought event. But 2003/04 drought events were the longest duration than 1984/85 on grid (02, 08), grid (03, 07), grid (05, 10), grid (09, 06) and grid (06, 09).

The result shows identical ranking of the historic drought events by SMDI and SPI-12 drought indices for all drought characteristics. All the drought indices rank the 1984/85 drought year first, based on both drought severity and duration. But the drought year 2003/04 ranks first based on the mean drought intensity for all drought indices on same selected grid. Based on maximum intensity the 1984/85 droughts rank first.

Table 5-6:- Characteristics of the historic drought events for grid (08, 12)

Data Type	ECMWF Soil Moisture Data set	ECMWF Data set			Bias Corrected ECMWF Data set			Observed PPT Data Set		
Drought Index	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Historic drought events in the year 1984-1985										
Mean Intensity, *M*	-2.04	-1.57	-1.41	-1.64	-1.56	-1.48	-1.25	-	-	-
Duration, D (months)	38.00	8.00	18.00	18.00	8.00	18.00	28.00	-	-	-
Severity, S	-77.70	-12.56	-25.41	-29.46	-12.49	-26.56	-35.10	-	-	-
Maximum intensity,	-3.89	-2.67	-2.55	-2.64	-2.65	-2.58	-2.78	-	-	-
Historic drought events in the year 1995-1996										
Mean Intensity, *M*	-	-0.76	-0.32	-0.10	-0.63	-0.72	-	-0.43	-0.22	-
Duration, D (months)	-	3.00	3.00	2.00	4.00	7.00	-	4.00	3.00	-
Severity, S	-	-2.29	-0.95	-0.20	-2.51	-5.07	-	-1.71	-0.65	-
Maximum intensity,	-	-1.05	-0.41	-0.14	-1.05	-1.50	-	-0.48	-0.50	-
Historic drought events in the year 2003-2004										
Mean Intensity, *M*	-0.49	-0.47	-0.95	-1.09	-0.42	-0.70	-0.96	-0.55	-0.34	-0.50
Duration, D (months)	12.00	3.00	22.00	27.00	7.00	18.00	17.00	4.00	10.00	43.00
Severity, S	-5.91	-1.41	-20.81	-29.39	-2.97	-12.53	-16.35	-2.19	-3.39	-21.6
Maximum intensity,	-0.99	-1.20	-2.18	-2.25	-0.73	-1.75	-1.49	-1.07	-0.72	-1.15
Historic drought events in the year 2009-2010										
Mean Intensity, *M*	-1.30	-0.93	-0.82	-0.58	-0.85	-0.68	-0.53	-3.12	-2.71	-0.95
Duration, D (months)	48.00	5.00	7.00	25.00	5.00	7.00	30.00	5.00	7.00	32.00
Severity, S	-62.27	-4.63	-5.73	-14.56	-4.23	-4.78	-15.76	-15.58	-18.95	-30.4
Maximum intensity,	-2.24	-1.75	-1.42	-1.15	-1.75	-1.27	-1.00	-4.15	-3.78	-2.06

Table 5-7:- Ranking of historic drought events for grid (08, 12)

rank		ECMWF Data set					Bias Corrected ECMWF Data set		
Drought Index	**Historical**	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**	**Historical**	**SPI_3**	**SPI_6**	**SPI_12**
Mean Intensity, *M*	Largest Intensity was 1984_85	1984-1985	1984-1985	1984-1985	1984-1985	Largest Intensity was 1984_1985	1984-1985	1984-1985	1984-1985
		2009-2010	2009-2010	2003-2004	2009-2010		2009-2010	1995-1996	2003-2004
		2003_2004	1995-1996	2009-2010	2003_2004		1995-1996	2003_2004	2009-2010
		1995-1996	2003_2004	1995-1996	1995-1996		2003_2004	2009-2010	1995-1996
Duration, D (months)	Longest Duration was in 2009_2010	2009-2010	1984-1985	2003_2004	2009-2010	Longest Duration was in 1984-85	1984-1985	1984-1985	2009-2010
		1984-1985	2009-2010	1984-1985	2003_2004		2003-2004	2003-2004	2003_2004
		2003_2004	2003_2004	2009-2010	1984-1985		2009-2010	2009-2010	1984-1985
		1995-1996	1995-1996	1995-1996	1995-1996		1995-1996	1995-1996	1995-1996
Severity, S	Most Severe Drought Was 1984_1985	1984-1985	1984-1985	1984-1985	1984-1985	Most Severe Drought Was 1984_85	1984-1985	1984-1985	1984-1985
		2009-2010	2009-2010	2003-2004	2003-2004		2009-2010	2009-2010	2003-2004
		2003_2004	1995-1996	2009-2010	2009-2010		2003_2004	2003_2004	2009-2010
		1995-1996	2003_2004	1995-1996	1995-1996		1995-1996	1995-1996	1995-1996
Maximum intensity, Mmax	Maximum Intensity Was in 1984_1985	1984-1985	1984-1985	1984-1985	1984-1985	Maximum Intensity Was in 1984-85	1984-1985	1984-1985	1984-1985
		2009-2010	2009-2010	2009-2010	2003-2004		2009-2010	2009-2010	2003-2004
		2003_2004	2003_2004	2003_2004	2009-2010		1995-1996	1995-1996	2009-2010
		1995-1996	1995-1996	1995-1996	1995-1996		2003_2004	2003_2004	1995-1996

Table 5-8:-Summery for Minimum and Maximum Drought Characteristics

Characteristic	ECMWF Data set				Bias Corrected ECMWF Data set			Observed Data set		
	SMDI	SPI_3	SPI_6	SPI_12	SPI_3	SPI_6	SPI_12	SPI_3	SPI_6	SPI_12
	Mean Intensity M									
Minimum	-1.38	-1.18	-1.11	-1.02	-1.13	-1.00	-0.90	-1.43	-1.30	-1.11
Maximum	-0.72	-0.59	-0.61	-0.34	-0.56	-0.50	-0.39	-0.48	-0.56	-0.42
	Duration D (months)									
Minimum	9.64	3.82	5.82	8.82	3.91	4.91	9.45	5.09	7.18	13.73
Maximum	41.09	8.00	16.36	28.91	8.18	14.64	30.36	11.73	21.64	38.09
	Severity, S									
Minimum	-54.83	-7.37	-15.83	-27.68	-7.33	-13.43	-26.15	-12.87	-20.41	-37.46
Maximum	-7.87	-3.16	-4.17	-4.74	-2.66	-2.63	-5.56	-3.31	-4.62	-8.73
	Maximum Intensity, Mmax									
Minimum	-2.78	-2.26	-2.21	-1.93	-2.09	-2.17	-1.72	-2.60	-2.62	-2.26
Maximum	-1.28	-1.21	-1.21	-0.60	-1.03	-0.88	-0.69	-0.98	-1.11	-0.83

Hence, the analysis shows that for most of selected station SMDI is better to capture drought events than the other and for all drought characteristics drought except duration the event on the year 1984/85 has severe drought in the history.

5.2.2.2. Relative Probability of Capturing Severe Drought Events

Drought indices are also investigated based on the percentage of occurrence of severe drought for each grid with respect to the total number of indices Value. Percentage is obtained by taking the ratio of severe drought to the total drought occurrence in the time span. The aim here is to identify which Drought index is better to capturing severe drought event over the basin. Table 5.9 and 5.10 presents percentage of drought occurrence for grid (06, 03) and grid (08, 12). Almost all results in selected grid show mild droughts occur most frequently and extreme droughts occur least frequently, as is expected.

Table 5-9:- Probability of Capturing %age Drought Categories for Grid (06, 03)

Data Type	**ECMWF Data set**			**Bias Corrected ECMWF Data set**			**Observed PPT Data Set**		
Drought Categories	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Extremely Wet	2.45	2.21	0.98	2.45	1.23	2.70	0.31	0.62	0.00
Very Wet	4.41	5.39	6.86	3.19	4.41	2.45	4.01	1.54	0.00

Moderately we	7.11	5.88	9.07	9.07	8.33	6.86	8.95	10.80	8.33
Mildly wet	37.99	39.46	35.78	34.80	37.99	39.95	42.28	46.30	50.93
Mild drought	34.80	32.11	32.60	36.76	33.82	32.84	30.56	26.23	28.09
Moderate drought	7.11	7.60	7.35	8.09	6.37	8.58	6.48	6.79	4.01
Severe drought	4.17	5.15	3.68	3.43	5.64	2.70	4.32	3.70	4.01
Extreme drought	1.96	2.21	3.68	2.21	2.21	3.92	3.09	4.01	4.63

Table 5-10:- Probability of Capturing %age Drought Categories for Grid (08,12)

Data Type	**ECMWF Data set**			**Biased Corrected ECMWF Data set**			**Observed PPT Data Set**		
Drought Categories	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Extremely Wet	1.96	2.94	2.94	1.72	2.21	0.98	1.23	0.93	0.62
Very Wet	3.19	2.94	3.92	3.43	4.17	3.68	2.16	3.40	5.86
Moderately we	8.58	5.39	7.35	9.56	7.11	7.84	7.72	11.11	9.26
Mildly wet	40.93	45.59	40.93	35.54	37.99	38.97	45.68	37.96	36.11
Mild drought	30.88	26.72	30.64	34.07	33.82	33.82	31.17	34.26	32.72
Moderate drought	6.37	9.07	5.88	8.09	7.84	8.09	3.40	5.86	8.95
Severe drought	4.90	3.92	4.66	4.66	2.94	1.96	5.25	2.78	4.01
Extreme drought	3.19	3.43	3.68	2.94	3.92	4.66	3.40	3.70	2.47

The analysis as shown in table there was no direct relation between relative probabilities of capturing severe drought event to time scale. In case of ECMWF data set more than 60% of grid shows SPI-12 and the remaining 30 % of shows SPI_6 has higher percentage of occurrence of drought extreme drought. On the other hand SPI using observed precipitation shows more than 70% of grid shows SPI_6 has higher percentage of occurrence of drought extreme drought.

5.2.3. Regional Based Drought Characteristics Analysis

Regional based Analysis was done by selecting some grid values from northern, southern, western, eastern and central part of the basin. Figure 5.18 and 5.19 shows time series plot of drought indices for central and western part of the basin. Regional based analysis shows a probability of severe drought occurrence on selected region at the given time. The drought may not be occurred in all selected grid. Accordingly, the map shows drought event continually occurred in the region and all historical drought events are captured by all indices. Table 5.11 shows the drought characteristics during historical drought event.

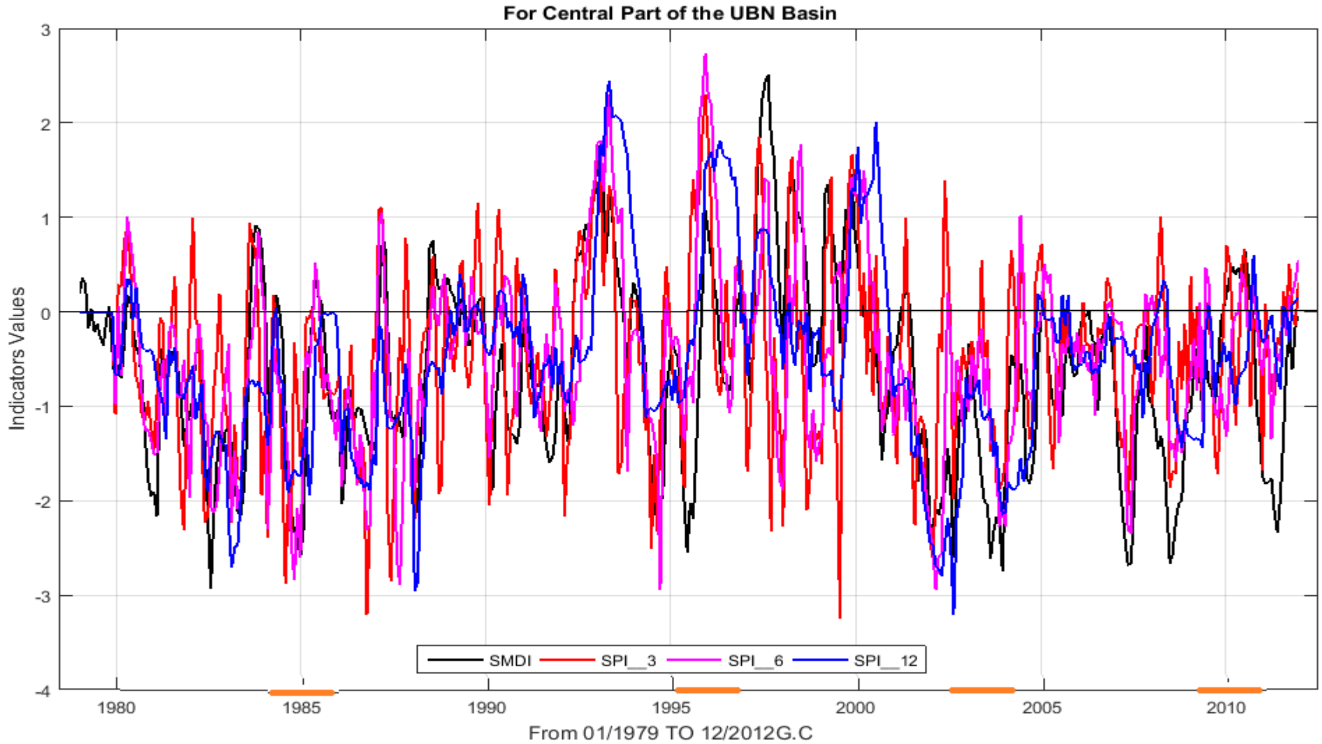


Figure 5-18: Time series indices value for Central part of the Basin

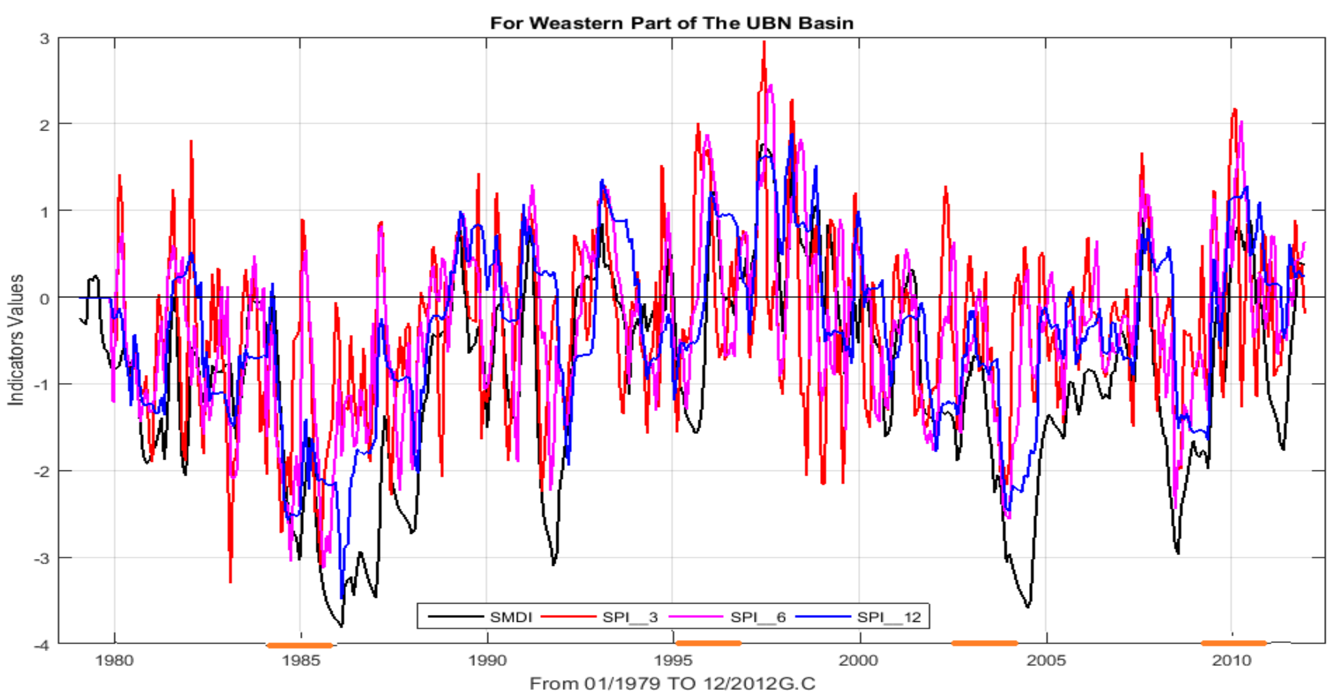


Figure 5-19:-Time series indices value for western part of the Basin

According to drought characteristics for chronic drought year as shown in table 5.11 all historical drought events are well captured by all indices. Drought characteristics show SMDI was better to capture drought events in depth. SMDI give longest duration from all categories of SPI and higher magnitude of drought and it has good correspondence with the extent historical drought events for selected region.

Table 5-11:- Characteristics of the drought events for Western Part of UBN basin

Data Type	**ECMWF Data set**			
Drought Index	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**
Historic drought events in the year 1984-1985				
Mean Intensity, *M*	-2.35	-1.33	-1.57	-1.70
Duration, D (months)	57.00	23.00	23.00	51.00
Severity, S	-134.04	-30.50	-36.03	-86.49
Maximum intensity, Mmax	-3.81	-3.09	-3.13	-3.48
Historic drought events in the year 1995-1996				
Mean Intensity, *M*	-1.15	-0.66	-0.64	-0.55
Duration, D (months)	11.00	7.00	8.00	22.00
Severity, S	-12.67	-4.64	-5.14	-12.16
Maximum intensity, Mmax	-1.58	-1.56	-1.29	-1.19
Historic drought events in the year 2003-2004				
Mean Intensity, *M*	-1.52	-1.37	-1.39	-1.11
Duration, D (months)	73.00	9.00	14.00	48.00
Severity, S	-111.08	-12.35	-19.51	-53.29
Maximum intensity, Mmax	-3.59	-2.16	-2.56	-2.47
Historic drought events in the year 2009-2010				
Mean Intensity, *M*	-1.62	-0.79	-1.06	-1.36
Duration, D (months)	25.00	17.00	18.00	13.00
Severity, S	-40.51	-13.51	-19.04	-17.68
Maximum intensity, Mmax	-2.96	-2.42	-2.44	-1.66

Using drought characteristics value rank of historical drought event was determined for selected regional in table 5.12. Accordingly, drought year 1984/85 is identified as an extreme drought for all indices based on drought characteristics value during drought events. At all evaluation criteria this chronic drought year was more severe than the other.

Table 5-12:-Ranking of drought events for Western Part of UBN basin

Data Type		**ECMWF Data set**			
Characteristics	**Historical**	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**
Mean Intensity, *M*	Largest Intensity was 1984_85	1984-1985	2003-2004	1984-1985	1984-1985
		2009-2010	1984-1985	2003-2004	2009-2010
		2003-2004	2009-2010	2009-2010	2003-2004
		1995-1996	1995-1996	1995-1996	1995-1996
Duration, D	Longest Duration	2003-2004	1984-1985	1984-1985	1984-1985

(months)	was in 1984-1985	1995-1996	2009-2010	2009-2010	2003-2004
		2009-2010	2003-2004	2003-2004	1995-1996
		1984-1985	1995-1996	1995-1996	2009-2010
Severity, S	Most Severe Drought Was 1984-1985	1984-1985	1984-1985	1984-1985	1984-1985
		2003-2004	2009-2010	2003-2004	2003-2004
		2009-2010	2003-2004	2009-2010	2009-2010
		1995-1996	1995-1996	1995-1996	1995-1996
Maximum intensity, Mmax	Maximum Intensity Was in 1984-1985	1984-1985	1984-1985	1984-1985	1984-1985
		2003-2004	2009-2010	2003-2004	2003-2004
		2009-2010	2003-2004	2009-2010	2009-2010
		1995-1996	1995-1996	1995-1996	1995-1996

Similar to grid based analysis, the regional based analysis shows that SMDI is better to capture drought events than the other and for all drought characteristics drought event on the year 1984/85 has severe drought in the history.

5.2.4. Spatial Extent of Historical Drought Event

Drought prevalence in the upper Nile river basin is investigated by analyzing the indicators values for consecutive months during chronic drought years. Drought maps were produced using the estimated annual maximum intensity values of SPI and SMDI during consecutive months. This is called kriging method of spatial severity of drought mapping (Arash A.,et.al, 2013). The Arc View GIS was used to generate drought severity maps for the study area for each historical drought events using annual maximum intensity values. Drought maps are shown in Figure 20 to 23 and its spatial extent of drought in percentage are summarized on table 5.14.

Table 5-13:- Probability of spatial Occurrence of Extreme Drought Events

Drought Categories	%age of Areas Captured by SPI_3			
	1984/85	1995/96	2003/04	2009/10
Mildly wet	0	0	0	0
Mild drought	0.641026	30.12821	32.05128	32.05128
Moderate drought	18.58974	32.69231	23.71795	49.35897
Severe drought	42.94872	21.79487	38.46154	16.02564
Extreme drought	37.82051	15.38462	5.769231	2.564103
	%age of Areas Captured by SPI_6			

Mildly wet	0	0	0	0.641026
Mild drought	0	37.82051	29.48718	53.20513
Moderate drought	10.25641	33.97436	20.51282	36.53846
Severe drought	32.05128	16.66667	30.12821	6.410256
Extreme drought	57.69231	11.53846	19.87179	3.205128
	%age of Areas Captured by SPI_12			
Mildly wet	0	1.923077	0	1.282051
Mild drought	7.692308	60.25641	30.76923	53.20513
Moderate drought	17.94872	21.79487	27.5641	42.94872
Severe drought	22.4359	14.74359	27.5641	2.564103
Extreme drought	51.92308	1.282051	14.10256	0

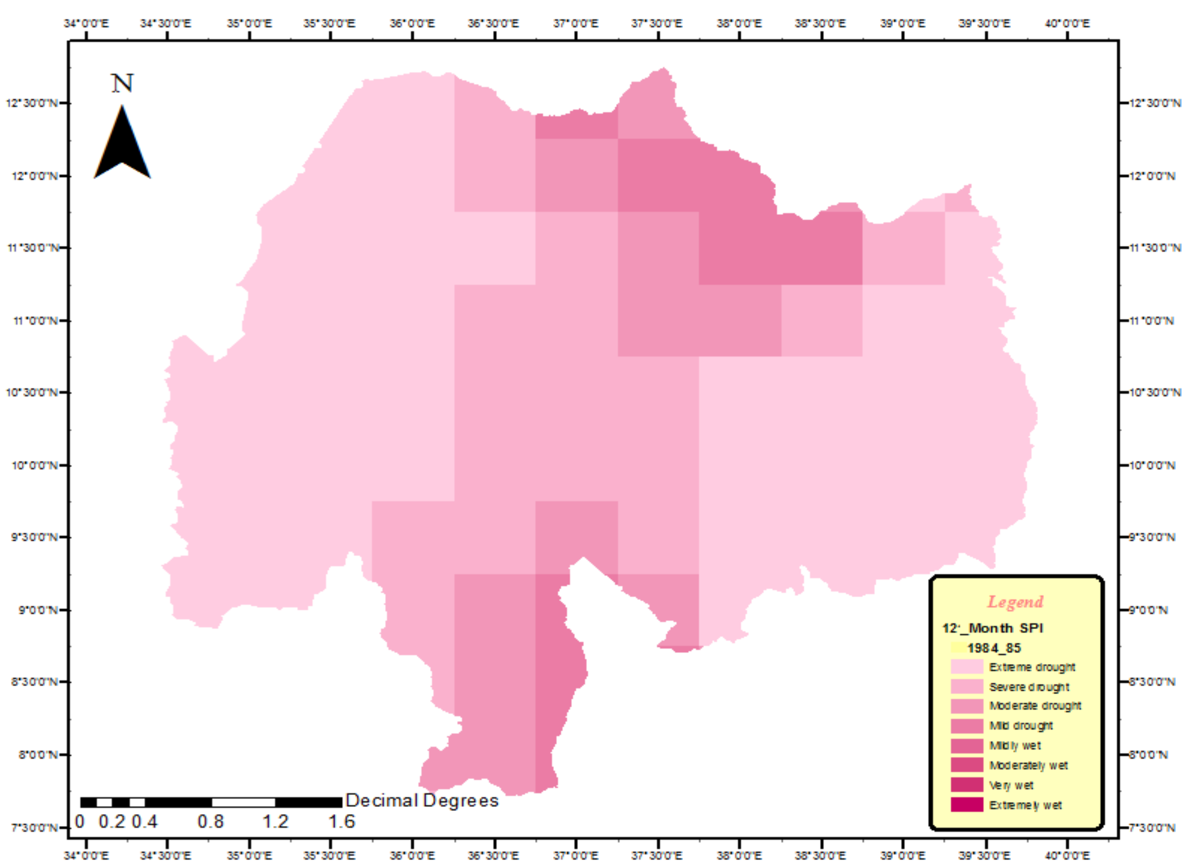


Figure 5-20:- SPI _12 Drought Map for 1984/85 Drought Year

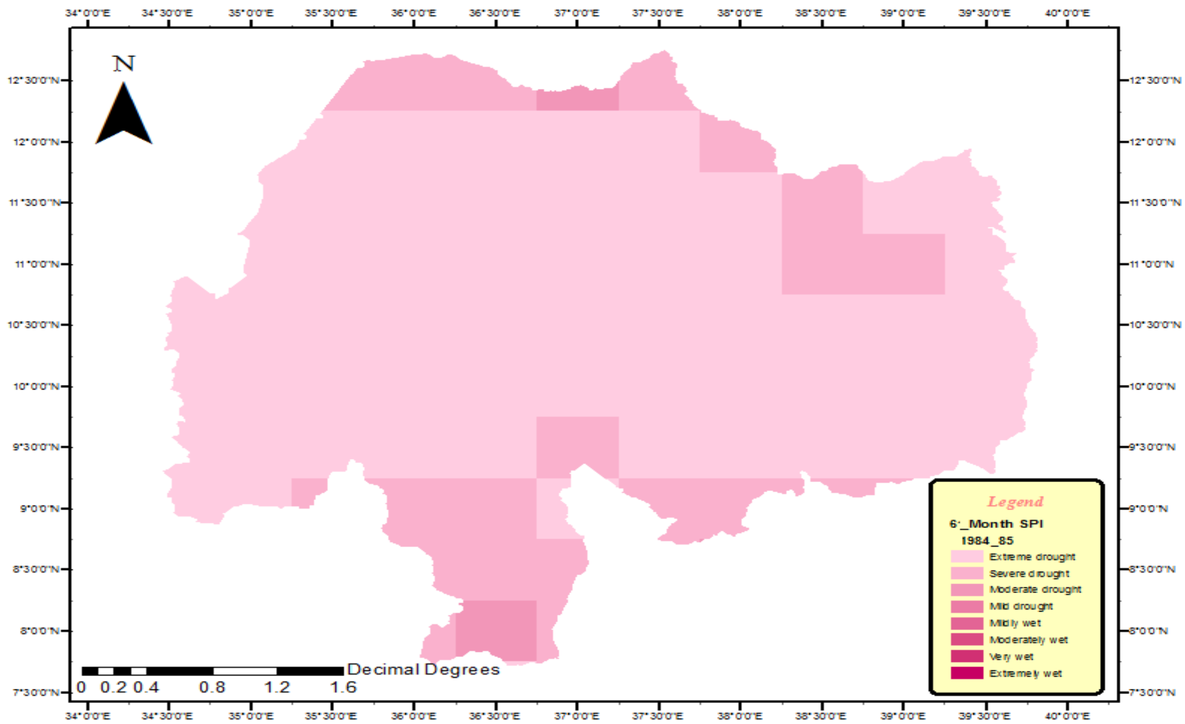


Figure 5-21:- SPI_6 Drought map during 1984/85 drought year

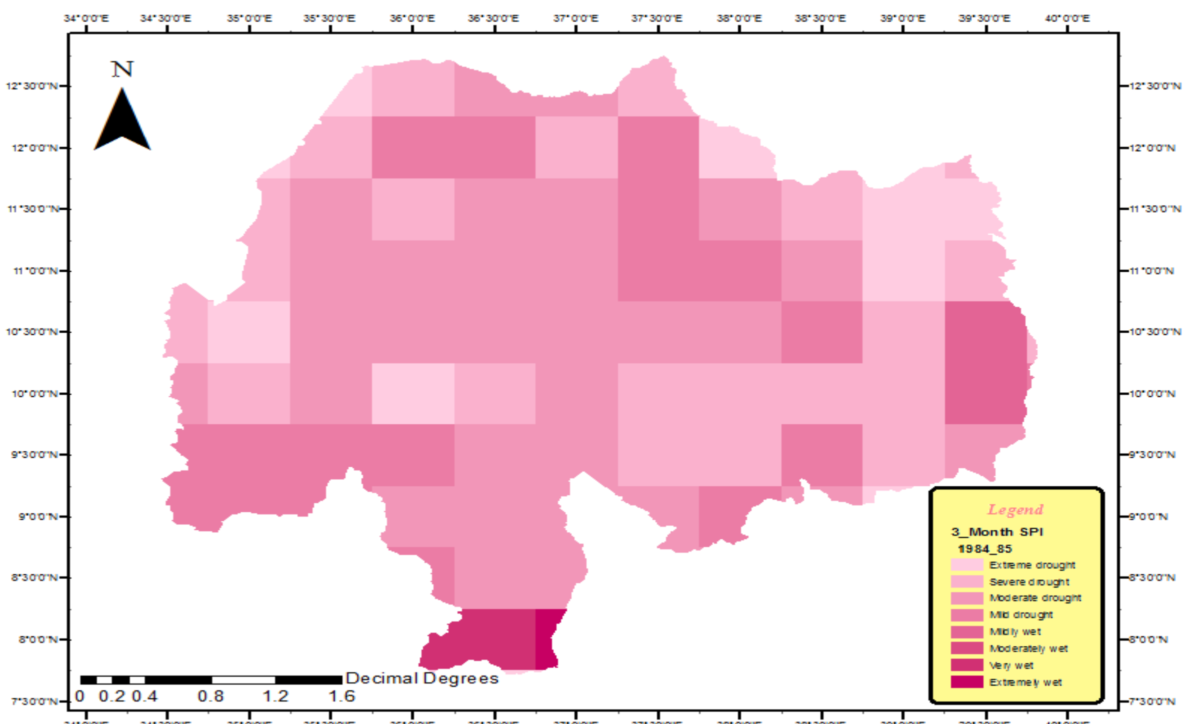


Figure 5-22:- SPI_3 Drought Map During 1984/85 drought year

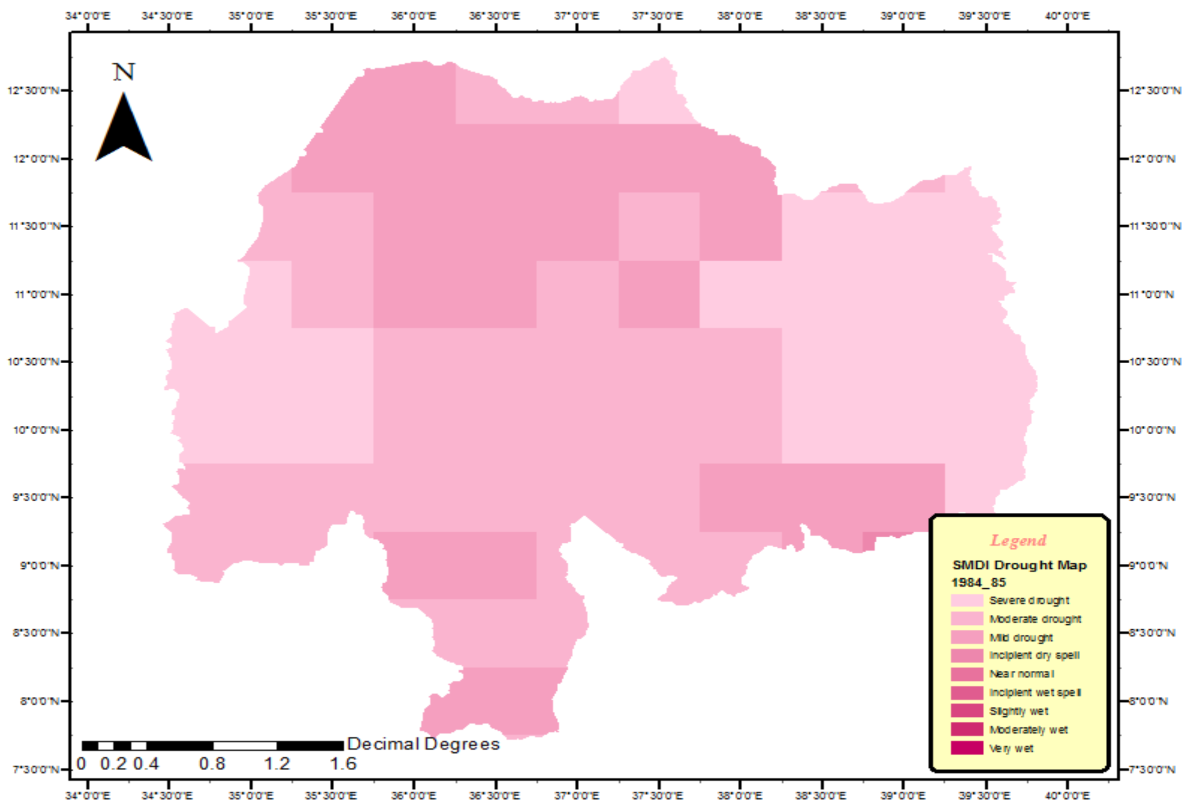


Figure 5-23:- SMDI Drought map during 1984/85 drought year

The occurrence of extreme drought event in varying indices was analyzed to identify which drought index's is better to capture extreme drought. It can be noted that the percentage occurrence of drought events of a given category varies with SPI time scale. As seen in Table 4.11 under the same drought event SMDI, SPI_3, SPI_6 and SPI_ 12 have different tendency to capture the occurrence extreme drought events. For example in the year 1983/84, spatial extent of drought under SMDI, shows that 32. %, under SPI _3 shows that 37 %, under SPI_6 shows that 57 % and under SPI_12 shows 51% of the total area in the basin was under extreme drought events. It shows that SPI_ 6 has a good performance in capturing extreme drought events. It is true for other historical drought year of 2003/04 and 2009/10 drought events. Therefore, SPI_6 identified the highest number of occurrences of extreme drought.

According to SPI_6; The years 1984/85 the most critical drought years in the basin with more than 57% of the total basin area under extreme drought and more than

32% of the total basin area under severe drought, coinciding with the historical deadly drought years in the country as a whole and as a result of which a large portion of the population was exposed to extreme famine situations. The year 2003/04 is found to be the second critical year, when about 19% of the total area of the basin was under extreme drought, more than 30% of the total basin area under severe drought.

6. Conclusion and Recommendation

6.1. Conclusion

This particular study examined the effectiveness of the newest Re-analysis product of ECMWF called ERA-Interim datasets on probability of capturing the historical extreme drought events in UBN basin. Two drought indices were used: - SMDI as agricultural index and SPI as metrological index. ECMWF Reanalysis precipitation and soil moisture product, Bias corrected ECMWF Reanalysis precipitation product and observed metrological data were used as input. MATLAB 2015a was used for developing a long-term SMDI and SPI in each time scale.

Comparison of datasets was undertaken in terms of percentage deviations, coefficient of determination (R^2) and histogram of monthly precipitation plot. Ninety percent of the observed datasets had a high correlation (R^2 greater than 50%) with that of ECMWF data sets. This shows that there is a good piecewise linear correlation between the datasets with respect to tread. In contrast, ECMWF has a tendency to underestimate 45% the whole data and 20.4% of the data was overestimated and Bias corrected ECMWF datasets underestimated in to 42% and overestimate 20% of the whole data. Hence, the bias corrected ECMWF datasets almost the same with that of the original ECMWF datasets.

Drought indices were characterized historical drought events differently. SPI with observed were better to characterized historical drought events and less frequently occurred than SPI using both ECMWF products due to all values of drought characteristics. On the other hand, SMDI was well characterized and captured the four drought events i.e. 1984/85, 1995/96, 2003/04 and 2009/10, by most of the grid. This shows that meaningful results for drought analysis and monitoring can be achieved by using ECMWF Reanalysis soil moisture product. On the other hand ECMWF Reanalysis Precipitation product needs further correction measure using different appropriate bias model.

Analysis of SPI shows that drought’s characteristics like duration and magnitude change proportionally with timescale and at longer time scales droughts become less frequent but their duration is longer. In addition, the SPI values of longer time scale of 6 month and 12 month were better to captured extreme drought events compared to 3-month SPI values. When SMDI compare with SPI-3, SPI-6 and SPI-12 using drought characteristics SMDI gave longest duration and more severe drought condition during each historical drought events. In addition, drought event in SMDI occurred less frequently, more persistent and has a tendency to capture severe drought events than metrological drought indices. Accordingly, SMDI is appropriate to characterize the drought condition of Upper Blue Nile Basins than other metrological drought indices.

Spatial coverage of historical drought event detected, tracked and mapped for different datasets. Accordingly, drought event at the years 1984/85 was most critical and cover more than 57% of the total area of the basin under Extreme drought and more than 32% of the total basin area under severe drought. Based on drought characteristics also the drought of 1984/1985 has been assessed as the most severe event by most of the drought indices.

Most commonly drought indices are directly related to precipitation and /or temperature datasets. But, this research contributes that in order to understand drought Characteristics in Upper Blue Nile Basin it is better to focused on amount of soil moisture available at the root zone rather than precipitation datasets. In addition, this paper examines and shows the tendency of globally available reanalysis datasets (ERA-Interim) to characterize the drought in Upper Blue Nile Basin. Accordingly, it concludes that ECMWF Reanalysis Soil moisture product give a meaningful result to characterize the drought condition of the Upper Blue Nile basin and ECMWF Reanalysis precipitation product need a further correction with well known bias correction model.

6.2. Recommendation

1. Bias corrected ECMWF precipitation product used in this paper is only corrected for wet season (June to September) rainfall dataset. Even if, the result were not attractive it is recommended to conduct further correction using bias model for all rainfall season and may characterize the drought better.
2. Reanalysis ECMWF ERA-Interim product is not only soil moisture and precipitation datasets. So it is recommended evaluating other ECMWF product like temperature and evapotranspiration for its effectiveness to capturing drought events.
3. For the best gauged grid that has five metrological stations (06, 09) has the lowest dispersion in datasets compare with other grid. It means density of rain gauges and its location relatively to grid plays a significant role in determining the agreement between data sets. So it is recommended to evaluate this Reanalysis ERA-Interim product at a sub basin level or to other basin in Ethiopia which have relatively better gauged station than UBN basin.
4. In recent years, several global reanalysis datasets with high spatial and temporal resolution are available in the globe. Most of them are more effective for the area where developed. So it is recommend evaluating other data sets until we find the best reanalysis product that well characterized the drought events of the UBN basin.
5. There was no well documented evidence regarding to the extent and impact of historical drought event in the basin and it was too difficult to evaluate and compare the reanalysis product with real data. Therefore for further research it is essential to conduct a comprehensive study on impact and extent of historical and upcoming drought events for each area separately.

Reference

Adane, A., 2009. Hydrological Drought Analysis-Occurrence, Severity, Risks: The Case of Wabi Shebele River Basin, Ethiopia. Siegen: Bauingenieurwesen der Universit: Dissertation work.

Balaji, N., 2004. Development of indices for agricultural drought monitoring using a spatially distributed hydrologic model. Texas A & M University: - Dissertation Work.

Beyene, E. G., 2007. Drought Assessment for Nile Basin using Meteosat Second Generation data with special emphasis on the Upper Blue Nile Region. The Netherlands: International institute for geo -information science and earth observation enschede. Msc Work.

Bayissa, Y.A., Moges, S.A., Xuan, Y., Van Andel, S.J., Maskey, S., Solomatine, D.P., Griensven, A. and Van Tadesse, T., 2015. Spatio-temporal assessment of meteorological drought under the influence of varying record length: the case of upper Blue Nile Basin, Ethiopia. Hydrol. Sci. J., http://dx.doi.org/10.1080/0262 6667 .2015 .1032291.

Belayneh, A., Adamowski, J., Khalil, B., 2012. Long-term SPI drought forecasting in the Awash River Basin in Ethiopia using wavelet-neural network and wavelet-support vector regression models. NABEC CSBE/SCGAB Joint Meeting and Technical Conference on Ecological Engineering.

Boken, V.K., 2005. Agricultural Drought and Its Monitoring and Prediction: Some Concepts, In V.K Boken, A.P Cracknell and R.L Heathcote (ed.), Monitoring and Predicting Agricultural Drought: A Global Study. Oxford University Press

Christos, A. K., Stavros, A., Demetrios E. T. and George A., 2011. Application of the Standardized Precipitation Index (SPI) in Greece. Water, 3, 787-805; doi:10.3390/ w3030787.

Dejene, S., Semu, M.,Emmanouil, N. and Dereje.H., 2015. Error Analysis of Global Satelite Precipitation Products Using Daily Gauged Observations over the Upper Central Blue Nile Basin: Preliminary results. April 12 to 17, Austria Vienna.

Dereje, T., 2006. Catchment water balance for Blue Nile Basin, Msc Thesis Report; Arbaminch, Ethiopia.

Edwards, D. and McKee, T., 1997. Characteristics of 20th century drought in the United States at multiple time scales. climatology report number 972. Technical report, Colorado State University, Fort Collins, CO.

Edossa, D.C., Babel, M.S., Gupta, A.D., 2010. Drought Analysis on the Awash River Basin, Ethiopia. Water Resource Management 24: 1441 -1460

Ellen, V., Diriba K. & Asgeir S., 2012. Recent Drought and Precipitation Tendencies in Ethiopia. Thoretical and Applied Climatology.

Guttman, N. B., 1999. Accepting the Standardized Precipitation Index: a calculation algorithm, J. Am. Water Resource. As., 35, 311–322.

Jiahua, Z., Fengmei Y. & Xiaolu S., 2015. Estimation and Assessment of Drought in North China based on Evapotranspiration Drought Index and Remote Sensing Data. AASRI International Conference: Atlantis Press.

K. I. Hodges, and S. Hagemann, 2004b: Sensitivity of the ERA40 reanalysis to the observing system: Determination of the global atmospheric circulation from reduced observations. Tellus, 56A, 456–471.

Keshavarz, M., Karami, E., Vanclay, F., 2013. The social experience of drought in rural Iran. Journal of Land Use Policy 30, 120–129.

Linsley, R.K., Kohler, M.A., Paulhus, J.L.H. (1988). Hydrology for engineers. International Edition. McGraw-Hill, Singapore

Leszek, Ł. & Bogdan, B.,2014. Meteorological and agricultural drought indices used in drought monitoring in Poland: a review. Institute of Technology and Life Science, Kujawsko-Pomorski Research Centre, Glinki 60, 85-174 Bydgoszcz, Poland.

McKee, T.B., Doesken, N.J., Kleist, J., 1993. The relationship of drought frequency and duration to time scales, Proceedings of the 8th Conference of Applied Climatology, 17-22 January, Anaheim, California, 179-184.

Melaku, E.A., 2013. Assessment of Drought Early Warning in Ethiopia. The Netherlands: University of Twente: Enschede.

Mladen, M., Milan G. & Slaviša T., 2014. Analysis of meteorological and agricultural droughts in Serbia. University of Niš, Serbia,Vol. 12, No 3, 2014, pp. 253 – 264.

MOSAAD K. and ANDREAS S.,2015. Analysis of spatial and temporal variability of meteorological drought vulnerability in the Blue Nile river basin. E-proceedings of the 36th IAHR World Congress 28 June – 3 July, 2015, The Hague, the Netherlands.

Monica H., 2006, Hydrological Modelling of the Nile Basin, Msc. thesis, University of Brussels, Belgium.

M. Naresh Kumar, C. S. Murthy, M. V. R. Sesha Sai and P. S. Roy. 2009. On the use of Standardized Precipitation Index (SPI) for drought intensity assessment. Meteorol. A ppl. 16: 381–389 (2009) Published online 17 April 2009 in Wiley InterScience (www.interscience.wiley.com) DOI: 10.1002/met.136

M. Sigdel1 & M. Ikeda., 2010. Spatial and temporal Analysis of Drought in Nepal using Standardized precipitation Index and its relationship with Climate Indices. Hokkaido University, N10 W 5, Sapporo Graduate School Hokkaido 060-0810, Japan.

Narasimhan B.and R. Srinivasan R. S. 2004. "Development and evaluation of Soil Moisture Deficit Index (SMDI) and Evapotranspiration Deficit Index (ETDI) for agricultural drought monitoring." Agricutural and Forest Meteorology (133): 69-88.

Hodges, K. I., R. W. Lee, and L. Bengtsson, 2011. A comparison of extratropical cyclones in recent reanalyses ERA-Interim, NASA MERRA, NCEP CFSR, and JRA-25. J. Climate, 24, 4888–4906.

Hollinger SE, Isard SA, Welford MR., 1993. A New Soil Moisture Drought Index for Predicting Crop Yields. In: Preprints, Eighth Conf. on Applied Climatology, Anaheim, CA, Amer. Meteor. Soc., pp. 187-190

Hunt E.D., Hubbard K.D., Wilhite D.A., Arkebauer T.M., Dutcher A.L., 2009, The development and evaluation of a soil moisture index, International Journal of Climatology, 29 (5), 747-759, DOI: 10.1002/joc.1749

Husak, G.J., Funk, C.C., Michaelsen, J., Magadzire, T., Goldsberry, K.P., 2013. Developing seasonal rainfall scenarios for food security early warning. Theoretical and Applied Climatology. http://dx.doi.org/10.1007/s00704-013- 0838-8.

Rahel S. T., 2007. Agricultural Drought Assessment for Upper Blue Nile Basin, Ethiopia using SWAT. UNESCO-IHE Institute for Water Education. Delft, the Netherlands April 2007.

Sara Abebe A. March 2010, Mitigation Drought: Policy Impact Evaluation A case of Tigray Region, Ethiopia. University Twente Msc Work.

Seyed A. S. & Davoud K. D., 2015. Application development of soil moisture deficit index (SMDI) for agriculture drought monitoring (case study: zarghan region, Fars province in Iran). Indian Journal of Fundamental and Applied Life Sciences ISSN: 2231– 6345.

SYNOPSIS., 2016. Joint Government and Humanitarian Partners' Document Central Statistical Agency projection, Ethiopia

Wilhite, D. A., 2000. "Drought preparedness and response in the context of Sub-Saharan Africa." In: Journal of contingencies and crisis management, 8(2000)2, pp. 81-92.

World Metrological Organization, 2012. Standardized Precipitation Index User Guide. WMO-N0:1090 CH-1211 Geneva 2, Switzerland ISBN 978-92-63-11091-6.

Yohannes, H. S., 2009. Stochastic Simulation of Stream flow and Hydrologic Drought Analysis (Case Study: Upper Blue Nile Basin). Addis Ababa University: MSc work.

Appendices

Annex A: Evaluation of Observed Precipitation Datasets

Metrological Data for Selected Station

Period Of Records		Observed Mean Monthly Precipitation Data for stations Lay on Grid										
year	**Month**	**(03,05)**	**(03,07)**	**(04,04)**	**(05,10)**	**(06,03)**	**(06,06)**	**(06,09)**	**(07,12)**	**(08,12)**	**(09,06)**	**(11,07)**
1986	**Jan**	0.00	0.00	15.40	0.00	0.00	0.00	3.85	0.00	0.00	0.00	0.00
	Feb	26.80	19.70	33.90	0.00	0.00	0.00	8.48	58.50	32.70	6.70	0.00
	Mar	52.80	62.00	17.20	19.60	0.36	18.30	13.87	70.30	54.90	7.30	1.24
	April	90.90	140.30	53.20	75.20	63.80	38.70	57.73	12.00	138.70	36.10	6.66
	May	173.10	86.60	20.10	99.70	50.10	38.10	52.00	17.40	49.50	100.81	1.71
	Jun	362.80	580.00	241.50	78.40	278.40	49.60	161.98	175.00	118.20	418.50	190.59
	July	363.50	705.10	496.40	154.00	185.60	382.40	304.60	182.00	254.30	517.50	356.50
	Aug	205.70	336.20	271.10	317.80	248.20	465.80	325.73	281.00	336.10	430.30	250.54
	Sep	594.30	346.10	419.50	228.40	338.90	332.30	329.78	95.70	73.50	383.30	220.86
	Oct	91.50	120.40	63.10	196.20	220.10	378.80	214.55	18.54	6.90	86.55	69.65
	Nov	21.40	31.50	10.30	5.70	0.00	165.90	45.48	0.00	0.00	17.30	1.55
	Dec	0.00	0.20	1.20	0.00	0.00	37.70	9.73	0.00	20.20	0.00	1.35
1987	**Jan**	16.80	0.00	2.30	88.00	0.00	2.20	23.13	0.00	0.00	31.60	2.60
	Feb	21.00	12.80	4.50	290.50	0.00	0.00	73.75	74.80	74.80	0.00	0.15
	Mar	100.00	96.00	88.10	48.00	0.40	84.60	55.28	106.90	115.30	0.00	7.70
	April	75.50	131.80	40.90	275.40	58.00	84.40	114.68	81.40	39.50	36.10	24.25
	May	168.10	226.50	306.60	71.40	164.20	264.20	201.60	103.50	144.80	185.60	206.75
	Jun	266.50	308.50	464.10	513.30	237.80	283.60	374.70	0.00	0.00	374.10	208.50

	July	443.20	385.20	422.50	786.50	305.60	452.00	491.65	33.80	50.10	290.70	189.55
	Aug	331.30	299.50	555.30	425.70	373.30	198.40	388.18	249.20	289.80	246.10	201.75
	Sep	228.80	289.60	468.10	0.00	351.60	179.30	249.75	31.90	39.30	187.10	130.80
	Oct	166.70	175.20	162.00	0.00	148.50	209.00	129.88	22.20	36.20	175.80	123.40
	Nov	115.20	25.30	7.40	0.00	0.60	65.90	18.48	0.00	0.00	0.60	16.95
	Dec	7.90	4.30	0.00	0.00	0.00	0.90	0.23	2.80	10.40	0.00	0.00
1988	**Jan**	40.10	5.90	3.40	23.07	14.80	2.20	10.87	17.10	7.30	0.00	2.45
	Feb	109.00	99.00	19.10	229.00	43.60	2.60	73.58	64.70	96.80	15.30	10.75
	Mar	76.90	44.30	55.24	187.00	0.00	19.80	65.51	13.20	32.40	2.70	2.45
	April	30.00	13.80	0.00	0.00	0.00	30.80	7.70	101.30	100.60	0.00	1.55
	May	244.80	290.30	349.50	122.30	67.20	0.30	134.83	0.60	38.20	104.70	114.90
	Jun	554.20	485.10	422.10	0.00	249.20	119.40	197.68	27.80	45.10	390.20	187.05
	July	313.40	272.00	414.50	258.20	402.50	329.00	351.05	378.90	397.20	441.70	339.85
	Aug	309.10	292.70	392.20	392.20	287.70	325.30	349.35	239.90	271.30	466.10	225.15
	Sep	712.40	371.50	538.30	291.40	160.50	283.20	318.35	90.20	170.50	452.10	176.88
	Oct	365.80	218.10	280.10	117.30	48.90	280.20	181.63	17.30	29.70	125.10	122.90
	Nov	5.00	37.50	0.00	80.80	17.00	232.90	82.68	0.00	0.00	0.00	15.70
	Dec	2.40	3.40	5.40	0.00	8.50	0.50	3.60	0.00	5.60	0.00	0.00
1989	**Jan**	34.30	1.00	0.00	0.00	0.00	0.80	0.20	3.50	11.80	0.00	13.60
	Feb	3.80	6.20	30.00	45.50	15.60	0.00	22.78	75.30	43.70	0.00	0.05
	Mar	140.50	115.80	121.50	65.60	135.00	0.00	80.53	110.70	116.30	1.90	48.15
	April	54.60	90.80	91.00	48.60	132.20	129.60	100.35	63.60	165.20	36.90	53.45
	May	171.10	107.10	305.20	98.70	142.40	50.50	149.20	5.50	2.20	189.10	104.20
	Jun	355.60	312.30	322.60	12.00	250.00	211.70	199.08	19.90	18.50	230.20	160.25
	July	335.40	202.20	467.70	202.90	331.10	373.90	343.90	192.70	240.00	473.30	331.15
	Aug	381.10	284.40	338.30	434.10	404.50	332.80	377.43	252.80	249.50	348.20	243.00
	Sep	423.70	198.80	397.60	400.10	280.90	269.10	336.93	46.60	174.10	421.20	115.75
	Oct	93.90	94.60	144.70	234.60	76.00	319.80	193.78	22.30	23.80	99.70	59.50
	Nov	38.60	44.50	13.40	11.00	18.40	113.50	39.08	0.00	0.00	0.80	25.35

	Dec	196.50	161.20	53.30	16.50	123.80	4.00	49.40	26.90	104.10	0.20	0.00
1990	**Jan**	2.80	5.10	3.80	153.90	10.70	77.30	61.43	0.11	20.90	2.70	1.95
	Feb	25.80	29.40	0.00	0.00	5.60	5.00	2.65	56.05	99.00	0.00	0.00
	Mar	98.90	45.50	16.00	122.50	15.30	5.10	39.73	39.00	123.40	0.20	3.05
	April	66.20	68.90	31.40	86.90	34.80	15.40	42.13	43.11	116.40	0.00	22.20
	May	127.90	151.70	97.10	56.90	62.00	55.20	67.80	0.00	5.10	22.50	37.35
	Jun	385.90	336.90	468.00	62.50	290.40	127.20	237.03	49.81	0.00	254.50	136.20
	July	243.80	338.70	310.90	173.50	534.70	326.80	336.48	253.90	193.30	404.00	289.90
	Aug	644.80	308.30	610.00	381.50	351.20	415.50	439.55	242.18	115.20	386.50	219.70
	Sep	431.90	223.70	329.40	568.00	147.30	450.50	373.80	145.56	211.60	330.70	190.00
	Oct	10.00	69.30	74.00	237.30	18.80	219.00	137.28	5.29	7.90	133.30	33.85
	Nov	10.70	17.80	0.00	1.40	0.00	95.90	24.33	0.00	0.00	0.00	0.00
	Dec	2.40	2.00	0.00	0.00	0.00	17.70	4.43	0.10	0.00	0.00	0.00
1991	**Jan**	24.80	5.30	0.50	0.00	4.29	0.00	1.20	12.37	4.00	0.00	0.25
	Feb	9.70	21.80	2.00	41.70	0.00	0.00	10.93	28.73	35.00	0.00	7.71
	Mar	61.80	51.50	25.90	99.10	15.40	20.30	40.18	45.00	95.60	2.70	21.96
	April	179.30	118.00	197.70	90.20	58.30	62.60	102.20	7.38	15.40	56.31	21.69
	May	238.10	139.00	341.30	4.60	0.00	127.90	118.45	20.33	36.40	69.74	143.89
	Jun	246.90	247.00	277.40	55.80	107.30	83.80	131.08	109.30	104.97	184.06	203.71
	July	453.70	475.30	461.80	296.60	263.80	217.40	309.90	178.21	175.60	365.04	217.92
	Aug	529.70	401.90	403.40	276.70	41.10	217.80	234.75	279.48	204.70	228.23	219.45
	Sep	256.80	172.30	382.30	480.10	55.10	206.80	281.08	90.72	116.00	165.80	200.55
	Oct	26.10	73.10	47.70	119.20	0.00	169.40	84.08	6.24	26.70	63.99	122.55
	Nov	11.70	1.20	0.00	4.60	0.00	30.00	8.65	0.00	0.00	0.00	3.80
	Dec	31.66	23.20	6.70	14.00	0.00	0.00	5.18	7.20	34.60	0.00	1.79
1992	**Jan**	0.00	8.40	7.20	6.10	39.00	24.60	19.23	43.50	82.80	0.00	0.00
	Feb	0.00	3.10	0.00	74.10	25.90	0.00	25.00	6.60	18.40	0.00	0.95
	Mar	52.40	56.00	94.90	31.60	14.70	0.00	35.30	14.00	49.30	1.80	0.95
	April	70.70	156.60	146.30	71.30	15.00	14.00	61.65	42.07	137.30	57.20	66.10

	May	236.90	127.10	263.20	42.70	73.50	104.20	120.90	16.40	27.20	71.40	53.47
	Jun	332.00	250.70	318.00	90.80	178.80	99.10	171.68	13.60	6.10	175.90	153.36
	July	503.90	217.80	226.10	117.80	282.40	202.60	207.23	232.10	174.60	337.80	251.26
	Aug	548.60	311.00	312.70	365.70	463.18	186.20	331.94	264.00	208.20	481.60	309.35
	Sep	477.60	208.00	608.20	362.30	12.10	207.40	297.50	58.10	149.30	238.90	62.55
	Oct	446.10	226.90	257.20	249.70	60.20	153.70	180.20	36.00	82.60	199.80	117.14
	Nov	96.30	119.10	45.90	97.80	23.80	209.90	94.35	8.50	55.30	9.10	2.90
	Dec	7.60	1.90	1.50	33.30	12.90	26.50	18.55	5.70	49.00	1.20	2.80
1993	Jan	41.30	1.20	0.00	52.60	0.00	34.35	21.74	2.20	46.20	0.00	0.00
	Feb	76.40	39.20	15.40	0.00	0.00	0.00	3.85	34.24	83.00	0.00	1.60
	Mar	59.80	73.70	41.00	76.40	72.83	3.60	48.46	13.48	37.10	8.20	16.60
	April	316.80	115.70	171.90	28.60	77.60	51.80	82.48	111.68	239.90	34.50	120.20
	May	373.70	189.00	320.80	225.80	119.79	118.20	196.15	75.50	181.00	112.20	107.00
	Jun	299.56	410.60	410.70	142.70	220.89	208.90	245.80	3.30	4.70	321.40	161.90
	July	268.70	222.30	329.00	263.10	522.16	270.50	346.19	231.80	256.80	370.50	302.05
	Aug	371.20	476.50	431.90	607.10	503.17	331.80	468.49	170.50	155.30	290.90	217.10
	Sep	231.90	201.60	332.20	593.80	261.77	314.50	375.57	67.60	226.60	167.60	255.50
	Oct	197.00	266.40	176.30	296.20	157.30	312.70	235.62	40.60	41.80	96.50	97.40
	Nov	14.90	3.50	38.20	58.80	10.91	141.00	62.23	0.00	0.00	31.80	10.20
	Dec	0.00	0.00	0.00	7.40	0.00	24.00	7.85	0.00	7.60	0.00	0.00
1994	Jan	22.20	15.60	0.00	3.70	3.15	0.00	1.71	0.00	0.00	0.00	0.47
	Feb	5.20	0.00	1.91	0.00	4.33	4.30	2.63	0.00	0.00	0.00	0.20
	Mar	43.30	21.50	26.51	0.00	26.56	3.90	14.24	78.60	53.90	0.00	36.07
	April	117.80	81.40	102.50	80.00	39.80	4.70	56.75	32.70	51.00	13.70	24.50
	May	199.40	191.00	576.20	5.40	195.30	78.70	213.90	9.30	86.00	154.70	54.80
	Jun	271.54	184.30	241.66	63.70	272.94	321.00	224.83	27.60	30.70	207.20	221.75
	July	377.50	273.00	285.50	154.90	345.10	412.70	299.55	299.60	436.60	290.70	232.25
	Aug	265.40	404.70	360.90	356.40	475.30	402.70	398.83	312.30	331.60	304.60	268.70
	Sep	0.00	285.90	265.70	271.60	166.70	422.60	281.65	83.70	154.40	305.40	162.15

	Oct	159.90	36.20	56.80	136.00	48.60	191.10	108.13	3.00	2.20	77.90	23.55
	Nov	0.00	54.60	57.30	0.00	64.60	8.90	32.70	8.70	36.80	48.90	14.00
	Dec	0.00	0.00	0.00	6.00	14.80	80.20	25.25	0.00	1.90	0.00	7.85
1995	**Jan**	4.37	1.50	0.00	0.00	0.00	14.70	3.68	0.00	0.00	0.00	0.00
	Feb	21.11	3.00	0.00	0.00	0.00	0.00	0.00	13.90	29.50	0.00	0.00
	Mar	113.03	187.60	13.40	32.50	91.08	0.00	34.25	29.00	48.00	35.30	40.45
	April	123.74	89.60	125.20	62.90	77.71	22.60	72.10	75.20	209.00	14.80	58.45
	May	192.70	157.40	161.20	136.80	256.91	190.30	186.30	26.50	79.40	92.70	99.80
	Jun	292.11	298.80	349.20	79.20	274.25	254.60	239.31	30.60	30.00	412.90	161.40
	July	253.70	321.80	245.50	29.50	325.00	225.50	206.38	348.20	284.20	233.30	265.25
	Aug	342.50	309.70	413.90	317.40	395.46	272.50	349.82	235.30	260.50	433.60	282.50
	Sep	291.80	331.80	248.40	196.90	315.07	321.10	270.37	63.40	80.50	248.10	106.75
	Oct	81.00	69.50	58.60	145.00	71.45	398.10	168.29	8.60	30.30	91.60	23.90
	Nov	4.50	9.10	3.10	0.00	23.92	43.30	17.58	0.00	0.00	0.00	3.65
	Dec	62.50	26.60	1.60	1.62	33.03	20.30	14.14	23.80	44.60	1.40	8.10
1996	**Jan**	59.30	100.80	8.90	41.00	45.50	17.40	28.20	53.40	48.40	0.20	0.00
	Feb	22.90	2.10	0.00	35.90	5.31	0.00	10.30	0.00	3.40	0.00	3.55
	Mar	150.90	158.90	61.30	2.90	119.53	2.30	46.51	127.40	139.70	42.50	25.65
	April	117.40	117.80	106.26	113.50	116.25	136.50	118.13	4.30	133.40	57.10	48.15
	May	214.10	288.80	298.50	106.10	310.78	79.00	198.60	75.60	124.80	98.80	91.05
	Jun	269.50	256.10	292.30	95.70	277.87	240.80	226.67	91.90	61.80	206.90	245.70
	July	342.90	271.70	474.40	206.10	540.10	370.50	397.78	294.60	164.40	370.50	229.95
	Aug	290.90	264.70	270.90	187.20	461.70	416.80	334.15	306.40	346.90	532.70	224.40
	Sep	236.80	238.50	276.60	353.70	223.40	229.30	270.75	37.00	37.30	272.20	132.50
	Oct	87.50	113.30	70.80	122.30	82.90	311.90	146.98	2.30	8.30	144.70	28.35
	Nov	38.90	19.40	20.20	12.70	93.00	112.40	59.58	21.30	57.20	12.30	34.80
	Dec	5.70	16.70	0.00	9.60	5.60	31.40	11.65	0.00	1.90	0.00	0.00
1997	**Jan**	69.50	8.30	0.00	2.10	16.00	5.20	5.83	41.50	33.60	0.00	0.00
	Feb	1.30	0.18	0.00	41.90	0.80	4.50	11.80	0.00	0.00	0.00	0.25

	Mar	53.10	76.00	13.00	0.00	79.90	0.00	23.23	9.60	64.00	2.10	13.15
	April	174.60	101.10	68.20	80.50	44.70	62.00	63.85	38.20	69.00	31.20	63.85
	May	251.90	220.70	224.50	34.80	288.40	106.50	163.55	14.20	13.60	147.40	165.55
	Jun	308.80	154.80	233.10	37.40	221.40	302.20	198.53	100.70	104.20	180.40	200.45
	July	224.60	165.20	295.40	81.00	461.30	263.20	275.23	269.40	234.80	330.80	221.05
	Aug	319.40	279.30	336.70	316.30	319.30	320.70	323.25	180.53	216.30	383.30	212.70
	Sep	240.60	112.10	204.70	196.00	172.30	364.70	234.43	30.70	52.00	175.70	130.80
	Oct	282.90	29.40	325.40	72.10	358.10	345.70	275.33	55.90	154.60	170.00	184.40
	Nov	43.10	77.30	58.20	75.60	187.60	279.00	150.10	23.40	87.00	16.90	44.10
	Dec	1.50	2.81	0.00	29.30	10.00	69.40	27.18	1.00	0.00	1.40	0.00
1998	Jan	8.70	11.40	0.00	4.60	13.10	1.10	4.70	26.90	95.40	0.00	0.00
	Feb	25.50	3.10	0.00	17.80	3.90	12.90	8.65	23.00	91.50	0.00	0.00
	Mar	102.90	88.80	8.50	25.70	56.70	0.30	22.80	48.70	36.30	9.80	17.15
	April	67.30	28.50	54.90	36.20	21.20	71.70	46.00	73.40	124.60	9.60	9.25
	May	161.40	275.00	186.10	36.70	204.70	24.60	113.03	51.30	49.20	153.60	83.55
	Jun	320.50	337.60	316.90	99.50	171.00	306.20	223.40	12.90	2.90	511.30	216.50
	July	272.90	334.10	308.50	128.20	403.10	306.20	286.50	448.20	480.20	384.80	281.20
	Aug	400.20	294.80	324.30	228.90	568.80	382.40	376.10	296.60	248.20	366.60	332.70
	Sep	265.40	180.60	332.40	243.70	251.00	367.80	298.73	54.70	114.50	243.00	113.10
	Oct	303.70	282.60	209.40	78.80	192.20	305.30	196.43	14.50	76.50	146.70	86.60
	Nov	38.10	0.00	18.00	65.80	56.70	265.10	101.40	0.00	0.00	5.60	1.40
	Dec	0.00	5.19	5.61	16.30	0.00	38.40	15.08	0.00	0.00	0.00	0.00
1999	Jan	31.82	20.80	13.40	0.00	41.70	0.00	13.78	18.50	54.40	2.20	8.70
	Feb	0.00	4.50	0.00	0.00	0.00	17.00	4.25	0.00	3.80	0.00	0.00
	Mar	6.40	2.40	0.00	0.00	3.40	0.50	0.98	21.70	22.70	0.00	0.00
	April	121.00	57.90	81.30	27.00	27.30	0.00	33.90	15.30	19.00	35.50	28.50
	May	360.50	335.20	382.70	10.00	163.20	96.90	163.20	22.30	5.40	180.70	108.75
	Jun	284.20	328.50	346.30	26.20	318.50	249.70	235.18	30.50	10.80	280.90	182.95
	July	306.50	257.10	234.90	175.70	453.50	265.20	282.33	445.30	374.30	285.70	343.25

	Aug	283.80	264.90	299.30	328.70	513.40	317.70	364.78	279.00	328.40	359.20	276.25
	Sep	417.60	191.90	272.00	142.30	203.60	332.90	237.70	48.60	109.10	223.60	161.83
	Oct	267.60	460.20	223.90	43.30	327.10	250.40	211.18	72.00	121.80	134.60	152.60
	Nov	0.40	15.80	18.10	60.30	30.70	353.10	115.55	0.00	1.70	19.20	5.20
	Dec	29.20	37.60	6.30	0.00	50.90	5.00	15.55	1.20	2.00	4.30	3.55
2000	**Jan**	0.90	0.00	0.00	6.50	0.10	21.40	7.00	0.00	0.00	0.00	0.00
	Feb	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Mar	4.60	14.80	0.00	0.00	16.70	0.00	4.18	11.00	6.20	2.10	2.10
	April	125.30	160.90	125.70	10.00	154.20	1.30	72.80	96.00	132.80	61.20	76.15
	May	262.20	188.40	330.10	36.80	61.70	112.90	135.38	18.50	70.80	188.70	74.60
	Jun	406.70	307.90	463.30	4.20	258.60	221.60	236.93	32.90	42.30	264.80	186.45
	July	231.80	221.50	256.10	29.50	424.00	265.90	243.88	337.60	326.60	200.90	279.10
	Aug	348.50	237.00	326.70	167.80	456.00	343.00	323.38	289.50	359.30	365.30	227.80
	Sep	336.00	432.00	366.60	367.00	397.30	252.70	345.90	77.00	119.30	176.70	155.75
	Oct	142.00	216.00	225.70	243.00	191.10	314.40	243.55	10.80	57.40	223.80	161.25
	Nov	31.85	29.60	34.70	36.80	76.70	197.60	86.45	13.40	58.50	23.50	31.05
	Dec	2.80	17.50	0.00	15.20	27.70	36.50	19.85	9.30	38.30	2.00	0.00
2001	**Jan**	0.00	0.50	0.00	4.00	0.00	18.80	5.70	0.00	5.10	0.70	0.00
	Feb	48.80	23.70	0.00	0.93	30.30	0.00	7.81	19.10	2.70	0.00	3.95
	Mar	77.30	63.20	8.10	14.20	51.70	17.40	22.85	146.20	139.90	0.00	1.30
	April	81.50	81.60	37.10	95.80	36.60	60.70	57.55	32.30	33.30	0.00	22.85
	May	333.40	256.90	176.90	26.21	128.10	29.80	90.25	54.40	42.90	100.30	92.30
	Jun	396.40	311.10	251.10	110.03	284.50	257.00	225.66	14.70	46.80	290.30	253.50
	July	291.80	250.60	358.50	130.07	565.80	358.20	353.14	449.10	349.40	417.40	307.65
	Aug	303.60	272.90	303.10	348.50	485.10	273.10	352.45	286.80	235.40	503.50	254.50
	Sep	286.70	230.60	230.00	169.00	213.80	290.80	225.90	34.60	115.30	247.60	83.50
	Oct	177.00	174.90	96.70	76.80	182.30	215.30	142.78	4.40	7.10	167.50	93.95
	Nov	19.80	11.00	12.00	2.00	35.70	153.00	50.68	0.00	0.80	0.00	2.85
	Dec	23.80	53.00	17.30	5.80	31.90	9.50	16.13	3.40	8.90	6.40	0.50

2002	**Jan**	14.10	16.00	14.00	13.50	32.00	15.20	18.68	37.30	18.10	0.00	0.00
	Feb	6.30	1.40	0.00	43.00	8.80	18.30	17.53	27.10	5.80	0.00	1.75
	Mar	73.40	39.20	15.20	6.70	82.20	12.60	29.18	98.60	58.90	0.00	5.05
	April	88.00	62.20	53.10	52.10	79.90	71.58	64.17	27.30	82.10	0.00	10.15
	May	116.60	160.90	110.20	25.30	43.90	58.18	59.39	11.80	20.70	0.00	58.20
	Jun	308.90	172.60	359.80	19.00	300.10	61.83	185.18	7.60	10.60	344.80	166.55
	July	365.90	272.60	451.60	92.50	376.60	378.60	324.83	266.40	278.50	283.30	220.60
	Aug	286.00	180.00	285.80	215.10	419.50	328.10	312.13	229.60	254.80	355.80	265.15
	Sep	259.60	205.90	466.80	269.30	209.10	235.20	295.10	33.30	86.80	190.00	178.95
	Oct	108.20	43.40	108.50	140.80	114.50	214.60	144.60	5.80	15.40	139.70	59.05
	Nov	3.00	7.30	0.00	0.00	32.20	62.00	23.55	0.00	0.00	39.50	4.45
	Dec	60.10	39.90	2.10	0.67	82.40	7.70	23.22	22.20	62.20	0.00	0.00
2003	**Jan**	20.50	0.00	0.00	38.60	0.00	41.40	20.00	23.90	64.70	15.50	0.00
	Feb	53.10	83.60	40.00	12.00	46.60	0.00	24.65	32.30	26.00	0.00	6.65
	Mar	116.10	59.30	64.10	62.00	45.40	35.80	51.83	43.60	75.00	0.00	2.05
	April	104.30	85.40	14.00	147.30	17.00	38.10	54.10	60.90	80.90	0.00	2.70
	May	38.40	52.07	123.10	63.70	21.60	27.00	58.85	6.60	5.80	3.00	18.25
	Jun	349.60	249.50	260.00	0.00	245.50	16.10	130.40	73.80	38.10	287.20	154.10
	July	242.60	238.10	449.20	98.80	386.00	348.60	320.65	322.40	208.90	402.30	235.55
	Aug	207.40	169.60	241.70	279.80	366.30	279.00	291.70	247.50	269.40	304.30	240.00
	Sep	287.60	219.20	263.00	351.30	274.40	326.48	303.79	84.10	149.30	310.30	202.05
	Oct	33.00	19.10	34.10	121.80	44.60	418.70	154.80	0.10	0.20	97.30	46.20
	Nov	14.80	13.20	48.40	0.00	10.20	42.90	25.38	5.40	12.90	5.90	3.85
	Dec	5.10	6.50	4.00	2.00	5.20	37.80	12.25	8.90	60.20	17.11	9.65
2004	**Jan**	5.00	4.90	8.00	11.00	0.00	5.70	6.18	37.10	12.60	0.00	0.00
	Feb	3.30	1.40	6.10	20.80	13.20	5.50	11.40	22.50	11.70	0.60	0.10
	Mar	27.50	18.90	0.40	21.60	52.30	31.90	26.55	75.50	39.70	0.10	5.50
	April	54.80	60.70	50.20	22.70	119.90	16.10	52.23	94.10	127.50	83.00	38.95
	May	237.30	204.50	166.90	74.60	9.40	45.00	73.98	6.00	14.80	45.00	17.75

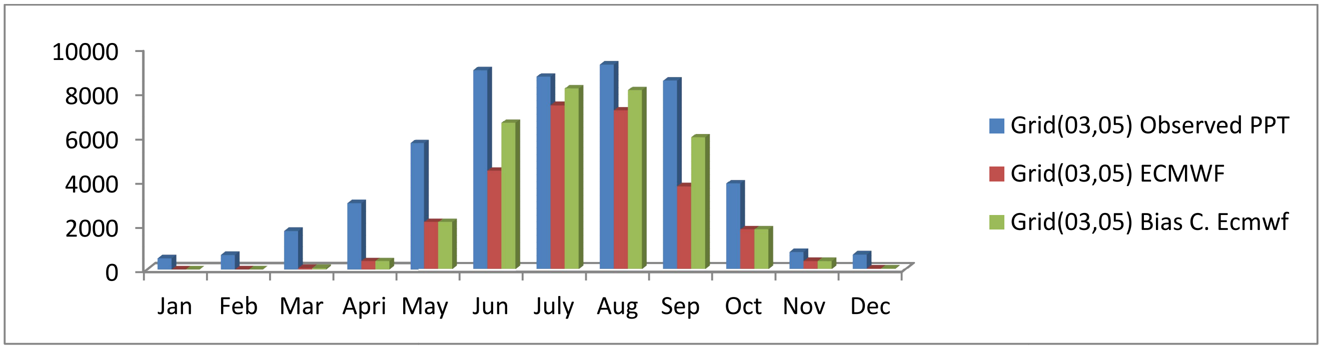
	Jun	449.30	325.20	337.30	15.00	199.30	82.90	158.63	59.70	28.00	264.40	153.90
	July	319.00	299.80	418.60	160.44	416.70	505.80	375.39	240.20	239.60	409.00	291.45
	Aug	327.00	298.20	453.40	291.98	331.20	375.70	363.07	244.90	239.40	455.30	221.20
	Sep	349.40	287.20	313.80	260.19	264.80	264.50	275.82	62.80	82.50	293.20	105.15
	Oct	132.20	188.20	122.30	138.86	138.90	333.90	183.49	9.30	66.80	69.70	82.40
	Nov	41.80	60.70	12.50	51.16	28.80	100.90	48.34	7.30	40.10	15.10	6.05
	Dec	7.70	3.70	0.00	6.96	28.80	68.20	25.99	7.40	5.50	4.00	0.00
2005	**Jan**	12.00	12.50	11.70	2.68	17.80	4.00	9.04	54.40	18.70	0.00	0.00
	Feb	3.40	0.00	0.00	30.30	0.50	0.70	7.88	1.00	4.50	0.00	4.05
	Mar	76.80	102.50	67.00	0.00	76.00	0.00	35.75	63.90	75.80	18.10	26.40
	April	106.60	60.50	11.00	69.60	25.20	139.90	61.43	97.10	67.00	3.00	17.20
	May	124.70	169.50	127.30	105.20	38.50	22.50	73.38	108.60	86.40	43.80	39.10
	Jun	318.50	348.20	422.10	47.20	234.60	131.60	208.88	54.50	20.90	166.00	256.30
	July	275.10	343.90	311.00	106.10	474.90	349.10	310.28	243.20	342.70	369.20	232.05
	Aug	405.80	258.90	366.80	247.70	357.90	314.20	321.65	198.30	293.90	361.50	186.00
	Sep	365.00	270.70	331.40	245.00	257.80	373.70	301.98	67.40	40.80	250.70	143.50
	Oct	106.90	92.70	143.10	105.10	67.20	361.20	169.15	3.70	17.70	153.90	31.25
	Nov	25.50	118.20	3.70	23.10	107.90	62.35	49.26	1.40	6.70	3.20	5.45
	Dec	4.90	0.00	0.00	0.00	7.60	41.80	12.35	0.00	0.00	0.00	0.00
2006	**Jan**	0.00	1.88	0.00	3.20	2.70	0.00	1.48	24.50	8.80	9.20	1.30
	Feb	1.40	10.80	0.00	2.90	4.00	10.70	4.40	9.00	0.00	11.20	0.65
	Mar	57.30	50.00	0.00	18.50	73.70	0.00	23.05	157.10	121.80	0.00	1.15
	April	21.90	193.68	2.40	129.90	57.90	13.50	50.93	32.30	87.10	18.00	14.25
	May	265.70	179.30	312.10	62.90	311.40	23.20	177.40	18.60	44.30	152.70	179.43
	Jun	370.70	285.40	353.40	84.60	206.40	220.50	216.23	24.30	14.70	226.60	151.35
	July	341.90	412.40	462.40	63.30	600.10	386.00	377.95	319.60	333.10	401.90	299.60
	Aug	231.30	311.60	442.70	384.40	492.70	373.70	423.38	358.20	277.20	660.20	272.95
	Sep	447.90	308.90	302.60	390.00	258.20	297.00	311.95	58.50	140.30	263.40	208.60
	Oct	86.70	166.30	174.80	148.60	133.20	139.40	149.00	10.90	61.90	192.30	123.10

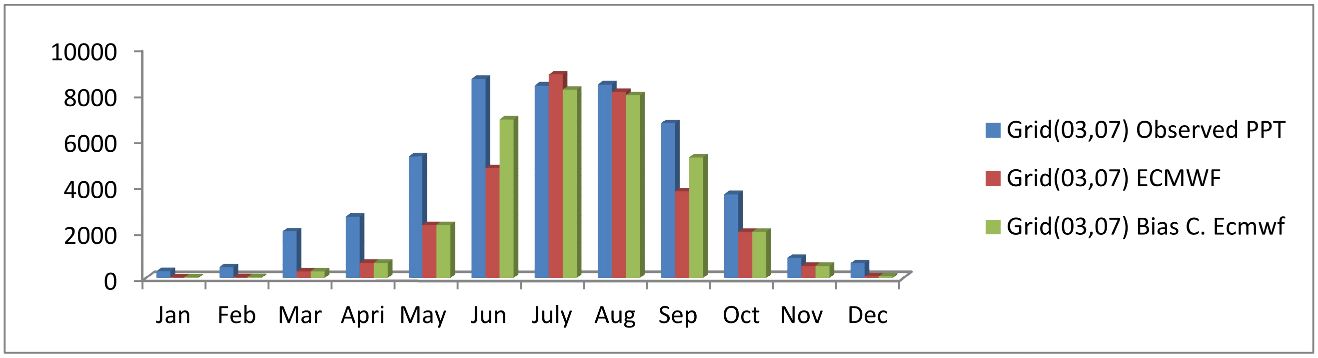
	Nov	51.80	14.60	5.30	11.20	52.20	95.70	41.10	0.00	1.20	6.20	0.00
	Dec	107.40	80.01	38.60	31.00	57.83	56.90	46.08	14.00	6.40	0.00	15.25
2007	**Jan**	13.70	8.60	0.40	17.80	22.20	27.90	17.08	25.90	40.50	0.00	0.75
	Feb	28.90	38.50	0.00	11.40	9.23	0.00	5.16	55.20	34.00	0.00	0.00
	Mar	43.50	67.40	34.70	68.30	24.20	15.10	35.58	29.10	52.30	1.90	6.60
	Apri	116.80	88.70	94.10	851.50	72.10	12.60	257.58	49.10	115.00	36.50	29.95
	May	292.90	169.50	167.60	19.80	108.70	93.90	97.50	11.50	14.90	99.80	157.25
	Jun	308.10	400.50	281.60	69.80	413.90	338.00	275.83	82.80	37.10	317.70	254.90
	July	312.70	420.50	251.30	162.96	345.20	438.10	299.39	286.70	320.70	348.70	233.05
	Aug	237.80	397.20	389.80	303.50	336.60	309.20	334.78	272.60	175.50	400.70	279.35
	Sep	322.30	404.20	360.80	300.00	254.80	242.60	289.55	112.80	92.30	314.40	141.00
	Oct	45.10	76.26	83.00	131.50	76.80	275.64	141.73	5.60	21.60	69.90	32.05
	Nov	27.00	3.50	35.62	26.50	39.60	97.37	49.77	5.90	6.60	27.30	28.35
	Dec	0.00	32.00	8.64	0.00	0.00	1.30	2.48	0.00	0.00	0.00	0.00
2008	**Jan**	26.90	10.95	7.00	0.00	39.30	0.00	11.58	1.90	25.50	2.20	58.80
	Feb	0.00	0.00	0.00	0.00	3.70	5.40	2.28	5.10	0.00	1.00	0.00
	Mar	0.40	356.90	0.00	0.00	2.00	0.00	0.50	0.00	0.00	0.00	0.05
	April	143.00	183.70	106.70	0.00	156.10	0.00	65.70	33.40	18.10	55.10	66.45
	May	305.27	291.40	248.30	41.40	278.80	250.80	204.83	27.00	52.70	141.50	113.15
	Jun	279.70	513.90	314.00	29.00	319.40	379.60	260.50	40.80	29.40	280.30	205.40
	July	441.71	378.48	365.10	84.20	410.80	155.30	253.85	302.80	294.90	489.50	286.15
	Aug	259.00	388.70	321.60	293.90	410.70	249.90	319.03	187.50	209.10	412.00	259.65
	Sep	162.40	191.30	235.50	288.50	192.70	240.60	239.33	85.66	68.70	232.20	139.20
	Oct	105.00	96.20	56.40	76.20	117.80	378.40	157.20	32.00	47.30	42.60	19.95
	Nov	27.20	89.20	2.60	18.00	32.50	58.70	27.95	61.80	75.60	13.00	15.00
	Dec	1.68	1.37	0.00	83.00	14.40	35.10	33.13	0.00	0.00	0.00	0.00
2009	**Jan**	30.60	5.30	5.20	12.81	4.68	16.80	9.87	17.10	23.60	0.00	0.00
	Feb	16.50	25.20	7.20	25.00	6.48	1.00	9.92	12.40	11.40	0.00	2.85
	Mar	36.64	102.10	46.60	17.80	41.94	29.40	33.94	72.80	17.00	3.20	20.40

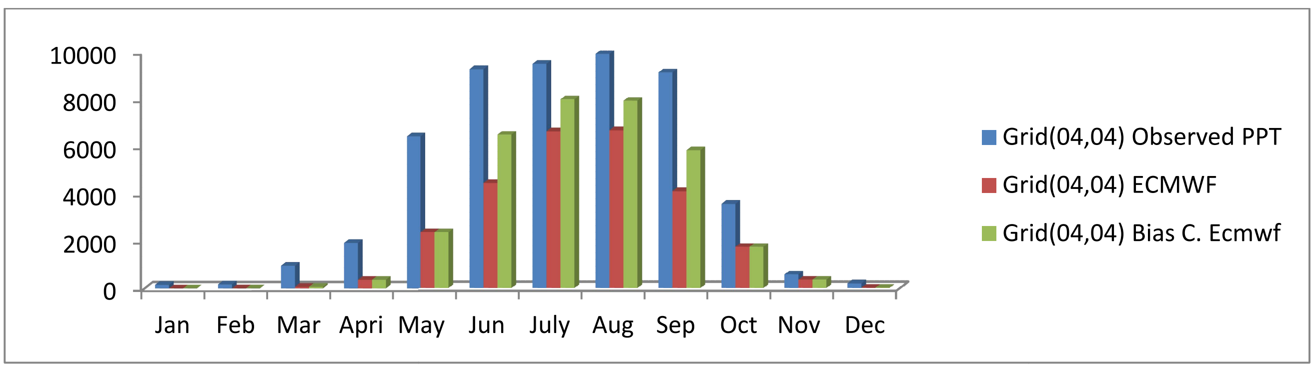
	April	251.60	282.90	18.10	84.92	16.29	18.50	34.45	8.70	13.40	22.90	43.35
	May	21.00	102.40	61.40	41.48	55.26	72.80	57.74	18.40	17.00	42.10	23.10
	Jun	333.30	215.10	299.70	19.76	269.73	24.00	153.30	58.70	34.60	305.10	194.85
	July	328.00	409.80	192.40	79.40	354.80	361.90	247.13	341.50	370.10	370.30	271.15
	Aug	417.90	515.40	324.30	328.28	291.87	290.60	308.76	245.90	320.40	218.30	300.40
	Sep	215.20	166.40	276.30	347.40	248.67	350.40	305.69	52.40	58.10	155.10	102.30
	Oct	59.40	204.00	95.30	92.12	85.77	181.90	113.77	39.20	63.20	58.90	44.25
	Nov	19.80	0.60	5.60	31.28	5.04	89.70	32.91	34.52	11.50	6.20	6.95
	Dec	43.00	43.10	23.20	1.80	20.88	2.50	12.10	5.00	31.60	0.00	30.55
2010	**Jan**	4.80	25.10	1.70	12.24	0.00	0.00	3.49	12.20	0.00	22.90	24.30
	Feb	41.90	13.90	0.40	18.00	0.00	4.70	5.78	50.20	31.60	5.20	0.00
	Mar	42.70	7.40	46.60	20.80	0.00	7.00	18.60	38.90	15.30	0.00	13.55
	April	61.90	25.60	18.10	23.60	8.00	0.00	12.43	105.80	102.70	0.00	34.20
	May	278.70	287.84	256.70	68.60	199.80	32.90	139.50	64.50	107.60	24.10	71.10
	Jun	389.30	263.12	514.90	69.40	406.50	0.00	247.70	30.70	15.90	63.20	210.30
	July	268.80	243.28	351.90	139.30	543.00	262.20	324.10	325.50	70.70	280.30	247.95
	Aug	305.60	307.60	139.00	377.40	499.50	477.40	373.33	64.50	57.90	435.10	248.40
	Sep	168.30	138.64	254.10	154.20	369.20	245.60	255.78	47.40	11.70	353.10	117.70
	Oct	156.80	30.56	100.80	103.60	66.70	280.90	138.00	6.80	15.20	242.40	49.15
	Nov	21.15	18.56	3.00	2.40	0.00	58.70	16.03	3.20	11.60	177.50	1.45
	Dec	20.11	39.04	1.10	14.58	1.40	28.10	11.30	21.70	107.60	6.40	4.85
2011	**Jan**	15.93	8.24	42.00	25.56	21.84	0.00	22.35	4.80	363.90	0.00	0.00
	Feb	26.28	22.08	2.00	4.60	1.04	16.90	6.14	6.00	15.00	0.00	0.00
	Mar	35.70	27.72	51.70	11.10	26.88	0.00	22.42	78.10	0.00	0.00	15.20
	April	141.08	45.24	77.80	59.40	40.46	64.70	60.59	45.30	50.40	7.50	12.68
	May	134.87	206.72	265.40	43.38	138.01	12.50	114.82	25.56	27.50	4.70	138.60
	Jun	282.30	291.32	403.40	114.81	209.77	318.30	261.57	12.90	130.90	180.80	145.30
	July	268.56	300.80	259.30	159.72	134.84	285.00	209.71	181.40	278.00	132.30	236.65
	Aug	325.58	263.88	418.20	226.29	217.46	189.60	262.89	292.50	338.60	237.20	278.70

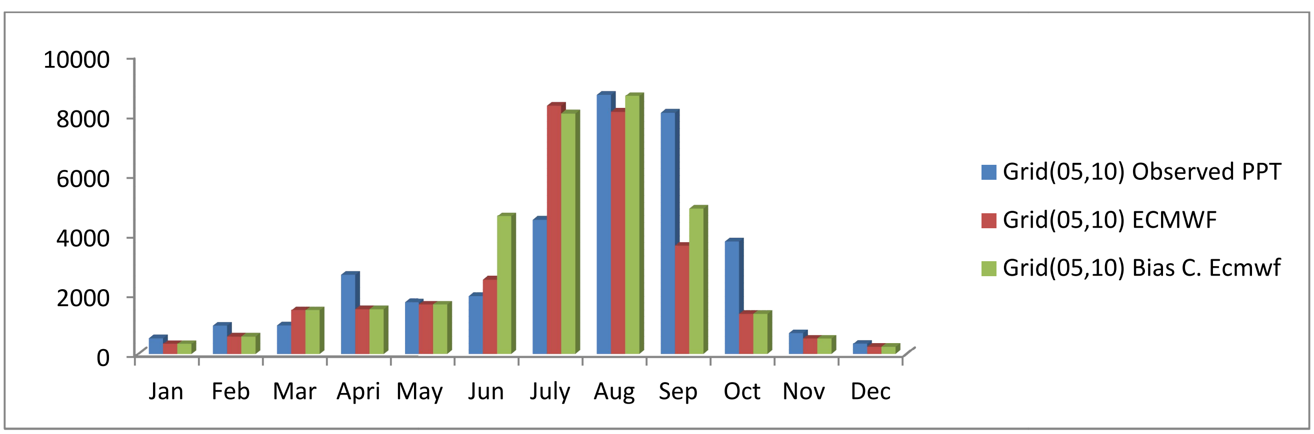
	Sep	172.58	276.56	349.40	312.81	181.69	288.20	283.02	70.60	90.50	361.60	117.10
	Oct	97.29	60.07	82.10	162.60	42.69	229.70	129.27	1.60	16.60	257.60	56.50
	Nov	18.43	19.96	57.40	2.40	29.85	34.10	30.94	4.60	41.40	80.50	26.22
	Dec	28.40	19.52	1.70	42.05	0.88	55.00	24.91	0.00	0.00	0.00	0.00
2012	**Jan**	0.00	12.42	0.00	0.00	0.00	16.80	4.20	0.00	0.30	0.00	0.75
	Feb	69.60	6.26	0.00	0.00	0.00	8.45	2.11	0.00	0.00	0.00	0.00
	Mar	33.32	47.25	26.90	0.00	13.99	1.30	10.55	54.30	109.00	0.00	5.53
	April	86.26	37.98	32.20	34.00	16.74	47.90	32.71	71.70	177.10	0.00	0.00
	May	175.77	244.86	251.90	71.80	130.99	6.55	115.31	38.60	34.00	0.20	105.45
	Jun	258.60	491.40	307.40	6.00	159.85	171.20	161.11	78.20	50.10	77.40	203.05
	July	322.42	144.90	399.80	163.59	207.90	293.40	266.17	362.00	284.00	216.20	352.75
	Aug	378.71	289.83	593.80	290.55	308.78	216.05	352.29	229.10	261.60	511.50	317.60
	Sep	348.50	254.30	314.00	307.20	118.30	308.95	262.11	18.90	52.90	591.00	121.25
	Oct	55.30	48.00	99.40	186.24	51.69	253.92	147.81	0.23	0.50	292.40	48.90
	Nov	39.80	37.40	68.80	17.28	35.78	66.92	47.19	0.00	0.00	83.10	70.45
	Dec	22.72	20.61	15.10	3.52	7.85	31.39	14.46	0.00	0.20	26.00	5.05

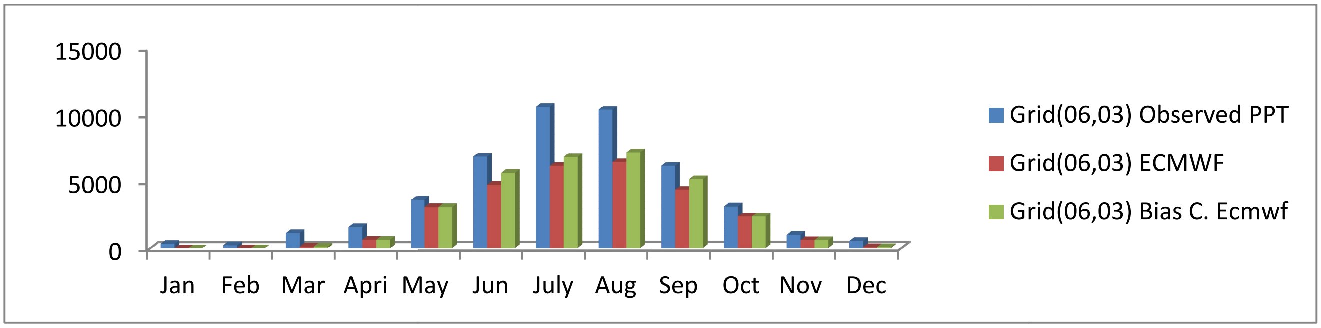
Histogram for Monthly Cycle of Datasets

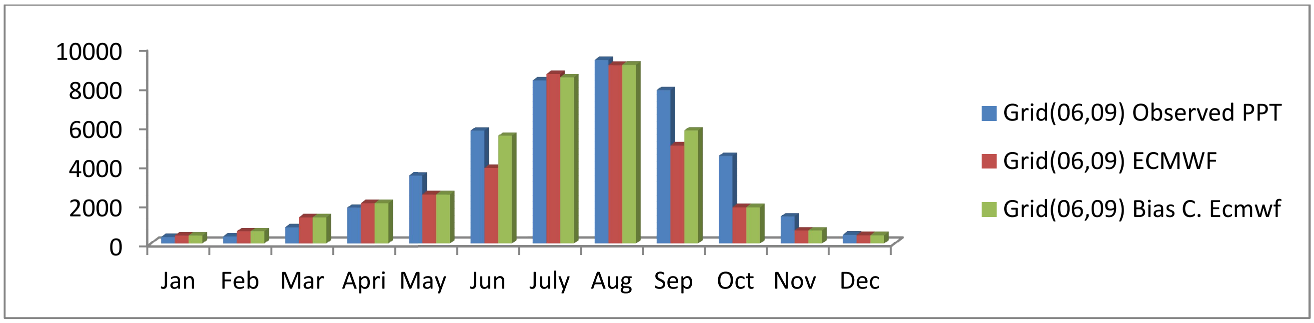


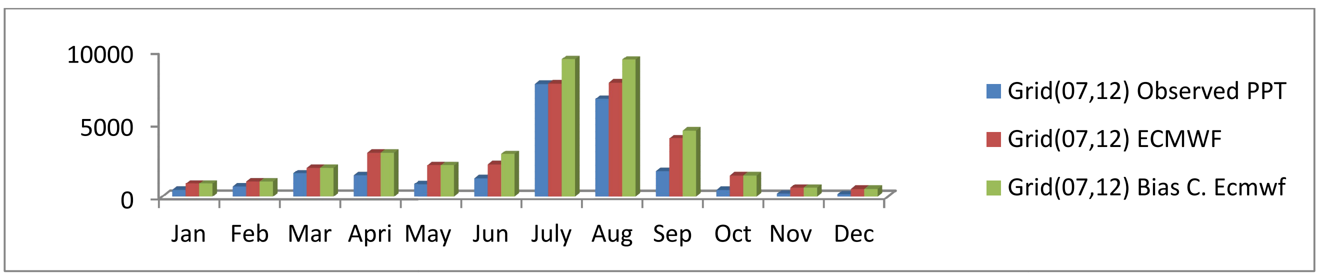


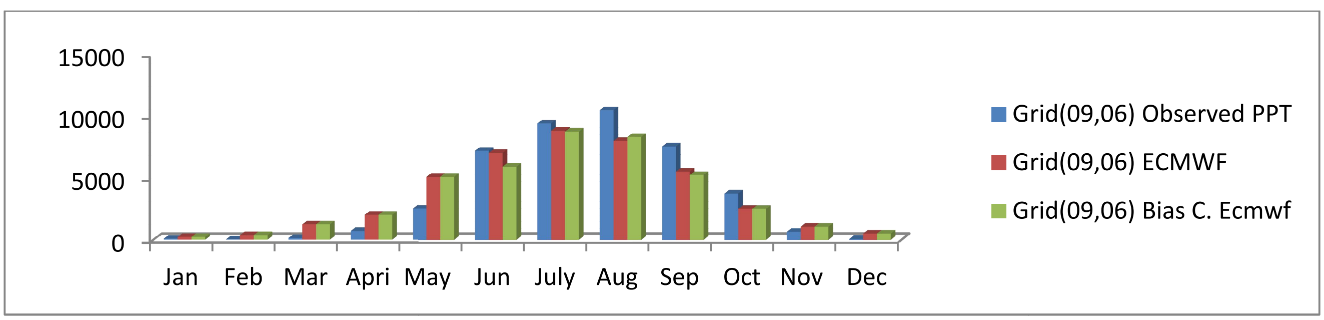


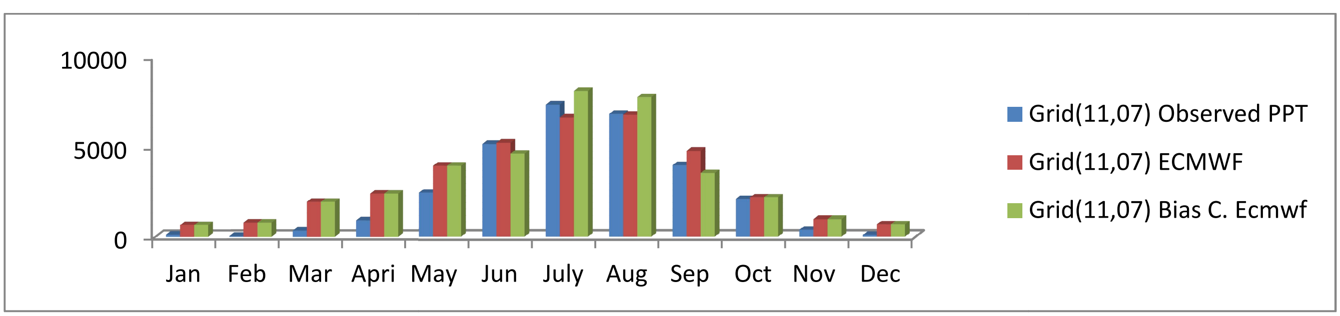



15000
10000
5000
0
Jan Feb Mar Apri May Jun July Aug Sep Oct Nov Dec
Grid(06,03) Observed PPT
Grid(06,03) ECMWF
Grid(06,03) Bias C. Ecmwf

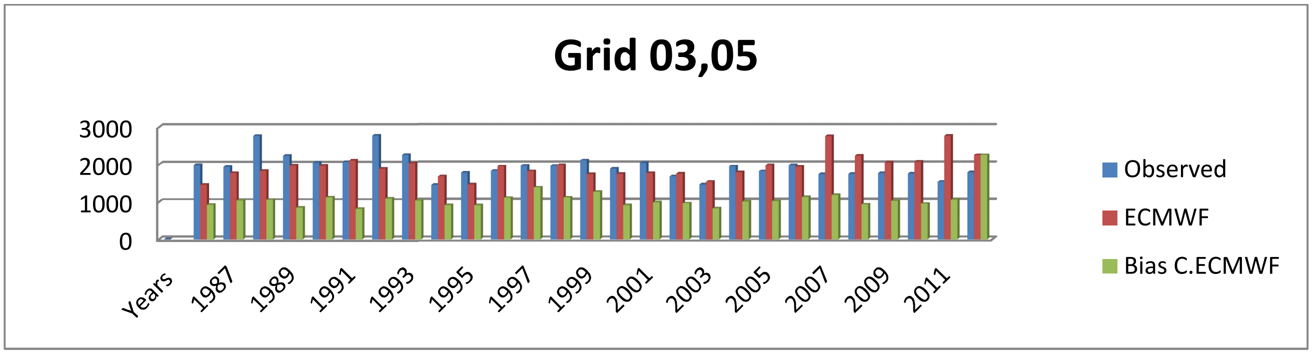

10000
8000
6000
4000
2000
0
Jan Feb Mar Apri May Jun July Aug Sep Oct Nov Dec
Grid(06,09) Observed PPT
Grid(06,09) ECMWF
Grid(06,09) Bias C. Ecmwf

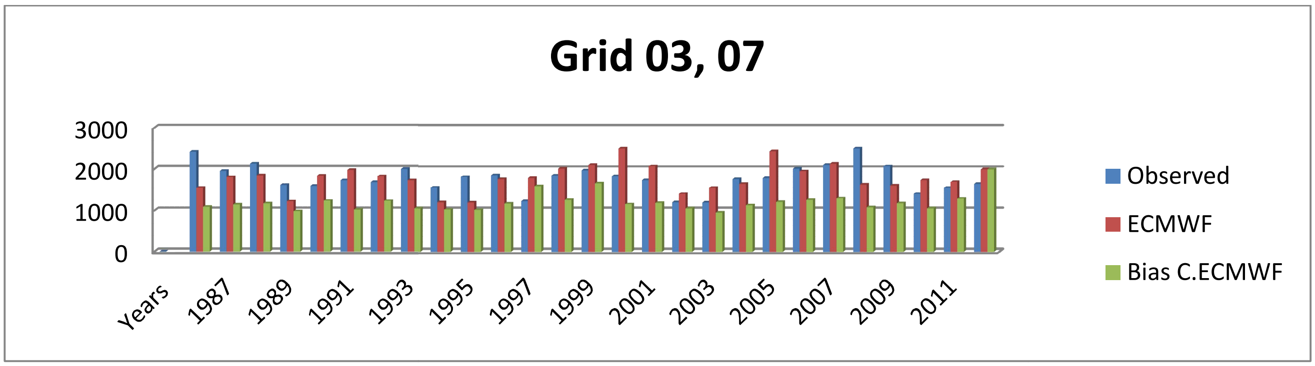

10000
5000
0
Jan Feb Mar Apri May Jun July Aug Sep Oct Nov Dec
Grid(07,12) Observed PPT
Grid(07,12) ECMWF
Grid(07,12) Bias C. Ecmwf

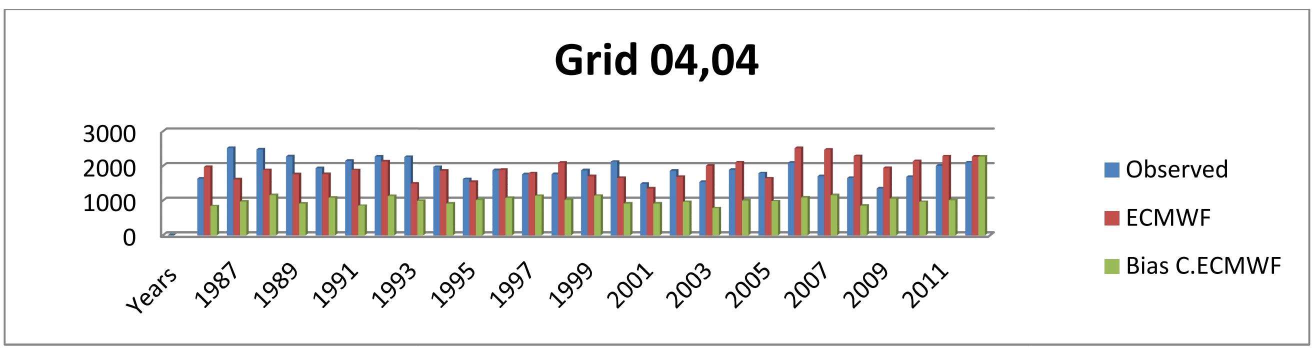

15000
10000
5000
0
Jan Feb Mar Apri May Jun July Aug Sep Oct Nov Dec
Grid(09,06) Observed PPT
Grid(09,06) ECMWF
Grid(09,06) Bias C. Ecmwf

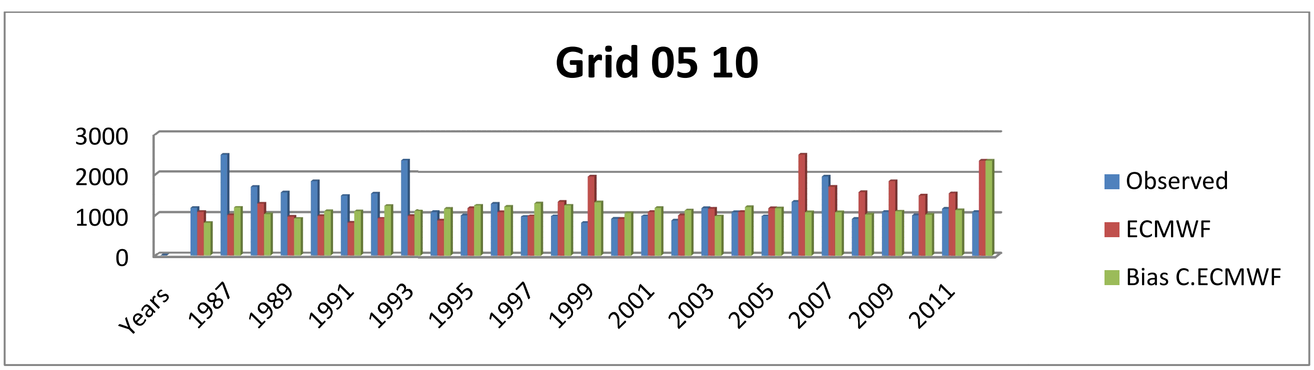

10000
5000
0
Jan Feb Mar Apri May Jun July Aug Sep Oct Nov Dec
Grid(11,07) Observed PPT
Grid(11,07) ECMWF
Grid(11,07) Bias C. Ecmwf

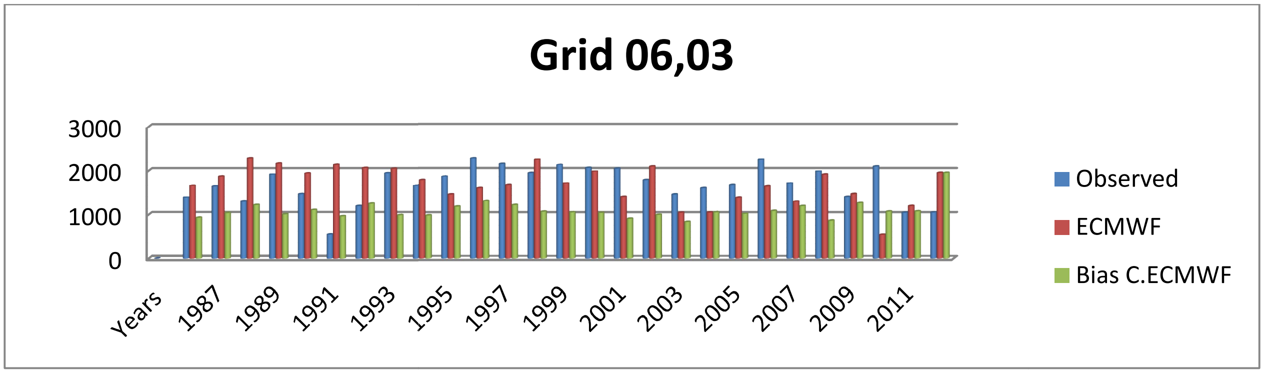
Histogram for Yearly Cycle of Datasets

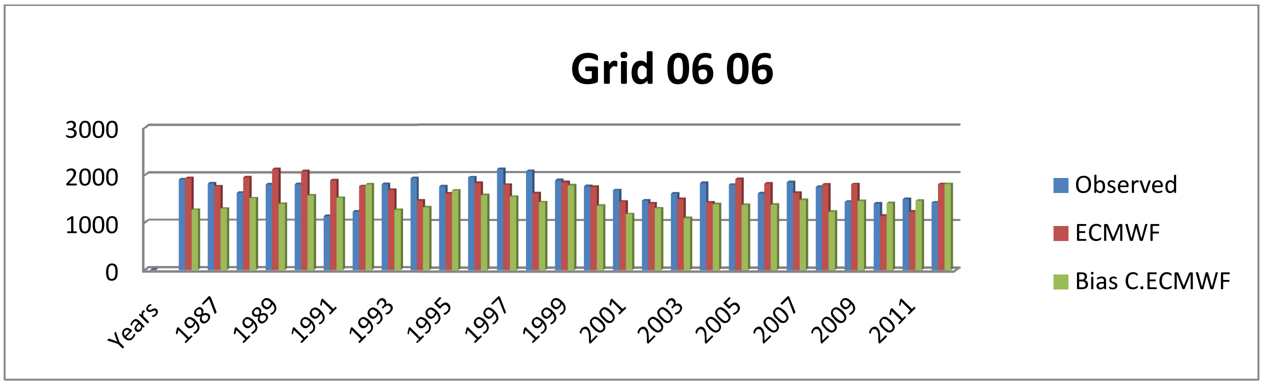


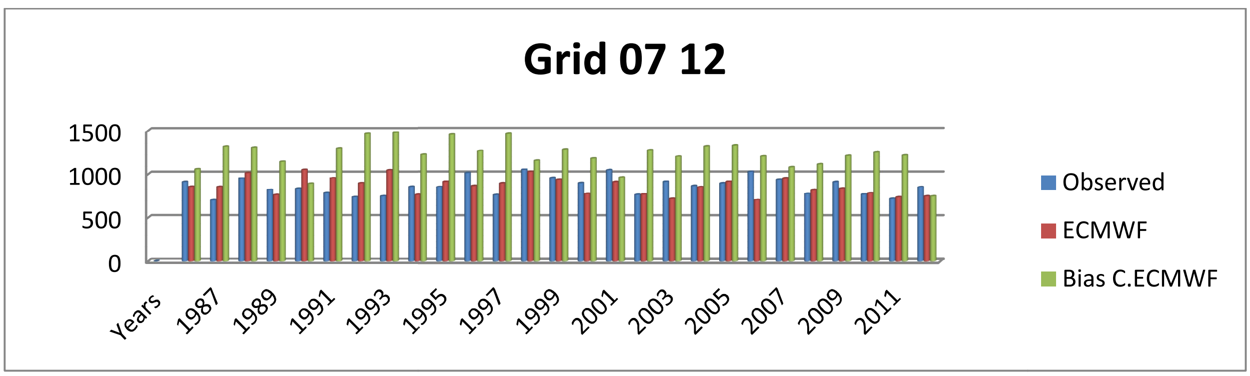


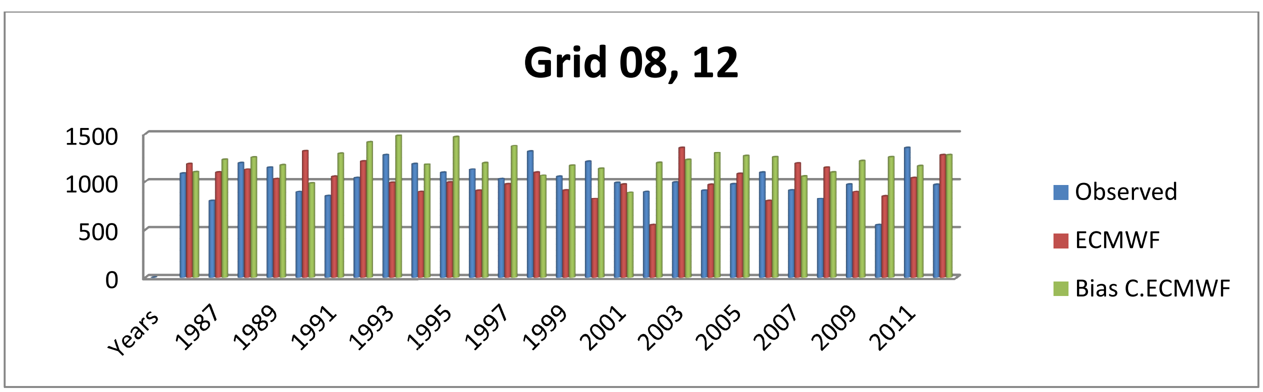


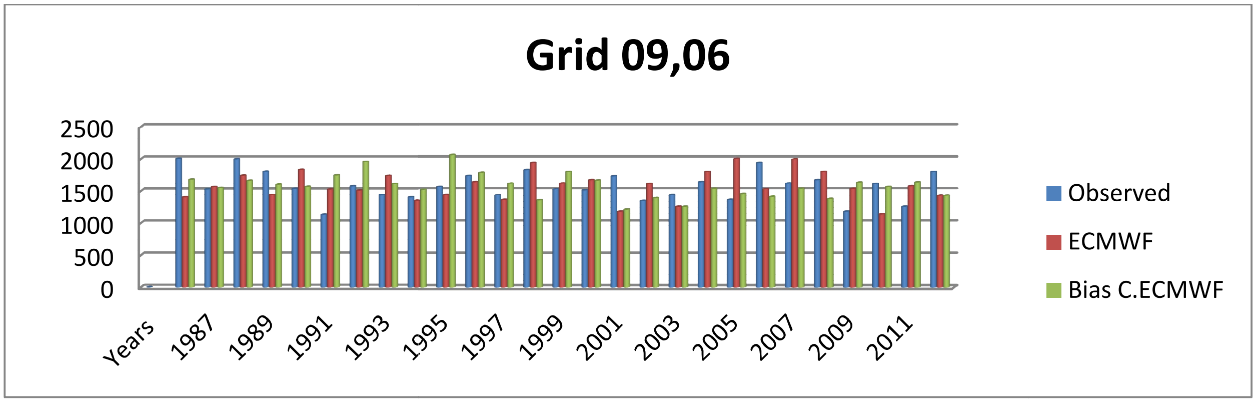


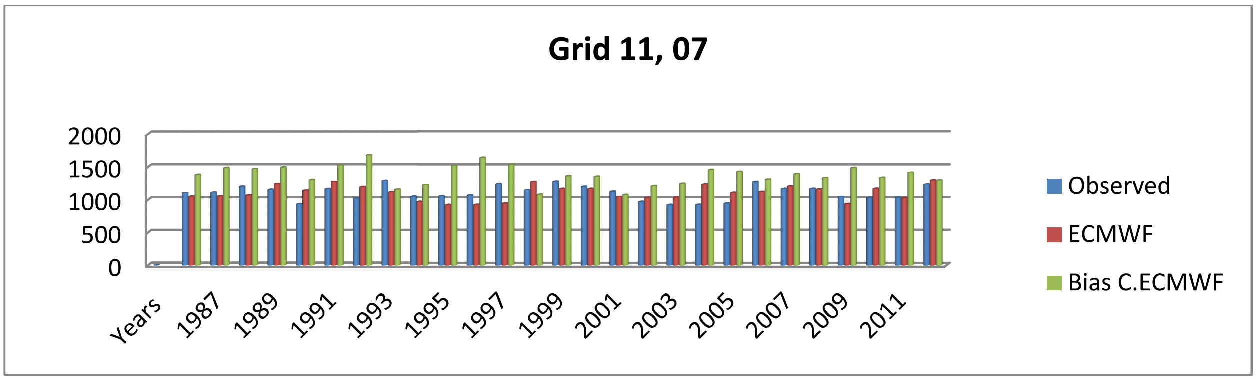

Grid 06,03
3000
2000
1000
0
Years
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Observed
ECMWF
Bias C.ECMWF


Grid 06 06
3000
2000
1000
0
Years
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Observed
ECMWF
Bias C.ECMWF

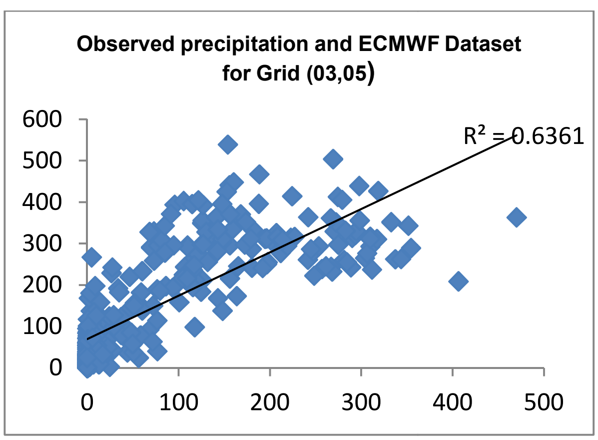

Grid 07 12
1500
1000
500
0
Years
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Observed
ECMWF
Bias C.ECMWF

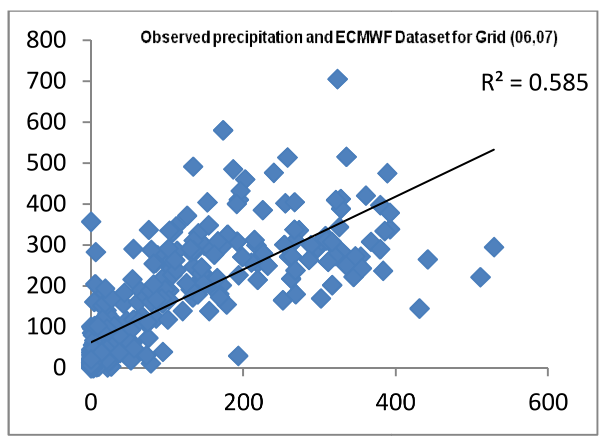

Grid 08, 12
1500
1000
500
0
Years
1987
1989
1991
1993
1995
1997
1999
2001
2003
2005
2007
2009
2011
Observed
ECMWF
Bias C.ECMWF

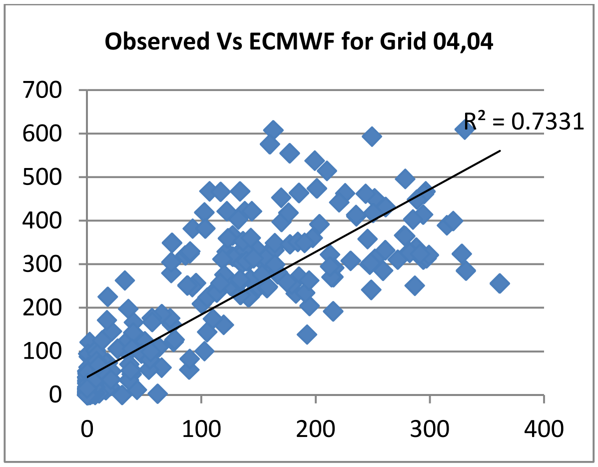


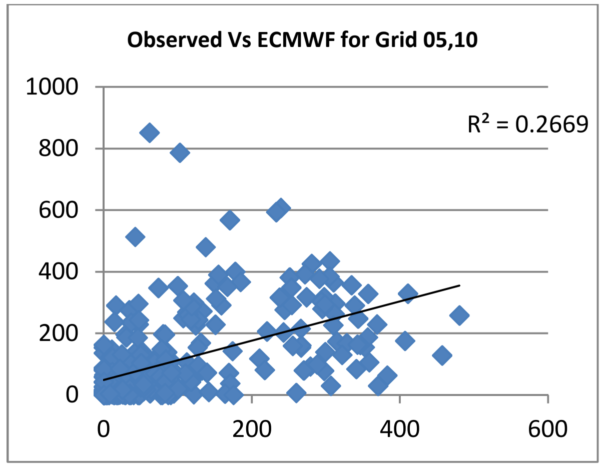


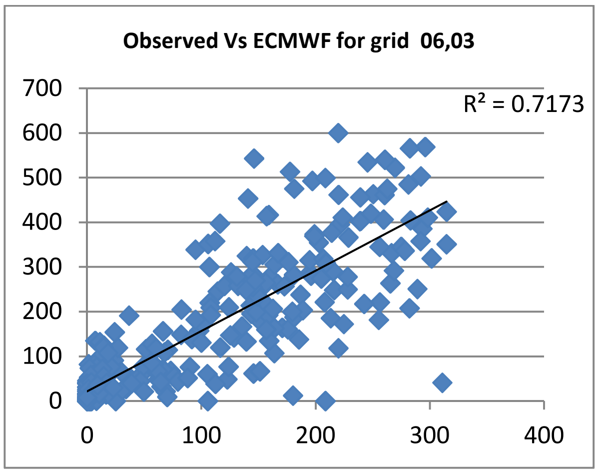
Correlation Between Datasets

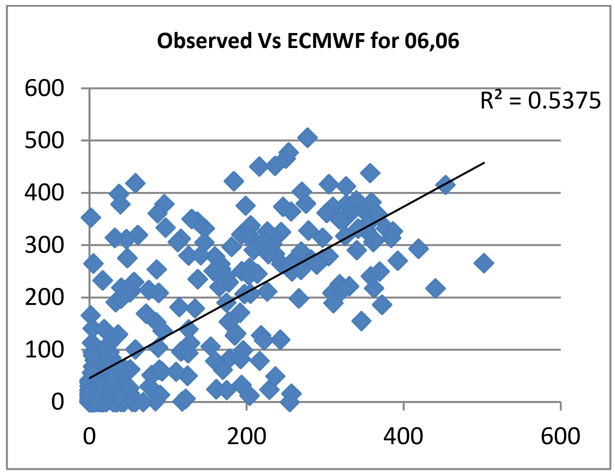


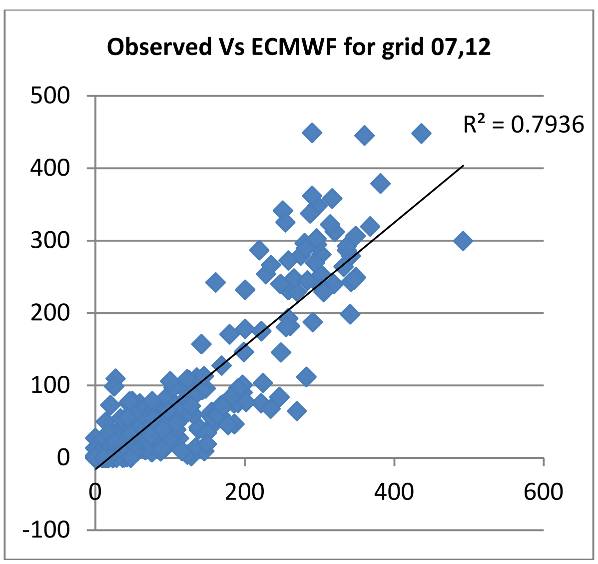


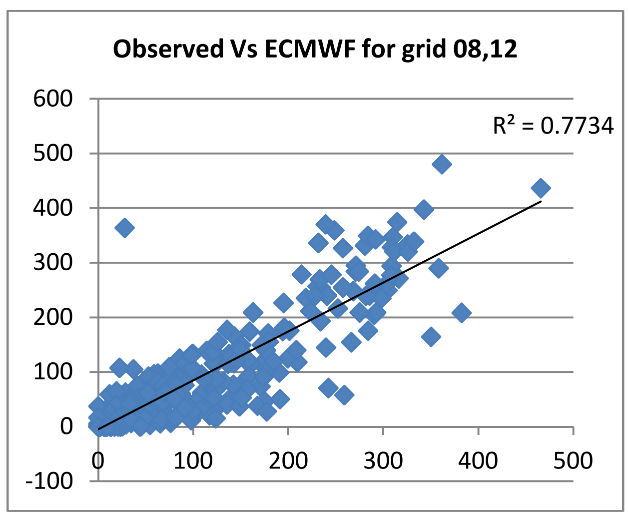

Observed Vs ECMWF for Grid 04,04
700
600
500
400
300
200
100
0
0
100
200
300
400
R² = 0.7331

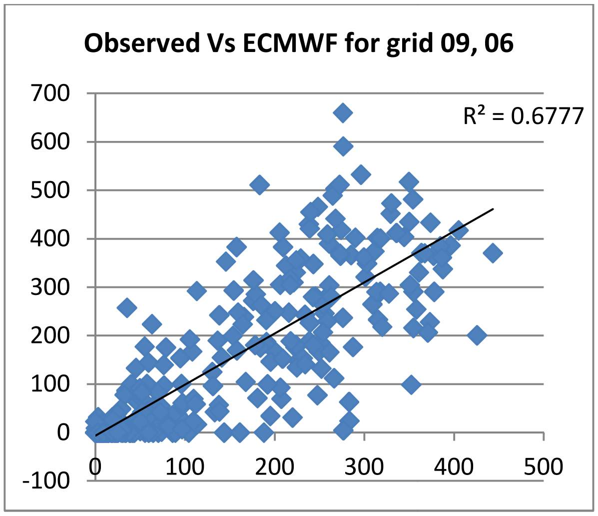

Observed Vs ECMWF for Grid 05,10
1000
800
600
400
200
0
0
200
400
600
R² = 0.2669

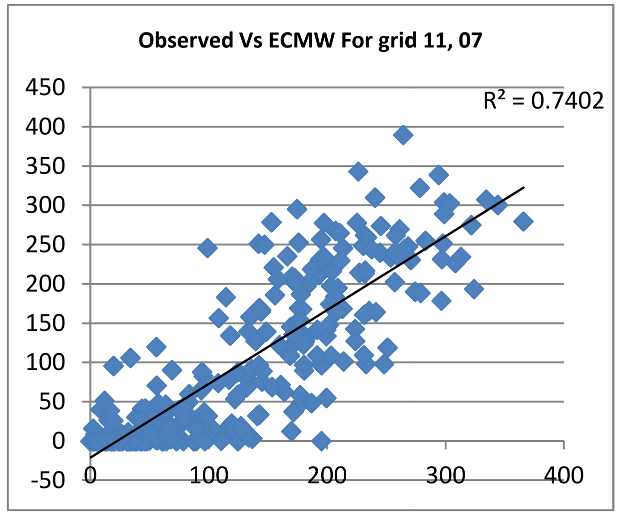

Observed Vs ECMWF for grid 06,03
700
600
500
400
300
200
100
0
0
100
200
300
400
R² = 0.7173


Observed Vs ECMWF for 06,06
600
500
400
300
200
100
0
0
200
400
600
R² = 0.5375


Observed Vs ECMWF for grid 07,12
500
400
300
200
100
0
-100
0
200
400
600
R² = 0.7936

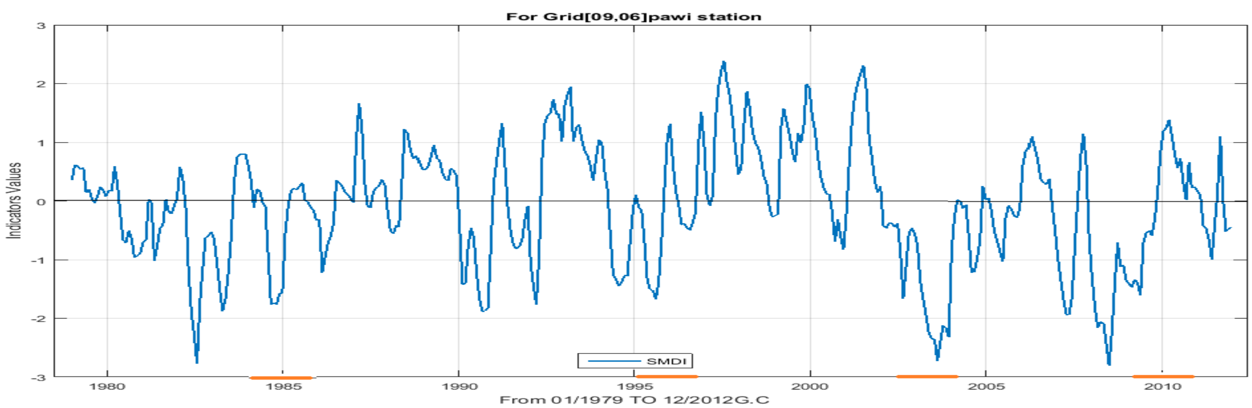

Observed Vs ECMWF for grid 08,12
600
500
400
300
200
100
0
-100
0
100
200
300
400
500
R² = 0.7734

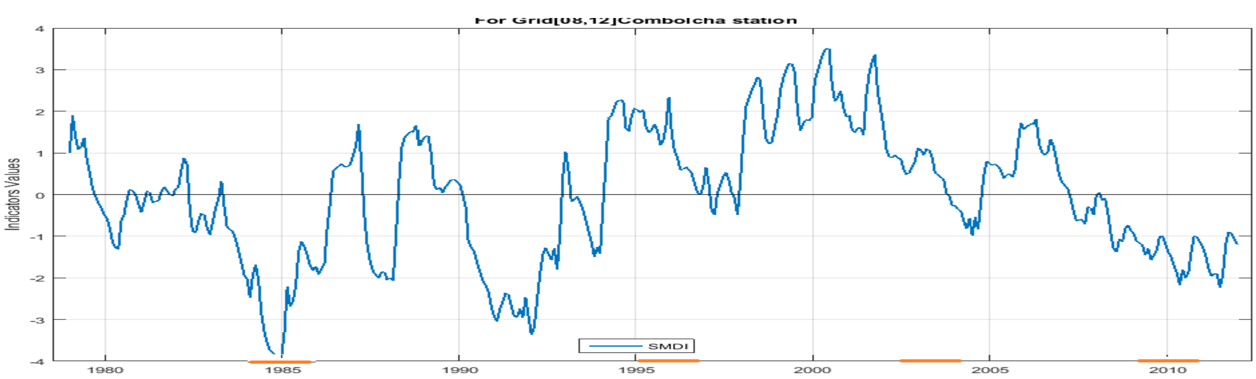


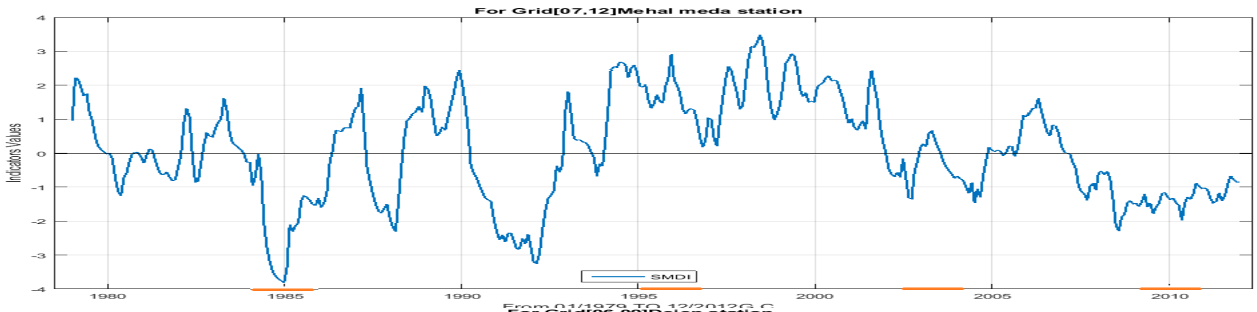


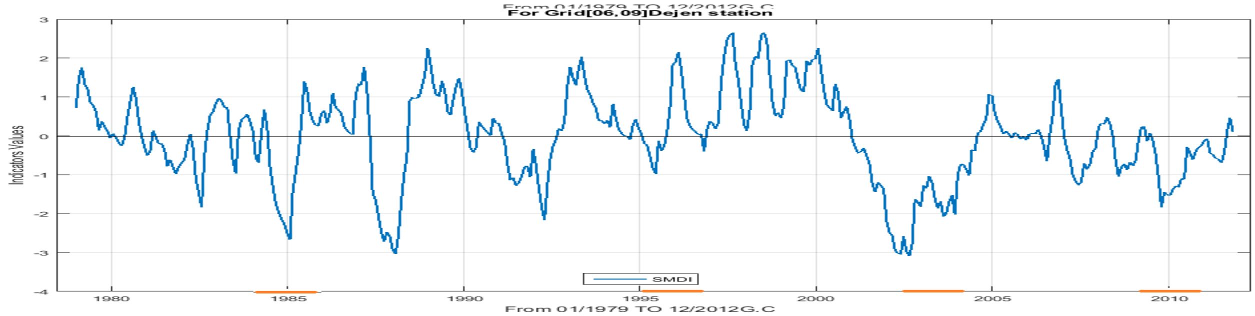
Annex B: Graph for Time Series Drought Indicator Values

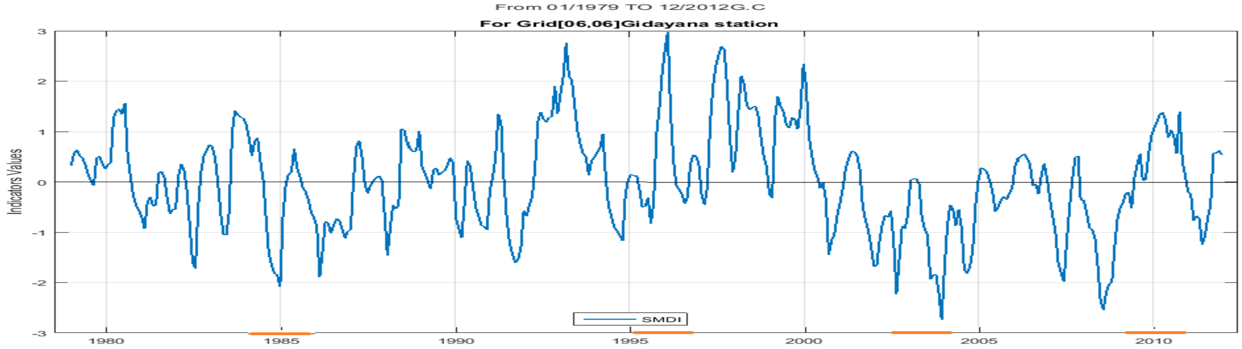
Time Series Plot for SMDI

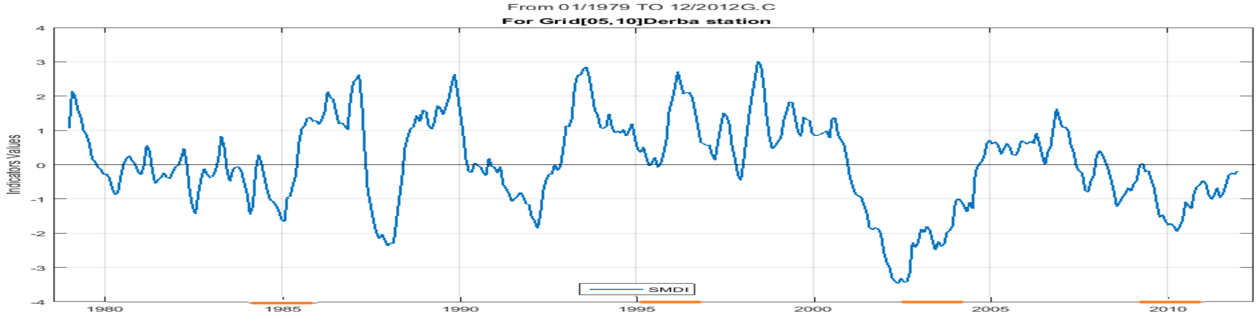


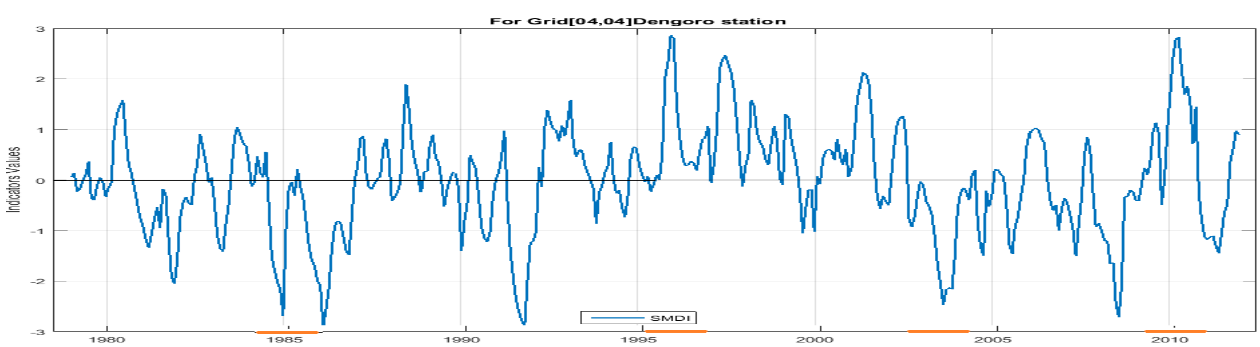


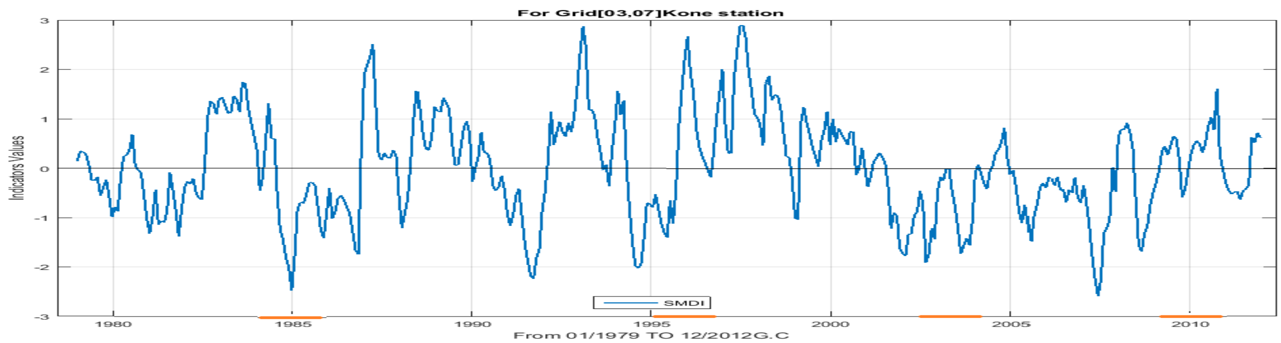

For Grid[07,12]Mehal meda station
Indicators Values
SMDI

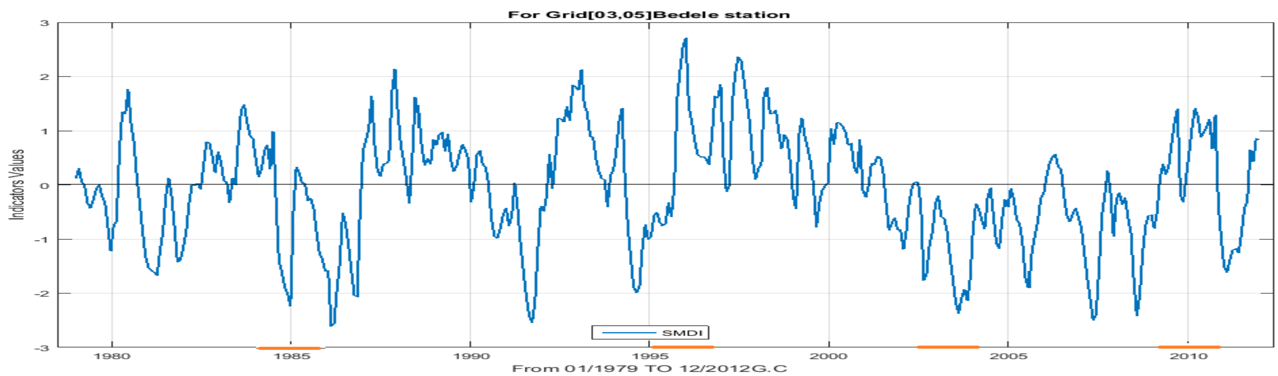

For Grid[06,09]Dejen station
Indicators Values
SMDI
From 01/1979 TO 12/2012G.C


For Grid[06,06]Gidayana station
Indicators Values
SMDI
From 01/1979 TO 12/2012G.C

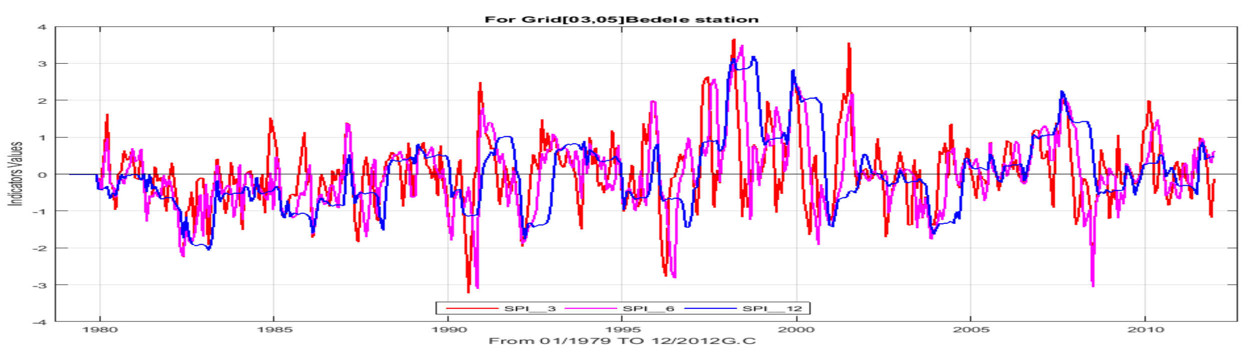

For Grid[05,10]Derba station
Indicators Values
SMDI
From 01/1979 TO 12/2012G.C

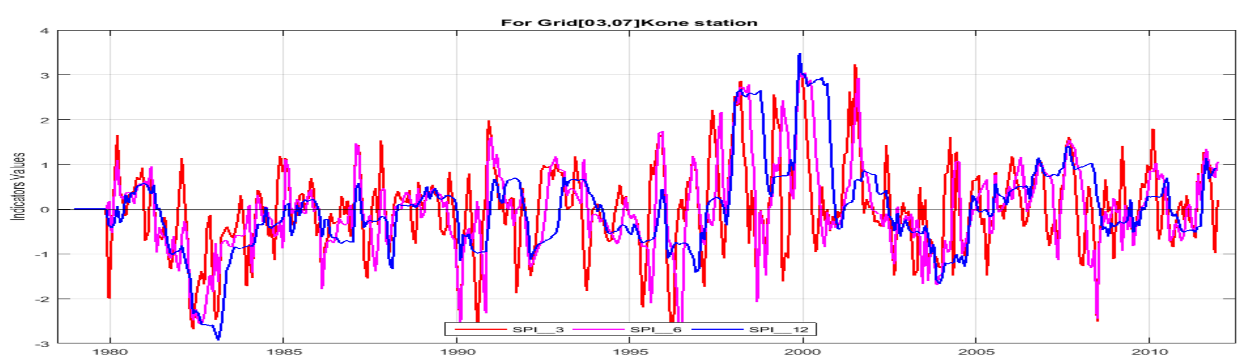

For Grid[04,04]Dengoro station
Indicators Values
SMDI
From 01/1979 TO 12/2012G.C

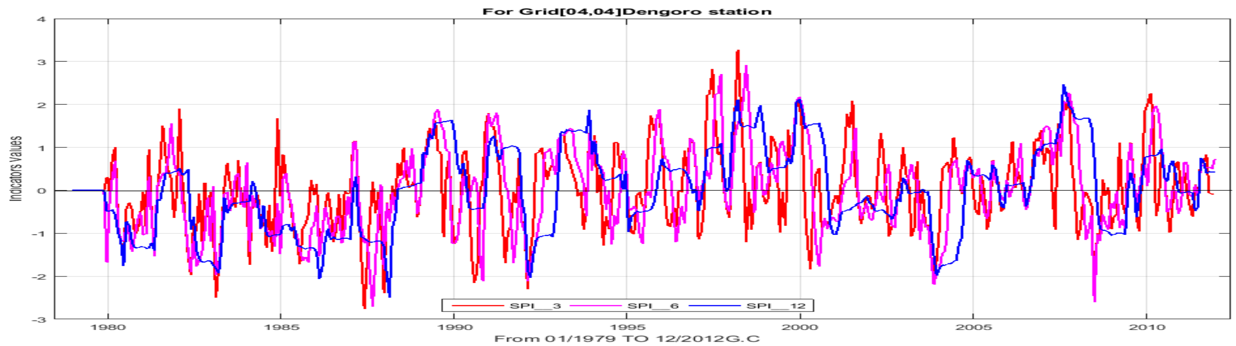


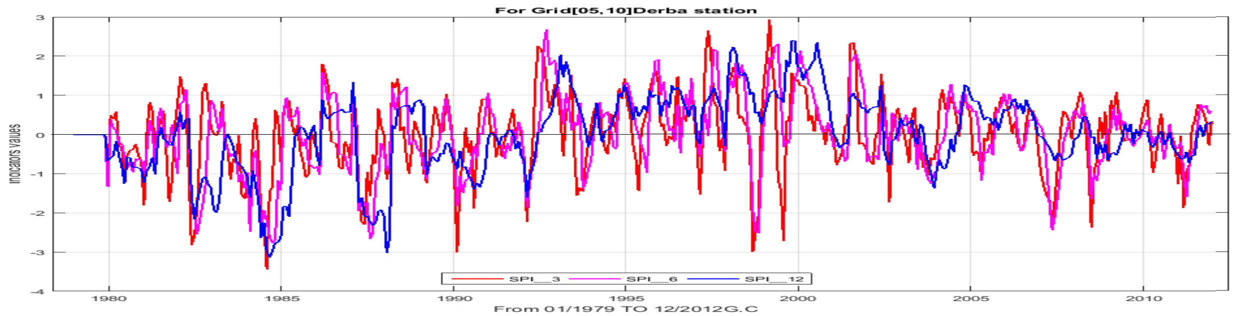


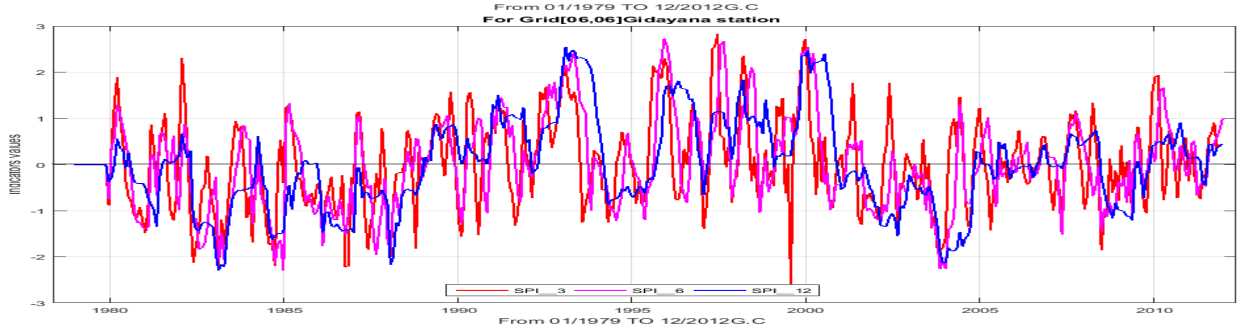
Time Series Plot for SPI with ECMWF Product

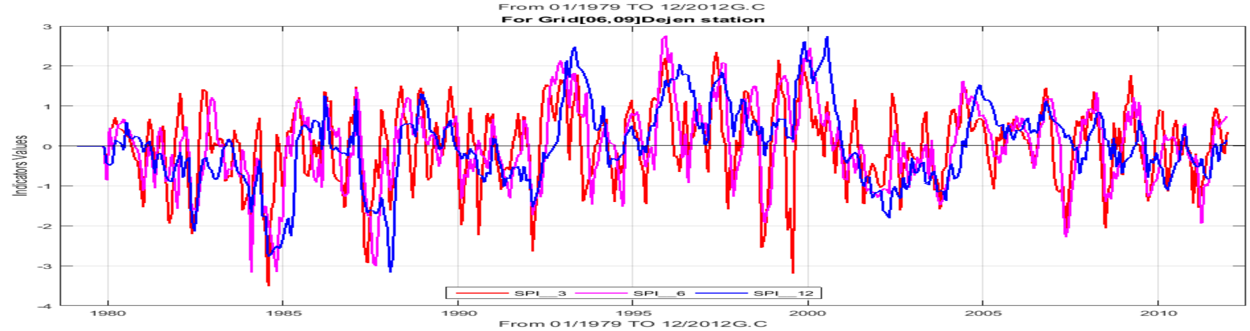


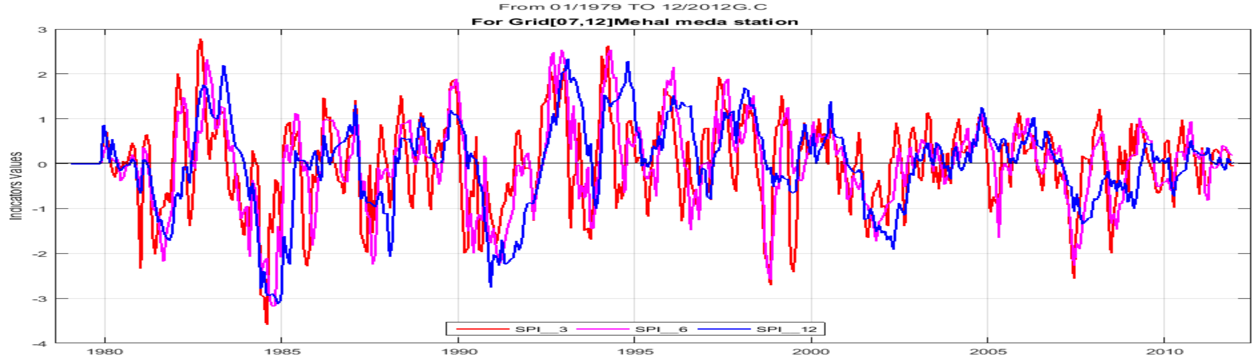


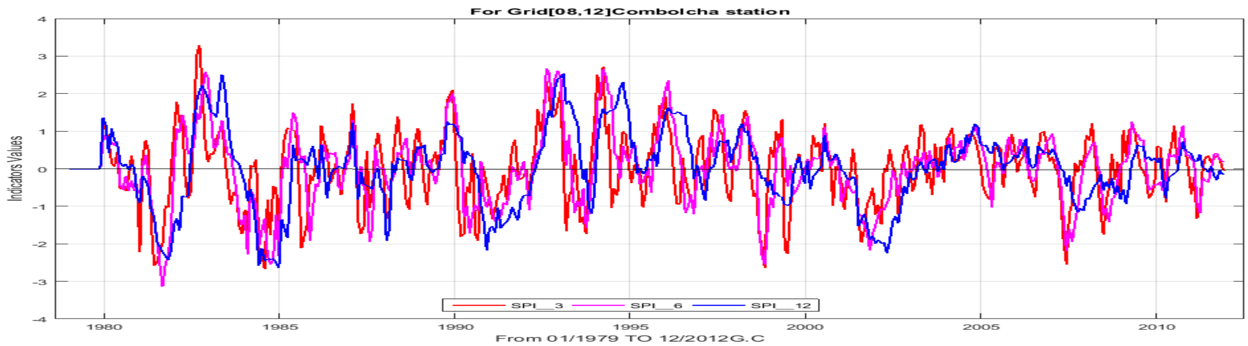

For Grid[04,04]Dengoro station
Indicators Values
SPI__3
SPI__6
SPI__12
From 01/1979 TO 12/2012G.C

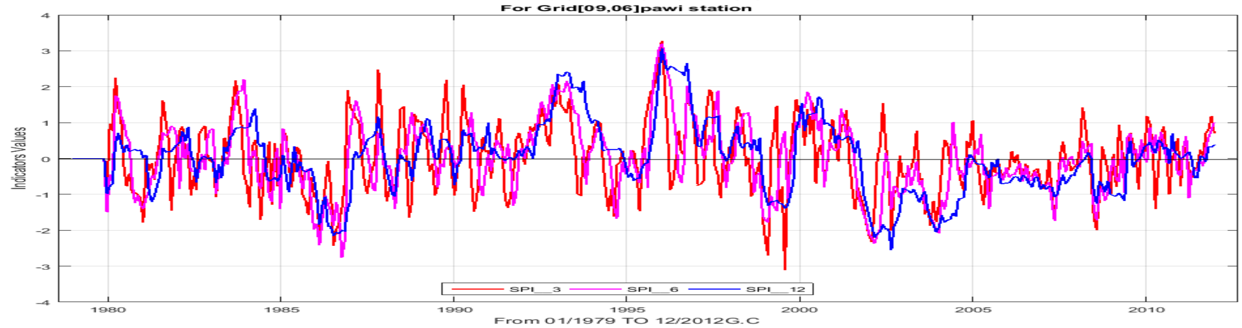

For Grid[05,10]Derba station
Indicators Values
SPI__3
SPI__6
SPI__12
From 01/1979 TO 12/2012G.C

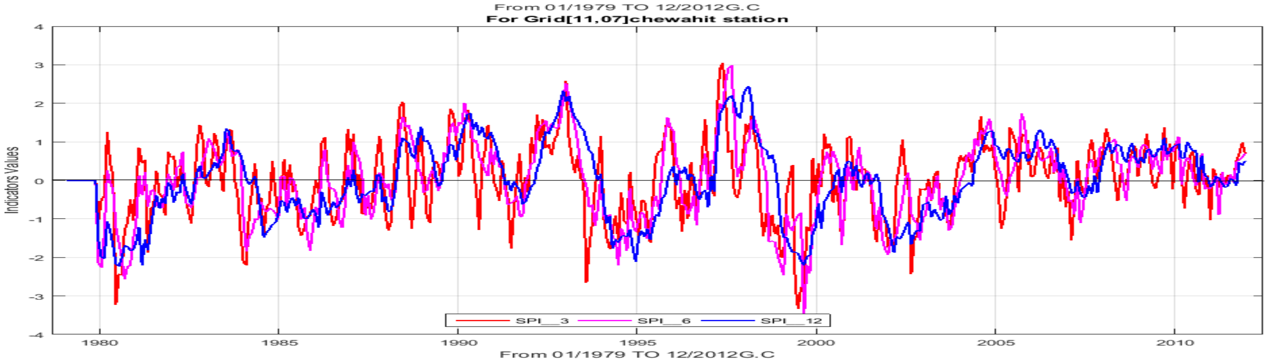

For Grid[06,06]Gidayana station
Indicators Values
SPI__3
SPI__6
SPI__12
From 01/1979 TO 12/2012G.C


For Grid[06,09]Dejen station
Indicators Values
SPI__3
SPI__6
SPI__12
From 01/1979 TO 12/2012G.C

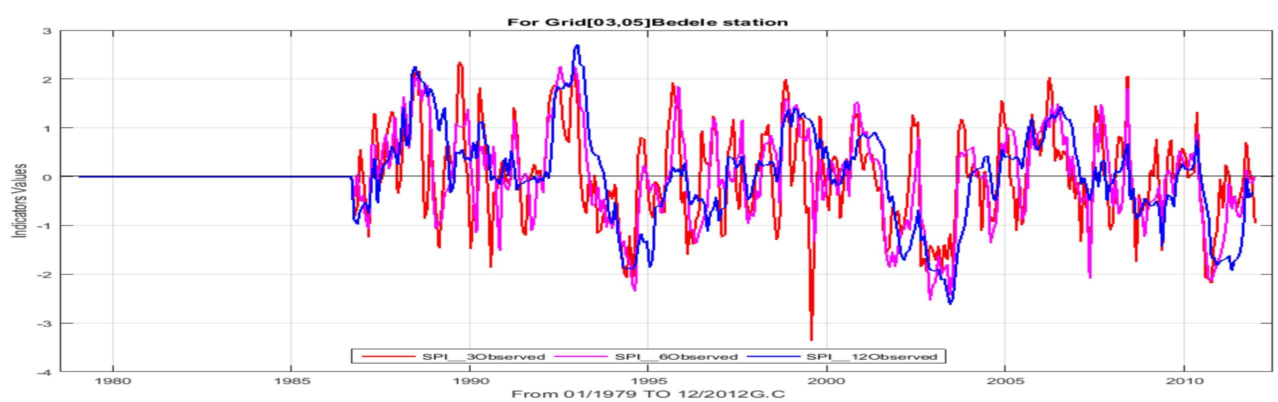

For Grid[07,12]Mehal meda station
Indicators Values
SPI__3
SPI__6
SPI__12
From 01/1979 TO 12/2012G.C

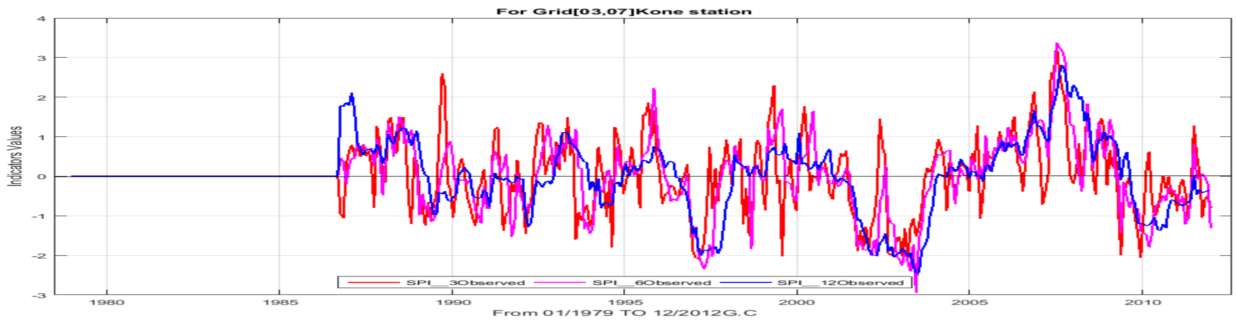


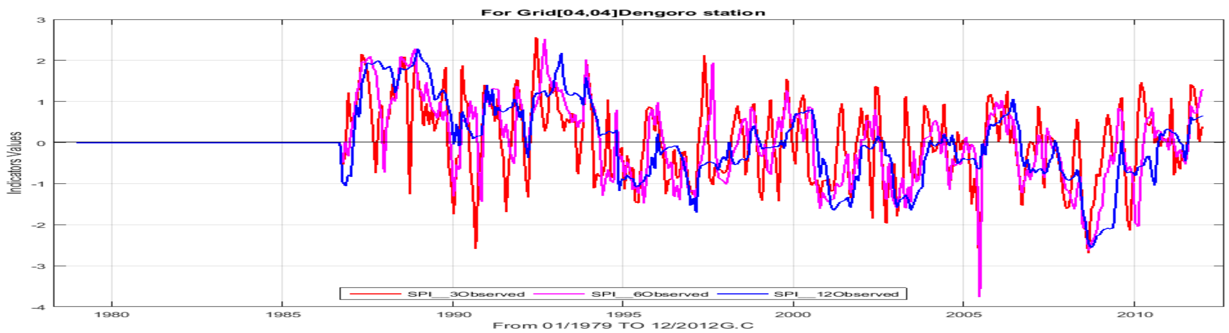


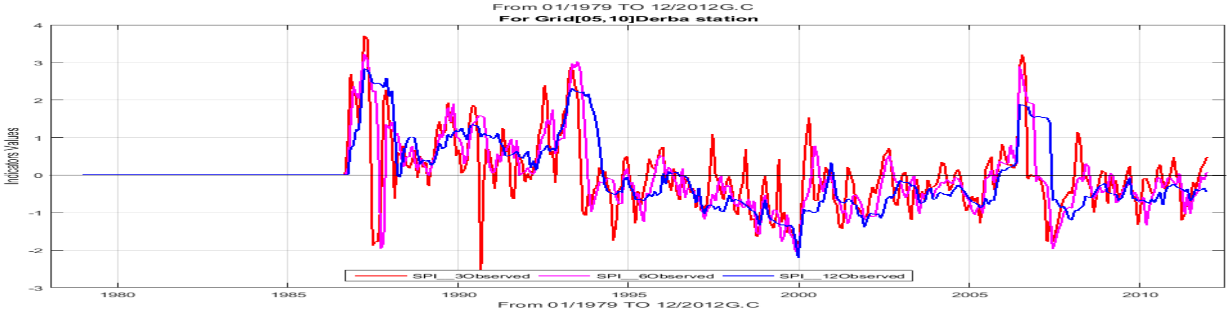


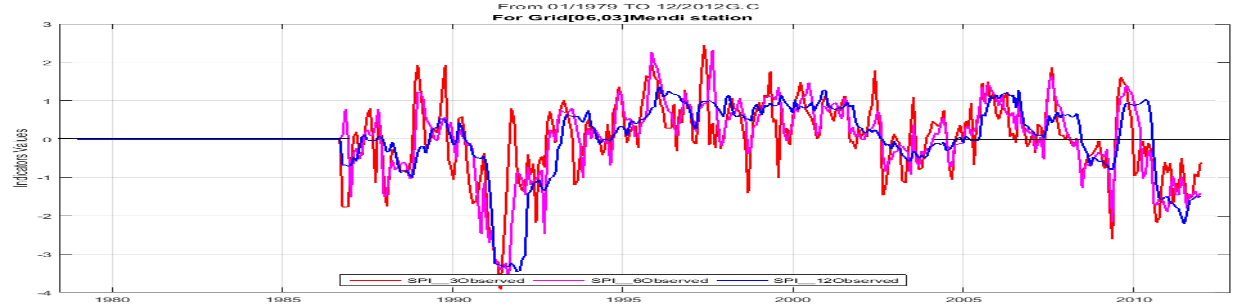
Time Series Plot for SPI with Observed Product

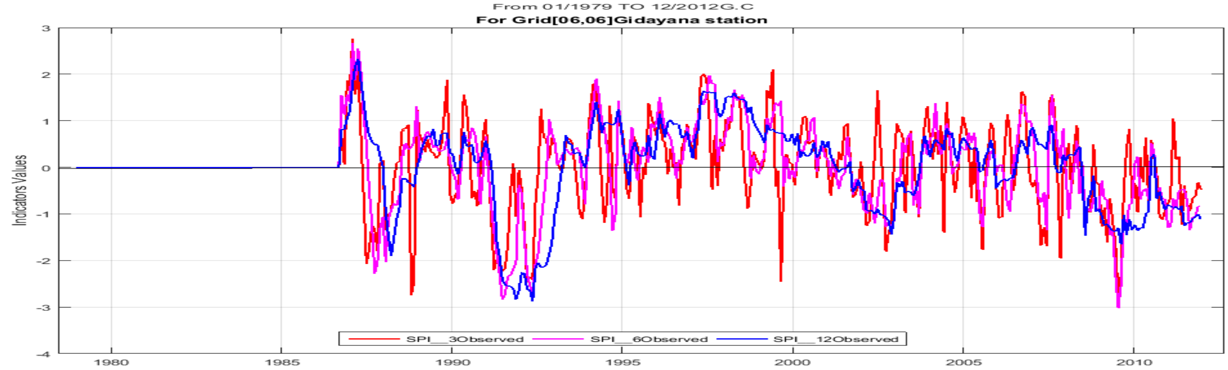


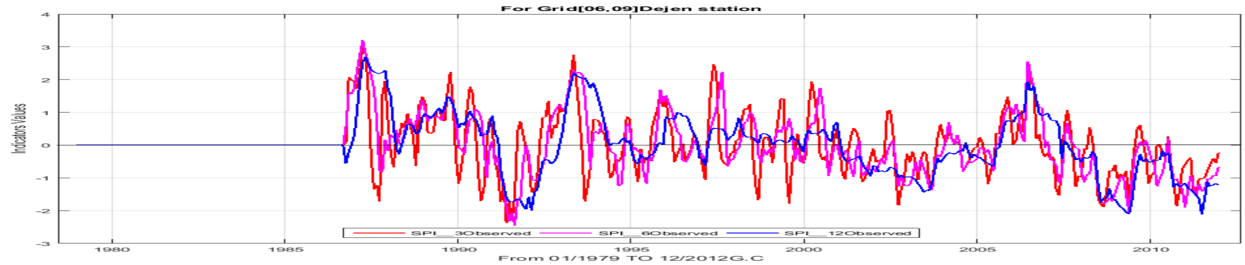

For Grid[03,07]Kone station
Indicators Values
SPI__3Observed
SPI__6Observed
SPI__12Observed
1980 1985 1990 1995 2000 2005 2010
From 01/1979 TO 12/2012G.C

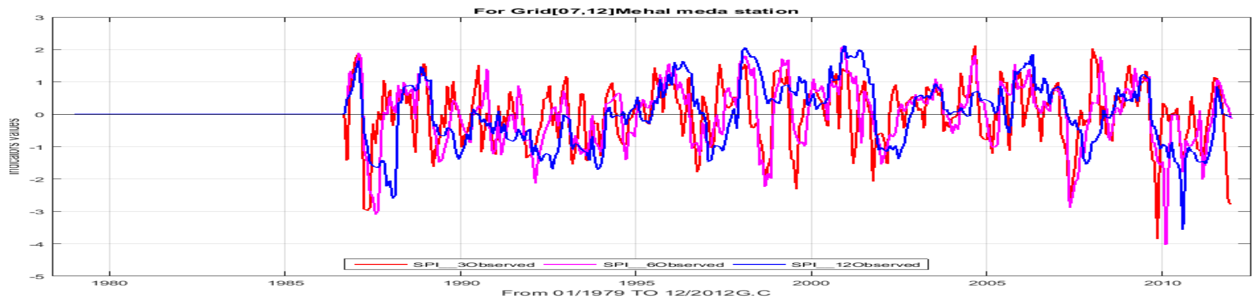

For Grid[04,04]Dengoro station
Indicators Values
SPI__3Observed
SPI__6Observed
SPI__12Observed
1980 1985 1990 1995 2000 2005 2010
From 01/1979 TO 12/2012G.C

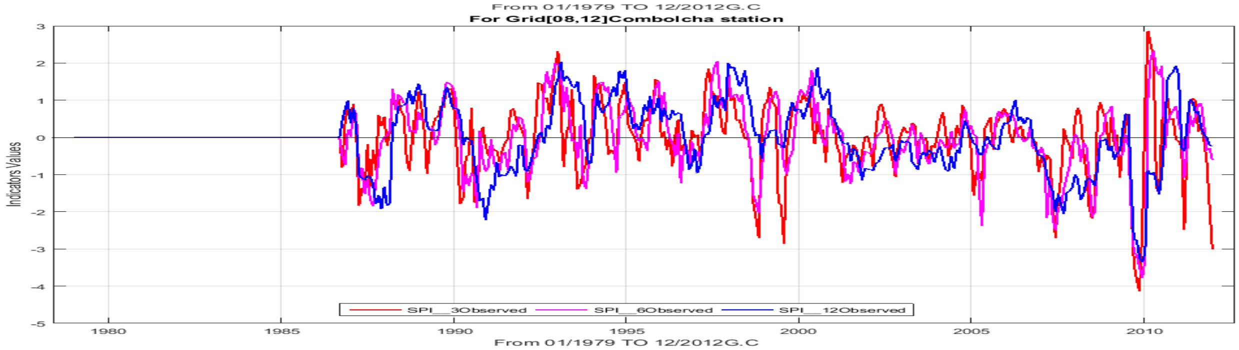

For Grid[05,10]Derba station
Indicators Values
SPI__3Observed
SPI__6Observed
SPI__12Observed
1980 1985 1990 1995 2000 2005 2010
From 01/1979 TO 12/2012G.C

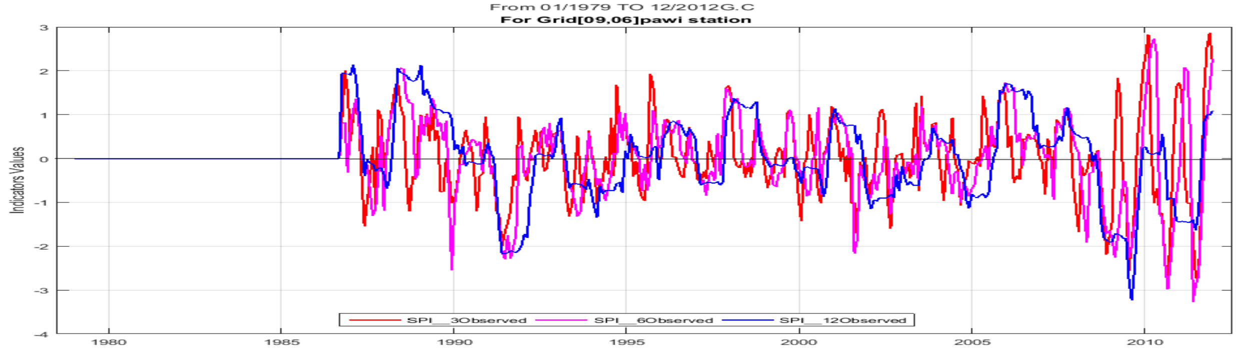

For Grid[06,03]Mendi station
Indicators Values
SPI__3Observed
SPI__6Observed
SPI__12Observed
1980 1985 1990 1995 2000 2005 2010
From 01/1979 TO 12/2012G.C

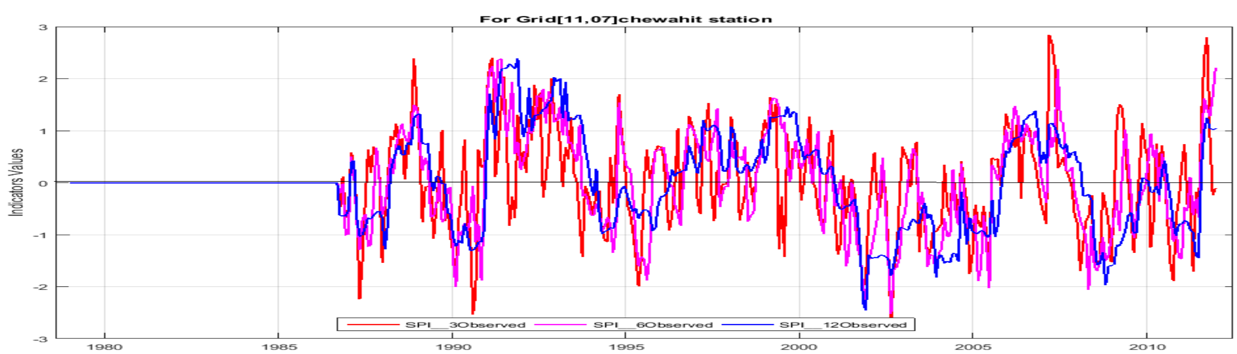

For Grid[06,06]Gidayana station
Indicators Values
SPI__3Observed
SPI__6Observed
SPI__12Observed
1980 1985 1990 1995 2000 2005 2010
From 01/1979 TO 12/2012G.C


For Grid[06,09]Dejen station
Indicators Values
SPI__3Observed
SPI__6Observed
SPI__12Observed
From 01/1979 TO 12/2012G.C

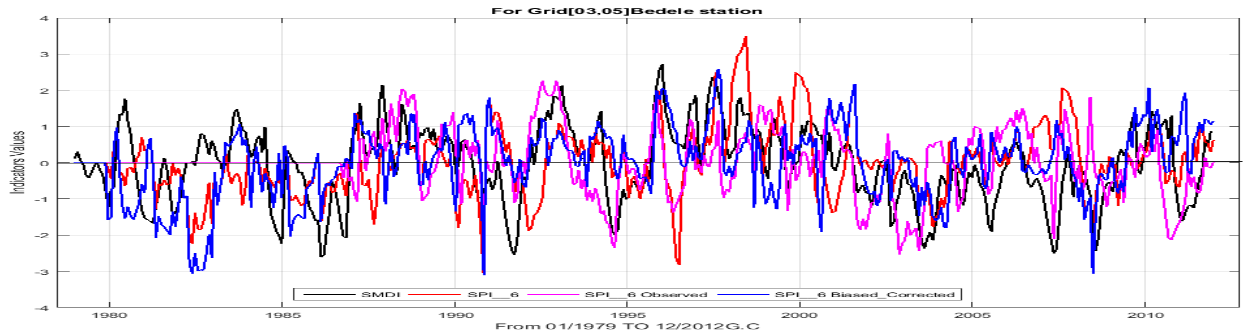

For Grid[07,12]Mehal meda station
SPI__3Observed
SPI__6Observed
SPI__12Observed
From 01/1979 TO 12/2012G.C

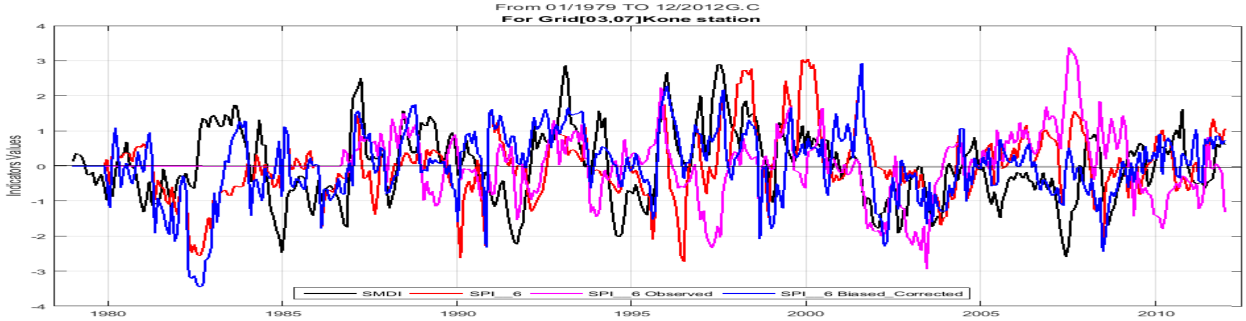

For Grid[08,12]Combolcha station
Indicators Values
SPI__3Observed
SPI__6Observed
SPI__12Observed
From 01/1979 TO 12/2012G.C

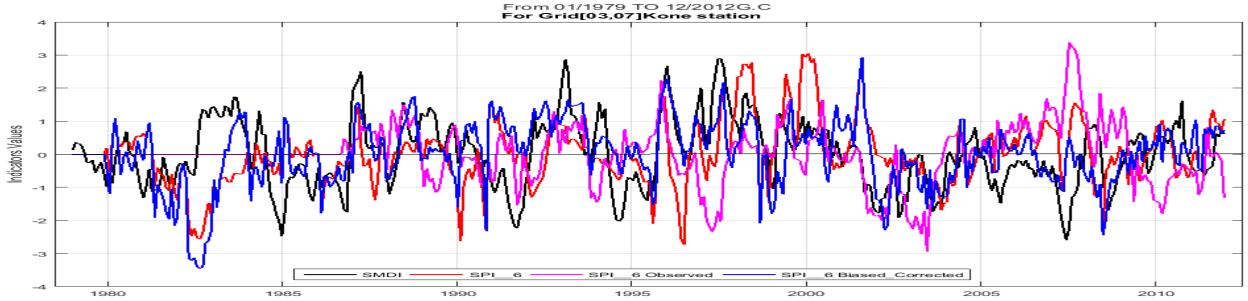

For Grid[09,06]pawi station
Indicators Values
SPI__3Observed
SPI__6Observed
SPI__12Observed
From 01/1979 TO 12/2012G.C

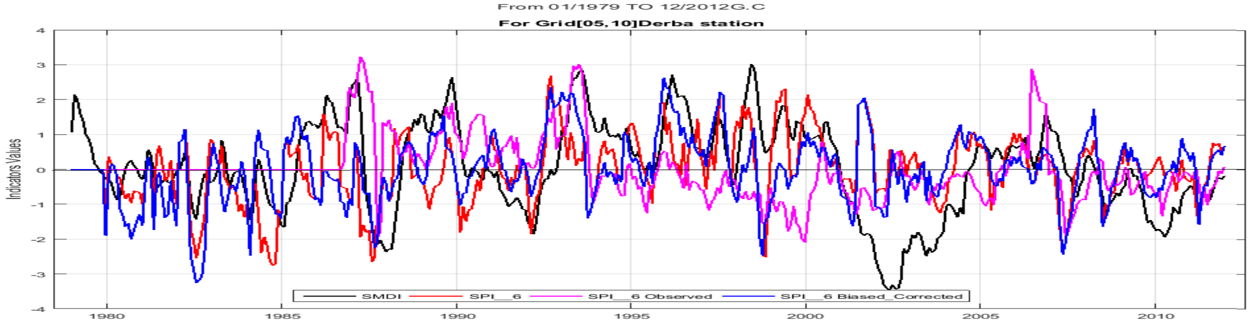

For Grid[11,07]chewahit station
Indicators Values
SPI__3Observed
SPI__6Observed
SPI__12Observed
From 01/1979 TO 12/2012G.C

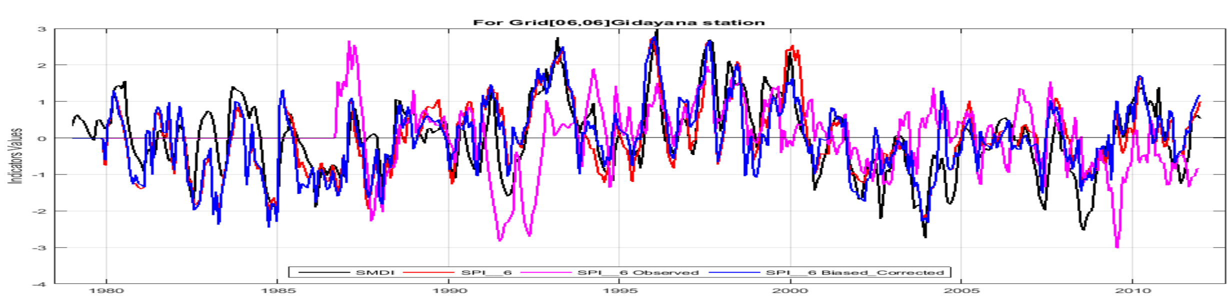
Combined Time Series Plot for Each Indices

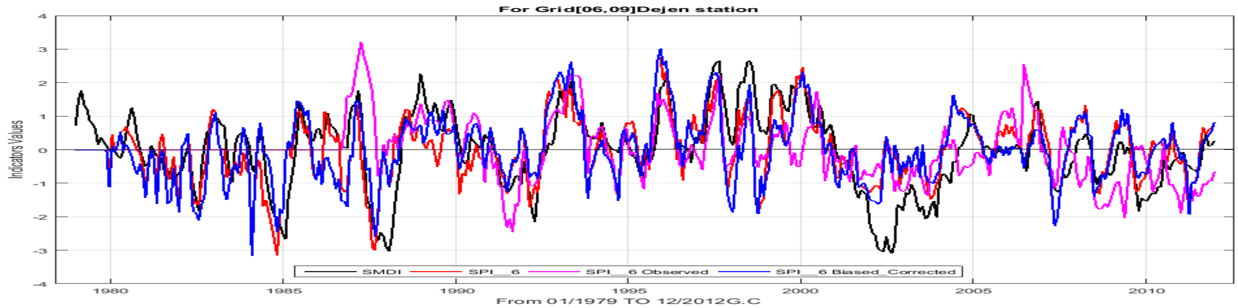


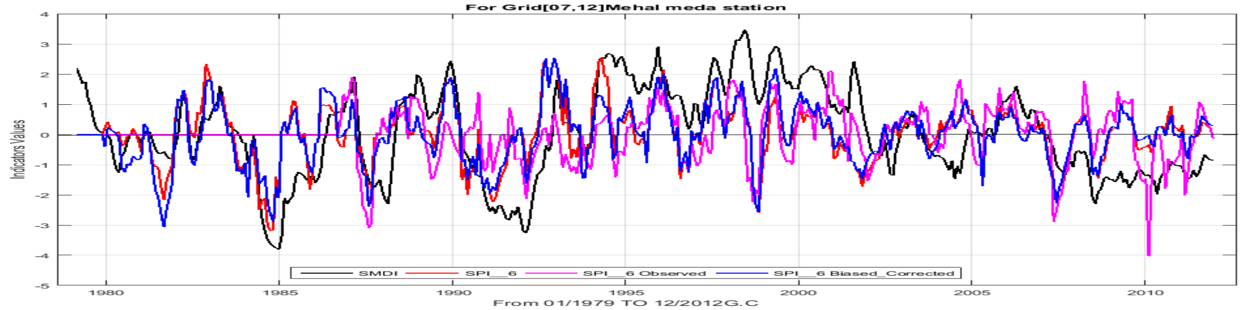


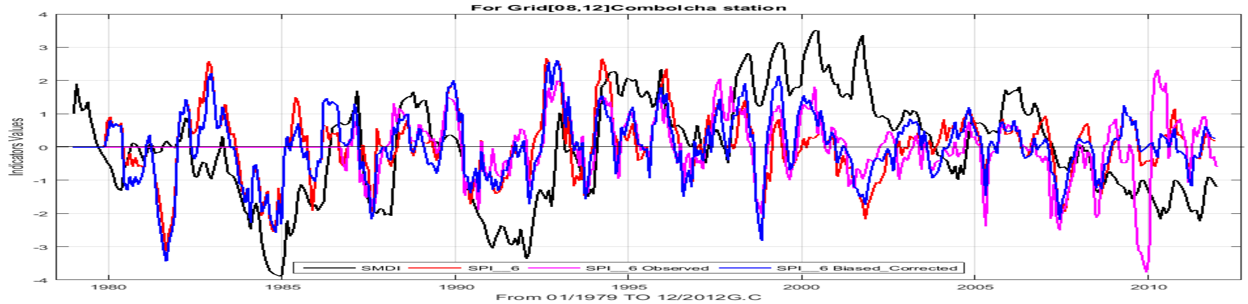


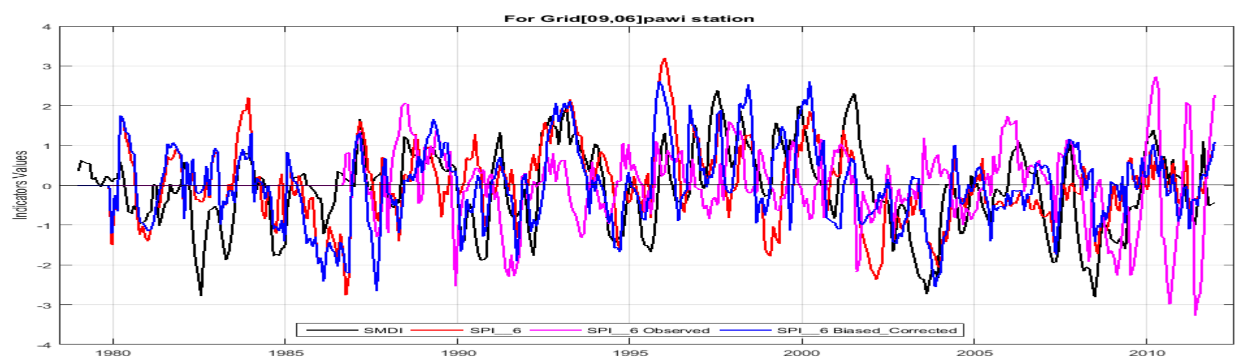


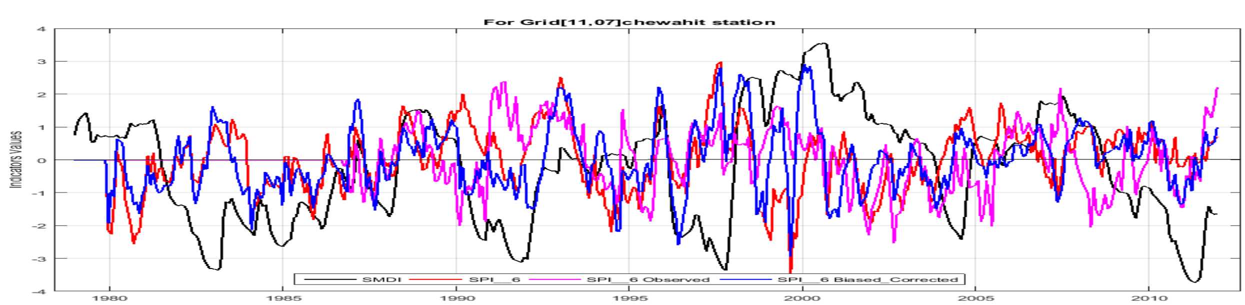


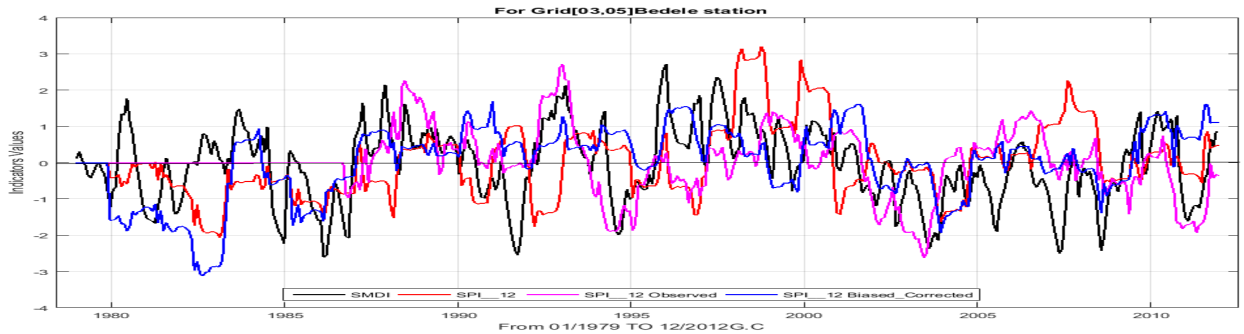

For Grid[06,09]Dejen station
Indicators Values
SMDI
SPI__6
SPI__6 Observed
SPI__6 Biased_Corrected
From 01/1979 TO 12/2012G.C

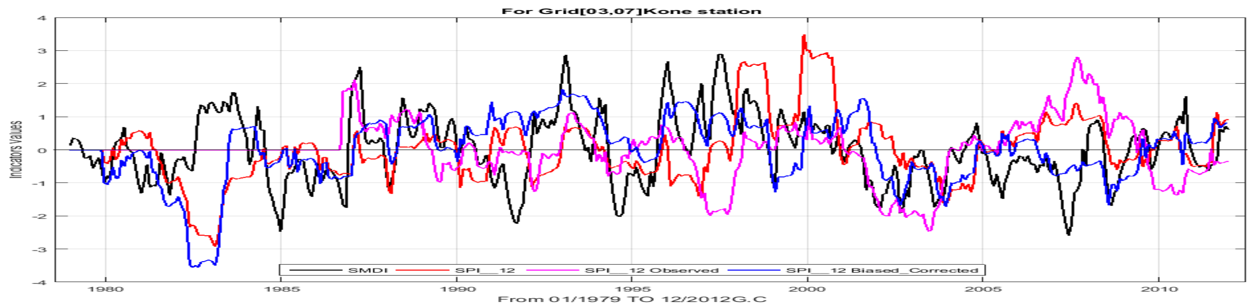

For Grid[07,12]Mehal meda station
Indicators Values
SMDI
SPI__6
SPI__6 Observed
SPI__6 Biased_Corrected
From 01/1979 TO 12/2012G.C

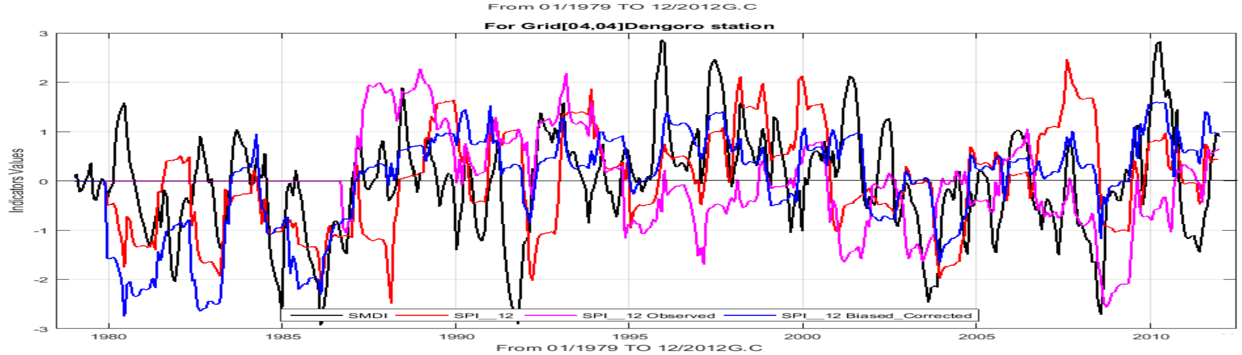

For Grid[08,12]Combolcha station
Indicators Values
SMDI
SPI__6
SPI__6 Observed
SPI__6 Biased_Corrected
From 01/1979 TO 12/2012G.C

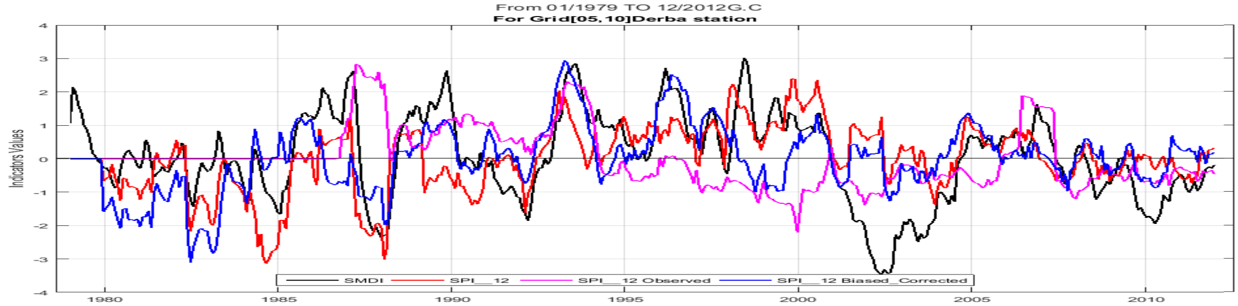

For Grid[09,06]pawi station
Indicators Values
SMDI
SPI__6
SPI__6 Observed
SPI__6 Biased_Corrected
From 01/1979 TO 12/2012G.C

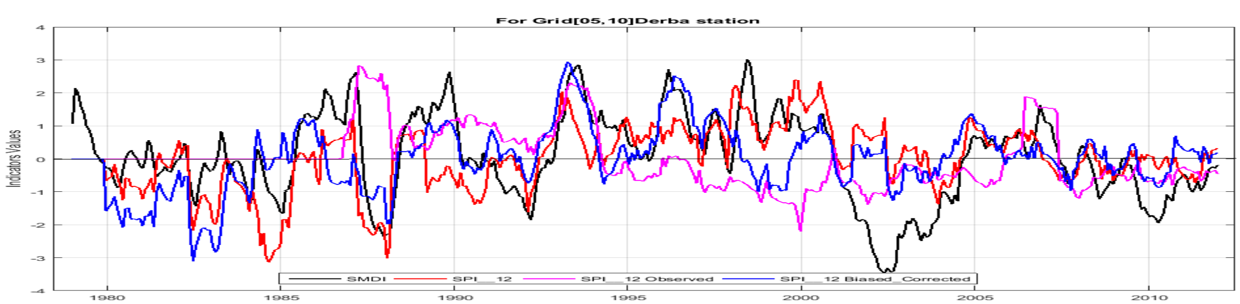

For Grid[11,07]chewahit station
Indicators Values
SMDI
SPI__6
SPI__6 Observed
SPI__6 Biased_Corrected
From 01/1979 TO 12/2012G.C

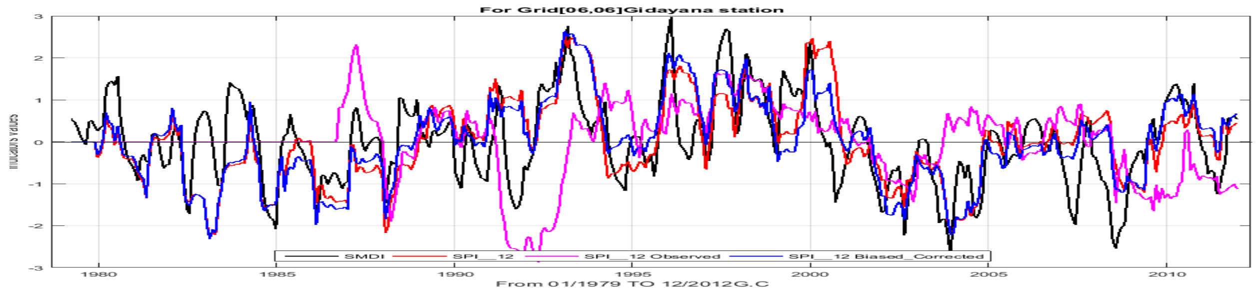

For Grid[03,05]Bedele station
Indicators Values
SMDI
SPI__12
SPI__12 Observed
SPI__12 Biased_Corrected
From 01/1979 TO 12/2012G.C

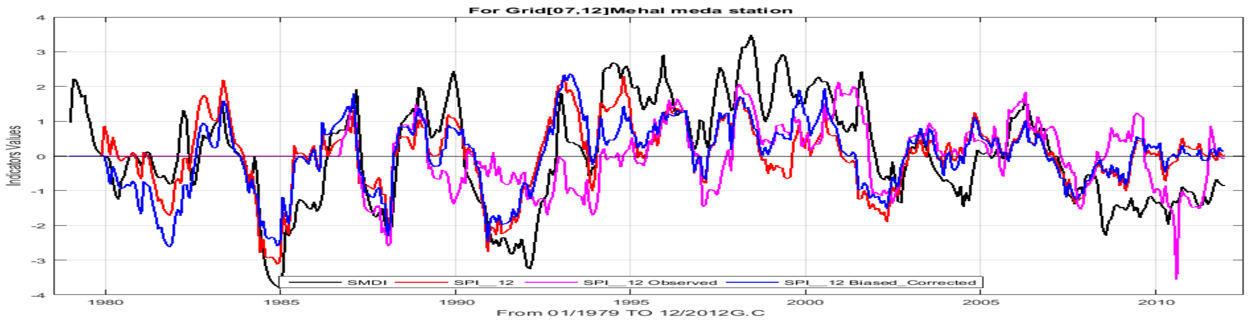

For Grid[03,07]Kone station
Indicators Values
SMDI
SPI__12
SPI__12 Observed
SPI__12 Biased_Corrected
From 01/1979 TO 12/2012G.C

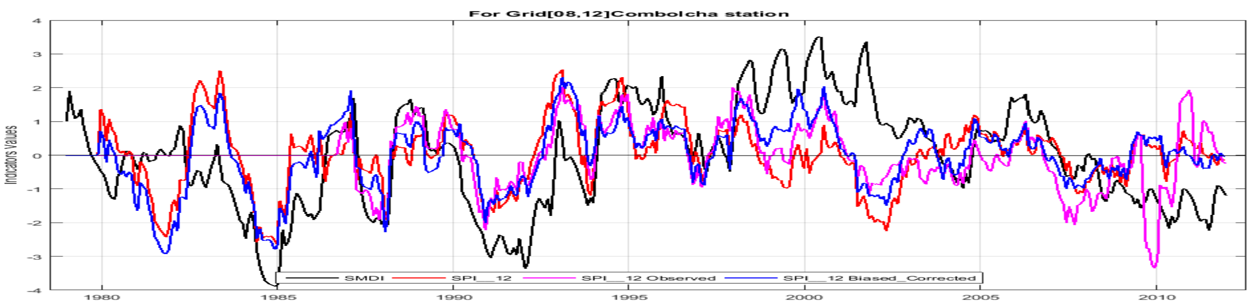

For Grid[04,04]Dengoro station
Indicators Values
SMDI
SPI__12
SPI__12 Observed
SPI__12 Biased_Corrected
From 01/1979 TO 12/2012G.C

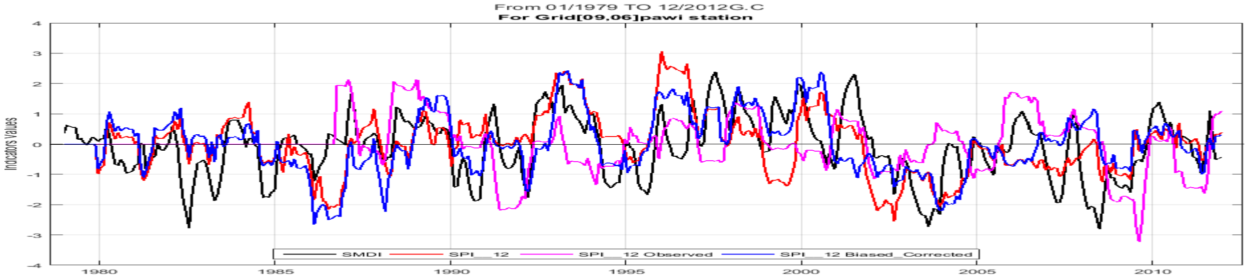

For Grid[05,10]Derba station
Indicators Values
SMDI
SPI__12
SPI__12 Observed
SPI__12 Biased_Corrected
From 01/1979 TO 12/2012G.C

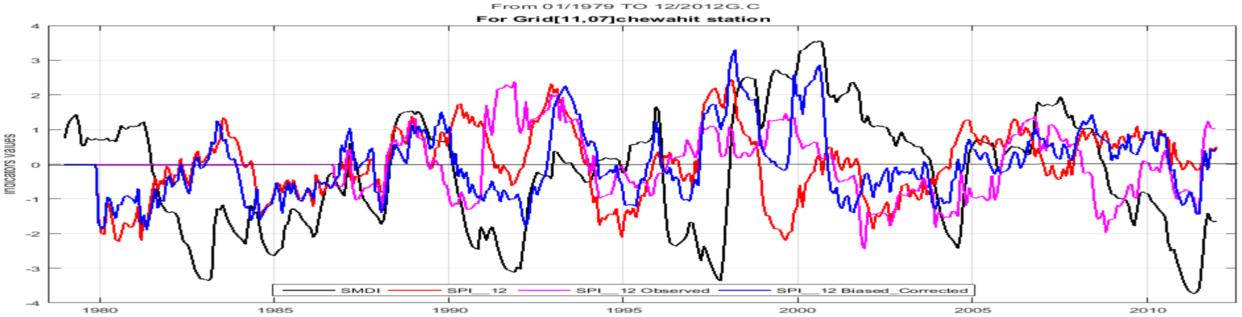

For Grid[05,10]Derba station
Indicators Values
SMDI
SPI__12
SPI__12 Observed
SPI__12 Biased_Corrected
From 01/1979 TO 12/2012G.C











Annex C: **- Drought Characteristics**

Characteristics of the historic drought events for Abedela Station Grid (03,05)										
Data Type	**ECMWF Soil Moisture Data set**	**ECMWF Data set**			**Biased Corrected ECMWF Data set**			**Observed PPT Data Set**		
Drought Index	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Historic drought events in the year 1984-1985										
Mean Intensity, *M*	-1.30	-0.48	-0.82	-0.90	-1.37	-1.15	-0.84			
Duration, D (months)	19.00	5.00	10.00	69.00	5.00	10.00	33.00			
Severity, S	-24.75	-2.38	-8.17	-62.04	-6.85	-11.51	-27.69			
Maximum intensity, Mmax	-2.61	-1.51	-1.19	-2.06	-2.09	-2.04	-1.74			
Historic drought events in the year 1995-1996										
Mean Intensity, *M*	-0.94	-1.06	-1.23	-0.78	-0.48	-0.47	-0.12	-0.86	-0.77	-1.13
Duration, D (months)	17.00	7.00	8.00	14.00	6.00	6.00	8.00	20.00	27.00	23.00
Severity, S	-15.96	-7.42	-9.84	-10.92	-2.86	-2.80	-0.98	-17.21	-20.69	-26.00
Maximum intensity, Mmax	-1.99	-2.78	-2.82	-1.45	-0.90	-0.87	-0.21	-2.23	-2.35	-1.90
Historic drought events in the year 2003-2004										
Mean Intensity, *M*	-0.95	-1.10	-1.07	-0.80	-1.23	-1.08	-0.89	-1.54	-1.79	-1.40
Duration, D (months)	43.00	6.00	12.00	22.00	7.00	15.00	21.00	13.00	13.00	30.00
Severity, S	-40.89	-6.63	-12.88	-17.62	-8.60	-16.26	-18.69	-20.01	-23.29	-42.09
Maximum intensity, Mmax	-2.37	-1.39	-1.76	-1.63	-2.16	-1.79	-1.93	-1.97	-2.54	-2.62
Historic drought events in the year 2009-2010										
Mean Intensity, *M*	-0.84	-0.85	-0.89	-0.45	-0.93	-0.88	-0.51	-0.63	-0.56	-0.61
Duration, D (months)	17.00	10.00	10.00	11.00	11.00	14.00	19.00	7.00	12.00	16.00
Severity, S	-14.31	-8.47	-8.89	-4.93	-10.28	-12.38	-9.77	-4.40	-6.70	-9.83
Maximum intensity, Mmax	-2.42	-3.01	-3.06	-0.56	-3.01	-3.06	-1.38	-1.75	-1.22	-1.43

Characteristics of the historic drought events for Kone Station Grid (03,07)										
Data Type	**ECMWF Soil Moisture Data set**	**ECMWF Data set**			**Biased Corrected ECMWF Data set**			**Observed PPT Data Set**		
Drought Index	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Historic drought events in the year 1984-1985										
Mean Intensity, *M*	-1.03	-0.91	-0.46	-1.40	-0.76	-0.56	-0.62			
Duration, D (months)	29.00	5.00	6.00	37.00	8.00	9.00	20.00			
Severity, S	-29.92	-4.55	-2.74	-51.65	-6.11	-5.04	-12.35			
Maximum intensity, Mmax	-2.47	-1.72	-0.88	-2.93	-1.72	-1.41	-1.03			
Historic drought events in the year 1995-1996										
Mean Intensity, *M*	-1.14	-0.73	-1.44	-0.44	-1.08	-0.74	-0.26	-0.39	-0.40	-0.43
Duration, D (months)	17.00	8.00	7.00	23.00	4.00	6.00	8.00	8.00	8.00	12.00
Severity, S	-19.31	-5.84	-10.07	-10.15	-4.31	-4.45	-2.11	-3.10	-3.20	-5.14
Maximum intensity, Mmax	-2.03	-2.19	-2.72	-0.76	-1.69	-1.52	-0.39	-0.70	-0.64	-0.80
Historic drought events in the year 2003-2004										
Mean Intensity, *M*	-1.02	-1.16	-0.91	-0.77	-0.93	-0.78	-0.91	-1.46	-1.56	-1.37
Duration, D (months)	31.00	6.00	16.00	30.00	7.00	20.00	35.00	14.00	16.00	37.00
Severity, S	-31.49	-6.94	-14.51	-23.08	-6.49	-15.51	-31.98	-20.50	-25.04	-50.80
Maximum intensity, Mmax	-1.92	-1.59	-1.69	-1.67	-1.59	-1.67	-1.72	-2.11	-2.94	-2.46
Historic drought events in the year 2009-2010										
Mean Intensity, *M*	-0.89	-0.97	-0.76	-0.36	-1.53	-0.83	-0.66	-0.97	-0.67	-0.80
Duration, D (months)	9.00	4.00	10.00	10.00	4.00	17.00	36.00	10.00	33.00	29.00
Severity, S	-8.00	-3.89	-7.56	-3.64	-6.12	-14.09	-23.79	-9.69	-22.27	-23.14
Maximum intensity, Mmax	-1.69	-2.51	-2.44	-0.61	-2.51	-2.44	-1.68	-2.06	-1.80	-1.38

Characteristics of the historic drought events for Dengoro Station Grid (04,04)										
Data Type	**ECMWF Soil Moisture Data set**	**ECMWF Data set**			**Biased Corrected ECMWF Data set**			**Observed PPT Data Set**		
Drought Index	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Historic drought events in the year 1984-1985										
Mean Intensity, *M*	-1.31	-0.59	-0.90	-1.11	-1.49	-1.13	-1.25			
Duration, D (months)	20.00	13.00	23.00	34.00	8.00	23.00	35.00			
Severity, S	-26.26	-7.64	-20.61	-37.74	-11.92	-26.09	-43.72			
Maximum intensity, Mmax	-2.92	-1.74	-1.67	-2.06	-2.21	-2.39	-2.31			
Historic drought events in the year 1995-1996										
Mean Intensity, *M*	-0.42	-0.48	-0.48	-0.54	-1.08	-0.23	-0.10	-0.68	-0.85	-0.68
Duration, D (months)	5.00	7.00	9.00	10.00	4.00	6.00	6.00	10.00	14.00	29.00
Severity, S	-2.09	-3.36	-4.35	-5.35	-4.31	-1.38	-0.58	-6.78	-11.85	-19.81
Maximum intensity, Mmax	-0.73	-1.02	-1.24	-0.97	-1.69	-0.44	-0.28	-1.47	-1.43	-1.70
Historic drought events in the year 2003-2004										
Mean Intensity, *M*	-0.97	-1.27	-1.31	-1.26	-0.99	-1.00	-1.03	-1.10	-0.99	-1.10
Duration, D (months)	22.00	6.00	11.00	15.00	7.00	12.00	14.00	8.00	16.00	15.00
Severity, S	-21.41	-7.60	-14.45	-18.90	-6.90	-12.02	-14.43	-8.77	-15.80	-16.55
Maximum intensity, Mmax	-2.47	-1.87	-2.19	-1.97	-1.62	-1.51	-1.65	-1.97	-1.60	-1.65
Historic drought events in the year 2009-2010										
Mean Intensity, *M*	-1.00	-0.76	-0.81	-0.93	-0.76	-1.05	-0.24	-1.37	-1.18	-1.16
Duration, D (months)	18.00	10.00	16.00	11.00	11.00	8.00	12.00	9.00	24.00	37.00
Severity, S	-18.00	-7.60	-13.02	-10.26	-8.38	-8.40	-2.84	-12.29	-28.27	-42.76
Maximum intensity, Mmax	-2.71	-2.59	-2.60	-1.04	-2.59	-2.60	-1.18	-2.70	-2.63	-2.57

Characteristics of the historic drought events for Derba Station Grid (05,10)										
Data Type	**ECMWF Soil Moisture Data set**	**ECMWF Data set**			**Biased Corrected ECMWF Data set**			**Observed PPT Data Set**		
Drought Index	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Historic drought events in the year 1984-1985										
Mean Intensity, *M*	-0.98	-1.86	-1.38	-1.64	-1.31	-1.06	-1.48			
Duration, D (months)	12.00	6.00	21.00	24.00	5.00	4.00	53.00			
Severity, S	-11.74	-11.18	-28.93	-39.37	-6.57	-4.22	-78.47			
Maximum intensity, Mmax	-1.65	-3.45	-2.77	-3.14	-2.06	-2.48	-3.11			
Historic drought events in the year 1995-1996										
Mean Intensity, *M*	-0.03	-0.77	-0.44	0.00	-0.26	-0.23	-0.45	-0.76	-0.56	-0.47
Duration, D (months)	1.00	3.00	4.00	1.00	3.00	6.00	6.00	6.00	9.00	21.00
Severity, S	-0.03	-2.30	-1.76	0.00	-0.77	-1.38	-2.72	-4.55	-5.01	-9.80
Maximum intensity, Mmax	-0.03	-1.44	-0.98	0.00	-0.47	-0.44	-0.77	-1.74	-1.25	-0.68
Historic drought events in the year 2003-2004										
Mean Intensity, *M*	-1.95	-0.55	-0.73	-0.77	-0.48	-1.06	-0.59	-0.44	-0.43	-0.63
Duration, D (months)	45.00	8.00	10.00	10.00	5.00	6.00	20.00	12.00	35.00	60.00
Severity, S	-87.75	-4.42	-7.28	-7.70	-2.40	-6.37	-11.79	-5.24	-15.07	-37.68
Maximum intensity, Mmax	-3.47	-1.04	-1.25	-1.37	-0.85	-1.38	-1.27	-1.19	-1.05	-1.39
Historic drought events in the year 2009-2010										
Mean Intensity, *M*	-0.95	-1.21	-0.77	-0.36	-0.66	-0.77	-0.62	-0.52	-0.44	-0.57
Duration, D (months)	33.00	4.00	7.00	12.00	5.00	7.00	12.00	9.00	23.00	57.00
Severity, S	-31.47	-4.83	-5.41	-4.27	-3.28	-5.36	-7.42	-4.71	-10.04	-32.51
Maximum intensity, Mmax	-1.95	-2.37	-1.65	-0.66	-1.08	-1.65	-0.88	-1.33	-1.34	-1.20

Characteristics of the historic drought events for Mendi Station Grid (06,03)										
Data Type	**ECMWF Soil Moisture Data set**	**ECMWF Data set**			**Biased Corrected ECMWF Data set**			**Observed PPT Data Set**		
Drought Index	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Historic drought events in the year 1984-1985										
Mean Intensity, *M*	-2.22	-1.74	-1.40	-1.42	-1.83	-1.79	-1.47			
Duration, D (months)	56.00	8.00	20.00	51.00	9.00	9.00	50.00			
Severity, S	-124.17	-13.92	-27.96	-72.57	-16.45	-16.08	-73.68			
Maximum intensity, Mmax	-3.79	-2.87	-2.88	-3.21	-3.37	-2.73	-3.33			
Historic drought events in the year 1995-1996										
Mean Intensity, *M*	-0.68	-0.96	-0.61	-0.35	-0.55	-0.28	-0.40	-0.11	-0.17	-0.05
Duration, D (months)	9.00	3.00	6.00	11.00	3.00	2.00	2.00	1.00	5.00	2.00
Severity, S	-6.12	-2.88	-3.67	-3.85	-1.64	-0.57	-0.80	-0.11	-0.85	-0.09
Maximum intensity, Mmax	-0.87	-1.54	-1.09	-0.93	-1.06	-0.47	-0.53	-0.11	-0.69	-0.05
Historic drought events in the year 2003-2004										
Mean Intensity, *M*	-1.24	-1.01	-1.21	-0.87	-0.89	-1.06	-0.76	-0.61	-0.45	-0.27
Duration, D (months)	71.00	8.00	11.00	21.00	8.00	11.00	20.00	10.00	11.00	27.00
Severity, S	-88.00	-8.05	-13.28	-18.30	-7.15	-11.71	-15.13	-6.09	-4.96	-7.40
Maximum intensity, Mmax	-3.05	-1.73	-2.06	-1.77	-1.44	-1.85	-1.59	-1.46	-0.93	-0.57
Historic drought events in the year 2009-2010										
Mean Intensity, *M*	-0.99	-0.80	-0.89	-1.17	-1.20	-0.75	-0.54	-0.70	-0.60	-0.51
Duration, D (months)	15.00	10.00	17.00	12.00	4.00	11.00	12.00	14.00	17.00	14.00
Severity, S	-14.86	-8.04	-15.19	-14.02	-4.81	-8.21	-6.43	-9.86	-10.19	-7.20
Maximum intensity, Mmax	-1.40	-2.32	-2.26	-1.47	-2.32	-2.26	-1.05	-2.62	-2.17	-0.80

Characteristics of the historic drought events for Gidayana Station Grid (06,06)										
Data Type	**ECMWF Soil Moisture Data set**	**ECMWF Data set**			**Biased Corrected ECMWF Data set**			**Observed PPT Data Set**		
Drought Index	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Historic drought events in the year 1984-1985										
Mean Intensity, *M*	-1.29	-0.79	-1.43	-1.15	-0.89	-1.12	-0.85			
Duration, D (months)	8.00	21.00	9.00	23.00	22.00	20.00	56.00			
Severity, S	-10.31	-16.67	-12.86	-26.54	-19.65	-22.35	-47.88			
Maximum intensity, Mmax	-2.08	-2.22	-2.29	-2.29	-2.22	-1.77	-1.98			
Historic drought events in the year 1995-1996										
Mean Intensity, *M*	-0.78	-0.54	-0.67	-0.55	-0.44	-0.47	-0.20	-0.41	-0.82	-0.20
Duration, D (months)	7.00	6.00	9.00	19.00	3.00	5.00	5.00	3.00	3.00	2.00
Severity, S	-5.49	-3.26	-6.02	-10.36	-1.33	-2.37	-1.01	-1.23	-2.45	-0.40
Maximum intensity, Mmax	-1.17	-0.85	-1.22	-0.87	-0.63	-0.79	-0.34	-1.07	-1.36	-0.38
Historic drought events in the year 2003-2004										
Mean Intensity, *M*	-1.25	-1.60	-1.20	-0.93	-1.65	-0.95	-1.23	-1.19	-0.71	-0.70
Duration, D (months)	21.00	6.00	14.00	49.00	6.00	22.00	39.00	4.00	18.00	25.00
Severity, S	-26.30	-9.57	-16.81	-45.51	-9.90	-20.83	-47.87	-4.75	-12.79	-17.59
Maximum intensity, Mmax	-2.74	-1.88	-2.27	-2.13	-1.99	-2.32	-2.22	-1.80	-1.29	-1.44
Historic drought events in the year 2009-2010										
Mean Intensity, *M*	-1.10	-1.07	-0.64	-0.87	-1.12	-0.84	-1.04	-1.23	-1.11	-1.10
Duration, D (months)	19.00	4.00	15.00	13.00	4.00	7.00	12.00	11.00	20.00	25.00
Severity, S	-20.99	-4.30	-9.65	-11.26	-4.48	-5.91	-12.45	-13.56	-22.24	-27.57
Maximum intensity, Mmax	-2.54	-1.85	-1.46	-1.21	-1.85	-1.40	-1.21	-2.77	-3.02	-1.65

Characteristics of the historic drought events for Dejen Station Grid (06,09)										
Data Type	**ECMWF Soil Moisture Data set**	**ECMWF Data set**			**Biased Corrected ECMWF Data set**			**Observed PPT Data Set**		
Drought Index	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Historic drought events in the year 1984-1985										
Mean Intensity, *M*	-1.65	-2.04	-1.24	-1.59	-1.36	-1.06	-0.85			
Duration, D (months)	11.00	5.00	22.00	22.00	5.00	9.00	12.00			
Severity, S	-18.13	-10.21	-27.31	-34.93	-6.82	-9.52	-10.24			
Maximum intensity, Mmax	-2.67	-3.51	-3.17	-2.77	-2.33	-2.47	-1.29			
Historic drought events in the year 1995-1996										
Mean Intensity, *M*	-0.44	-0.62	-1.03	-0.33	-0.63	-0.64	-0.45	-0.54	-0.58	-0.37
Duration, D (months)	8.00	6.00	3.00	6.00	6.00	6.00	7.00	6.00	6.00	9.00
Severity, S	-3.53	-3.70	-3.09	-2.00	-3.78	-3.82	-3.12	-3.26	-3.48	-3.32
Maximum intensity, Mmax	-0.98	-1.40	-1.52	-0.55	-1.40	-1.52	-0.74	-1.13	-1.24	-0.57
Historic drought events in the year 2003-2004										
Mean Intensity, *M*	-1.51	-0.50	-0.97	-0.86	-0.78	-1.16	-0.90	-0.76	-0.82	-0.70
Duration, D (months)	44.00	8.00	11.00	42.00	12.00	11.00	42.00	15.00	18.00	44.00
Severity, S	-66.51	-4.02	-10.67	-36.27	-9.37	-12.77	-37.87	-11.47	-14.70	-30.82
Maximum intensity, Mmax	-3.09	-1.61	-1.29	-1.80	-1.45	-1.63	-1.94	-1.83	-1.38	-1.44
Historic drought events in the year 2009-2010										
Mean Intensity, *M*	-0.77	-1.24	-0.95	-0.60	-1.20	-0.84	-0.44	-1.05	-1.06	-1.03
Duration, D (months)	26.00	4.00	6.00	12.00	4.00	7.00	8.00	15.00	23.00	54.00
Severity, S	-19.92	-4.95	-5.72	-7.15	-4.80	-5.91	-3.54	-15.80	-24.45	-55.67
Maximum intensity, Mmax	-1.84	-2.06	-1.40	-1.11	-2.06	-1.40	-0.82	-1.90	-2.04	-2.11

Characteristics of the historic drought events for Mehal Meda Station Grid (07,12)										
Data Type	**ECMWF Soil Moisture Data set**	**ECMWF Data set**			**Biased Corrected ECMWF Data set**			**Observed PPT Data Set**		
Drought Index	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Historic drought events in the year 1984-1985										
Mean Intensity, *M*	-1.79	-1.62	-1.65	-2.02	-1.60	-1.44	-1.20			
Duration, D (months)	31.00	9.00	17.00	17.00	8.00	17.00	25.00			
Severity, S	-55.38	-14.60	-28.04	-34.30	-12.83	-24.41	-29.89			
Maximum intensity, Mmax	-3.81	-3.58	-3.18	-3.12	-3.16	-2.89	-2.59			
Historic drought events in the year 1995-1996										
Mean Intensity, *M*		-0.75	-0.55		-0.50	-0.73	-0.95	-0.59	-0.81	-0.17
Duration, D (months)		3.00	8.00		5.00	2.00	17.00	6.00	5.00	5.00
Severity, S		-2.24	-4.38		-2.52	-1.46	-16.10	-3.56	-4.05	-0.84
Maximum intensity, Mmax		-1.28	-1.48		-1.00	-0.82	-1.52	-0.95	-1.41	-0.29
Historic drought events in the year 2003-2004										
Mean Intensity, *M*	-0.78	-0.57	-0.86	-0.93	-0.34	-0.66	-0.84	-0.27	-0.81	-0.91
Duration, D (months)	16.00	3.00	18.00	24.00	7.00	18.00	27.00	5.00	9.00	13.00
Severity, S	-12.47	-1.71	-15.54	-22.20	-2.36	-11.79	-22.73	-1.36	-7.26	-11.85
Maximum intensity, Mmax	-1.46	-1.39	-1.74	-1.91	-0.67	-1.48	-1.52	-0.53	-1.54	-1.38
Historic drought events in the year 2009-2010										
Mean Intensity, *M*	-1.19	-1.01	-0.88	-0.66	-0.95	-0.79	-0.58	-1.87	-1.09	-1.23
Duration, D (months)	61.00	5.00	7.00	28.00	5.00	7.00	30.00	4.00	17.00	23.00
Severity, S	-72.70	-5.03	-6.15	-18.49	-4.74	-5.52	-17.52	-7.50	-18.59	-28.33
Maximum intensity, Mmax	-2.29	-2.00	-1.46	-1.35	-2.00	-1.38	-1.24	-3.85	-4.03	-3.56

Characteristics of the historic drought events for Pawi Station Grid (09,06)										
Data Type	**ECMWF Soil Moisture Data set**	**ECMWF Data set**			**Biased Corrected ECMWF Data set**			**Observed PPT Data Set**		
Drought Index	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Historic drought events in the year 1984-1985										
Mean Intensity, *M*	-1.01	-1.25	-1.45	-1.16	-1.16	-1.54	-1.43			
Duration, D (months)	10.00	16.00	17.00	21.00	20.00	19.00	25.00			
Severity, S	-10.11	-19.97	-24.71	-24.30	-23.12	-29.28	-35.69			
Maximum intensity, Mmax	-1.76	-2.43	-2.76	-2.15	-2.09	-2.42	-2.66			
Historic drought events in the year 1995-1996										
Mean Intensity, *M*	-1.01	-0.75	-0.75	-0.37	-0.96	-1.10	-0.58	-0.53	-0.56	-0.69
Duration, D (months)	9.00	7.00	6.00	9.00	7.00	5.00	18.00	6.00	7.00	21.00
Severity, S	-9.12	-5.23	-4.50	-3.32	-6.74	-5.49	-10.41	-3.16	-3.95	-14.43
Maximum intensity, Mmax	-1.68	-1.61	-1.67	-0.62	-1.61	-1.67	-0.95	-0.96	-0.97	-1.34
Historic drought events in the year 2003-2004										
Mean Intensity, *M*	-1.28	-1.16	-1.02	-1.45	-1.35	-1.51	-1.04	-1.02	-0.39	-0.65
Duration, D (months)	26.00	9.00	23.00	39.00	8.00	11.00	49.00	3.00	9.00	23.00
Severity, S	-33.30	-10.41	-23.41	-56.42	-10.80	-16.60	-50.94	-3.07	-3.50	-14.84
Maximum intensity, Mmax	-2.73	-1.88	-2.08	-2.54	-2.19	-2.54	-2.20	-1.60	-1.27	-1.15
Historic drought events in the year 2009-2010										
Mean Intensity, *M*	-1.38	-1.28	-0.87	-0.95	-1.04	-0.93	-0.69	-1.49	-1.37	-1.79
Duration, D (months)	24.00	4.00	10.00	12.00	4.00	6.00	11.00	5.00	15.00	16.00
Severity, S	-33.10	-5.13	-8.65	-11.38	-4.17	-5.55	-7.62	-7.43	-20.50	-28.59
Maximum intensity, Mmax	-2.81	-1.99	-1.72	-1.25	-1.62	-1.41	-0.92	-2.57	-2.26	-3.23

Characteristics of the historic drought events for Chewahit Station Grid (11,07)										
Data Type	**ECMWF Soil Moisture Data set**	**ECMWF Data set**			**Biased Corrected ECMWF Data set**			**Observed PPT Data Set**		
Drought Index	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Historic drought events in the year 1984-1985										
Mean Intensity, *M*	-1.73	-1.01	-1.01	-0.78	-0.93	-0.77	-0.87			
Duration, D (months)	70.00	7.00	13.00	31.00	10.00	32.00	37.00			
Severity, S	-121.02	-7.08	-13.16	-24.06	-9.26	-24.74	-32.04			
Maximum intensity, Mmax	-3.37	-2.21	-1.85	-1.48	-2.48	-2.13	-1.64			
Historic drought events in the year 1995-1996										
Mean Intensity, *M*	-2.25	-1.17	-1.13	-1.22	-0.54	-0.71	-0.61	-1.14	-1.30	-0.48
Duration, D (months)	24.00	9.00	20.00	23.00	7.00	16.00	17.00	6.00	7.00	29.00
Severity, S	-54.05	-10.57	-22.58	-28.02	-3.81	-11.37	-10.34	-6.82	-9.11	-13.98
Maximum intensity, Mmax	-3.37	-1.77	-2.21	-2.12	-1.46	-2.18	-1.22	-1.99	-1.88	-0.99
Historic drought events in the year 2003-2004										
Mean Intensity, *M*	-1.50	-1.02	-0.81	-0.88	-0.75	-0.80	-0.60	-0.99	-1.07	-1.01
Duration, D (months)	13.00	6.00	9.00	33.00	8.00	11.00	33.00	9.00	12.00	60.00
Severity, S	-19.49	-6.11	-7.31	-29.13	-5.97	-8.76	-19.91	-8.95	-12.89	-60.71
Maximum intensity, Mmax	-2.43	-2.43	-1.56	-1.87	-1.29	-1.49	-1.40	-1.44	-1.76	-2.45
Historic drought events in the year 2009-2010										
Mean Intensity, *M*	-1.81	-0.27	-0.34	0.00	-0.41	-0.13		-0.86	-1.05	-1.01
Duration, D (months)	40.00	2.00	2.00	0.00	3.00	3.00		16.00	17.00	21.00
Severity, S	-72.53	-0.54	-0.67	0.00	-1.24	-0.38		-13.82	-17.89	-21.25
Maximum intensity, Mmax	-3.74	-0.52	-0.53	0.00	-0.64	-0.27		-1.69	-2.06	-1.97

Ranking of historic drought events for Chawit Station Grid (11,07)									
Data Type		**ECMWF Data set**					**Biased Corrected ECMWF Data set**		
Drought Index	**Historical**	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**	**Historical**	**SPI_3**	**SPI_6**	**SPI_12**
Mean Intensity, *M*	Largest Intensity was 1995_1996	1995-1996	1984-1985	1995-1996	1995_1996	Largest Intensity was 1984_85	1984-1985	2003-2004	1984-1985
		2009-2010	2003-2004	1984-1985	2003-2004		2003_2004	1984-1985	1995-1996
		1984-1985	1984-1985	2003-2004	1984-1985		1995-1996	1995-1996	2003-2004
		2003-2004	2009-2010	2009-2010	2009-2010		2009-2010	2009-2010	2009-2010
Duration, D (months)	Longest Duration 1995_1996	1984-1985	1995-1996	1995-1996	2003-2004	Longest Duration 1984_1985	1984-1985	1984-1985	1984-1985
		2009-2010	1984-1985	1984-1985	1984-1985		2003-2004	1995-1996	2003_2004
		1995-1996	2003-2004	2003-2004	1995-1996		1995-1996	2003-2004	1995-1996
		2003_2004	2009-2010	2009-2010	2009-2010		2009-2010	2009-2010	2009-2010
Severity, S	Most Sever Drought Was 1995_1996	1984-1985	1995-1996	1995-1996	2003-2004	Most Sever Drought Was 1984_1985	1984-1985	1984-1985	1984-1985
		2009-2010	1984-1985	1984-1985	1995-1996		2003-2004	1995-1996	2003_2004
		1995-1996	2003-2004	2003-2004	1995-1996		1995-1996	2003-2004	1995-1996
		2003_2004	2009-2010	2009-2010	2009-2010		2009-2010	2009-2010	2009-2010
Maximum intensity, Mmax	Maximum Intensity Was in 1995_96	2009-2010	2003-2004	1995-1996	1995-1996	Maximum Intensity Was in 1984_85	1984-1985	1995-1996	1984-1985
		1984-1985	1984-1985	1984-1985	2003-2004		2003_2004	1984-1985	2003_2004
		1995-1996	1995-1996	2003-2004	1984-1985		1995-1996	2003-2004	1995-1996
		2003-2004	2009-2010	2009-2010	2009-2010		2009-2010	2009-2010	2009-2010

Probability of Capturing Drought for Abedela Station Grid (03, 05))									
Data Type	ECMWF Data set			Bias Corrected ECMWF Data set			Observed PPT Data Set		
	SPI_3	SPI_6	SPI_12	SPI_3	SPI_6	SPI_12	SPI_3	SPI_6	SPI_12
Drought Categories									
Extremely Wet	3.19	4.41	5.39	1.47	1.47	0.00	2.47	0.93	2.16
Very Wet	3.43	2.21	0.98	4.17	2.94	2.94	4.01	5.56	4.01
Moderately we	5.88	5.64	6.62	9.56	9.56	9.31	10.49	10.19	8.33
Mildly wet	38.48	37.25	36.27	33.58	38.24	44.12	33.02	35.49	40.43
Mild drought	36.27	37.25	39.95	38.97	32.84	27.21	34.57	32.10	29.63
Moderate drought	8.09	8.33	5.88	5.39	7.11	7.60	9.26	7.72	4.94
Severe drought	3.19	3.43	2.45	3.92	4.90	5.88	4.32	5.25	8.95
Extreme drought	1.47	1.47	2.45	2.94	2.94	2.94	1.85	2.78	1.54

Probability of Capturing Drought For Kone Station Grid (03,07)									
Data Type	ECMWF Data set			Bias Corrected ECMWF Data set			Observed PPT Data Set		
	SPI_3	SPI_6	SPI_12	SPI_3	SPI_6	SPI_12	SPI_3	SPI_6	SPI_12
Drought Categories									
Extremely Wet	2.94	4.17	5.64	0.98	1.23	0.00	2.78	1.85	2.78
Very Wet	3.19	1.72	0.25	4.66	2.94	2.70	3.09	1.85	3.40
Moderately we	6.86	6.86	2.21	8.82	10.05	12.25	8.02	8.33	6.17
Mildly wet	38.48	35.54	41.91	36.03	37.50	36.52	37.65	44.44	42.59
Mild drought	35.29	41.67	40.69	37.25	35.54	37.50	31.79	28.70	29.01
Moderate drought	6.37	4.66	5.39	4.66	5.64	5.39	9.88	6.48	6.48
Severe drought	4.41	2.21	0.98	4.17	3.43	2.45	4.94	4.63	7.72
Extreme drought	2.45	3.19	2.94	3.43	3.68	3.19	1.85	3.70	1.85

Probability of Capturing Drought for Dengoro Station Grid (04,04)									
Data Type	**ECMWF Data set**			**Bias Corrected ECMWF Data set**			**Observed PPT Data Set**		
	SPI_3	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Extremely Wet	2.70	2.70	1.23	1.23	0.74	0.00	1.54	2.16	1.23
Very Wet	4.17	4.66	7.35	4.41	2.70	1.96	4.01	3.40	6.79
Moderately we	8.33	8.09	8.33	7.84	10.78	7.60	10.49	8.64	8.95
Mildly wet	32.60	35.29	35.29	36.27	40.93	51.47	35.80	37.96	31.48
Mild drought	40.93	33.33	26.72	38.48	30.15	23.28	34.57	32.10	38.58
Moderate drought	6.37	9.56	14.95	4.41	5.88	4.66	8.02	11.11	6.79
Severe drought	3.43	5.15	5.39	4.17	4.41	4.17	4.01	2.47	3.09
Extreme drought	1.47	1.23	0.74	3.19	4.41	6.86	1.54	2.16	3.09

Probability of Capturing Drought for Derba Station Grid (05,10)									
Data Type	**ECMWF Data set**			**Bias Corrected ECMWF Data set**			**Observed PPT Data Set**		
	SPI_3	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Extremely Wet	1.72	1.96	1.72	1.23	2.45	3.92	4.63	5.25	6.17
Very Wet	3.19	3.92	3.43	3.43	4.66	2.21	3.40	3.40	4.32
Moderately we	7.60	8.82	7.60	6.86	6.62	7.35	4.63	5.25	7.72
Mildly wet	41.67	38.24	41.67	43.38	35.29	37.75	32.72	26.85	21.30
Mild drought	32.84	33.82	32.60	29.90	37.50	37.01	42.59	48.15	51.54
Moderate drought	5.39	6.13	5.15	7.84	6.86	4.90	8.02	7.41	8.02
Severe drought	3.68	3.43	3.43	4.41	3.43	3.19	3.40	3.09	0.62
Extreme drought	3.92	3.68	4.41	2.94	3.19	3.68	0.62	0.62	0.31

Probability of Capturing Drought for Mendi Station Grid (06,03)									
Data Type	**ECMWF Data set**			**Bias Corrected ECMWF Data set**			**Observed PPT Data Set**		
	SPI_3	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Drought Categories									
Extremely Wet	2.45	2.21	0.98	2.45	1.23	2.70	0.31	0.62	0.00
Very Wet	4.41	5.39	6.86	3.19	4.41	2.45	4.01	1.54	0.00
Moderately we	7.11	5.88	9.07	9.07	8.33	6.86	8.95	10.80	8.33
Mildly wet	37.99	39.46	35.78	34.80	37.99	39.95	42.28	46.30	50.93
Mild drought	34.80	32.11	32.60	36.76	33.82	32.84	30.56	26.23	28.09
Moderate drought	7.11	7.60	7.35	8.09	6.37	8.58	6.48	6.79	4.01
Severe drought	4.17	5.15	3.68	3.43	5.64	2.70	4.32	3.70	4.01
Extreme drought	1.96	2.21	3.68	2.21	2.21	3.92	3.09	4.01	4.63

Probability of Capturing Drought For Gidayana Station Grid (06,06)									
Data Type	**ECMWF Data set**			**Bias Corrected ECMWF Data set**			**Observed PPT Data Set**		
	SPI_3	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**	**SPI_3**	**SPI_6**	**SPI_12**
Drought Categories									
Extremely Wet	2.94	4.41	4.66	2.21	3.19	2.94	1.23	0.93	0.62
Very Wet	4.66	2.21	3.92	5.39	3.19	5.39	4.94	4.01	2.78
Moderately we	8.09	8.33	5.88	7.35	8.58	6.37	7.72	8.64	6.48
Mildly wet	34.56	34.80	36.27	33.33	33.58	33.09	41.67	44.14	51.85
Mild drought	35.29	34.31	34.07	36.03	34.07	35.05	29.32	27.78	20.68
Moderate drought	9.07	10.54	10.05	10.05	11.27	9.07	7.72	8.33	10.19
Severe drought	3.92	3.68	3.43	3.68	4.41	6.62	3.40	0.93	2.16
Extreme drought	1.47	1.72	1.72	1.96	1.72	1.47	4.01	5.25	5.25

Probability of Capturing Drought for Dejen Station Grid (06,09)									
Data Type	ECMWF Data set			Bias Corrected ECMWF Data set			Observed PPT Data Set		
	SPI_3	SPI_6	SPI_12	SPI_3	SPI_6	SPI_12	SPI_3	SPI_6	SPI_12
Drought Categories									
Extremely Wet	1.47	2.70	2.70	1.72	3.68	5.88	3.09	4.01	4.32
Very Wet	2.70	4.17	5.88	3.92	3.19	3.43	4.63	3.70	3.09
Moderately we	10.29	7.60	5.88	8.58	6.86	6.13	9.26	8.33	4.32
Mildly wet	40.69	38.24	36.76	38.48	35.78	26.72	31.79	31.48	41.36
Mild drought	29.41	31.37	35.78	30.15	36.27	44.36	35.49	37.35	31.17
Moderate drought	7.60	9.80	6.13	10.29	6.86	10.78	10.49	10.49	8.02
Severe drought	4.41	4.17	3.92	3.43	5.64	1.72	4.63	3.40	6.79
Extreme drought	3.43	1.96	2.94	3.43	1.72	0.98	0.62	1.23	0.93

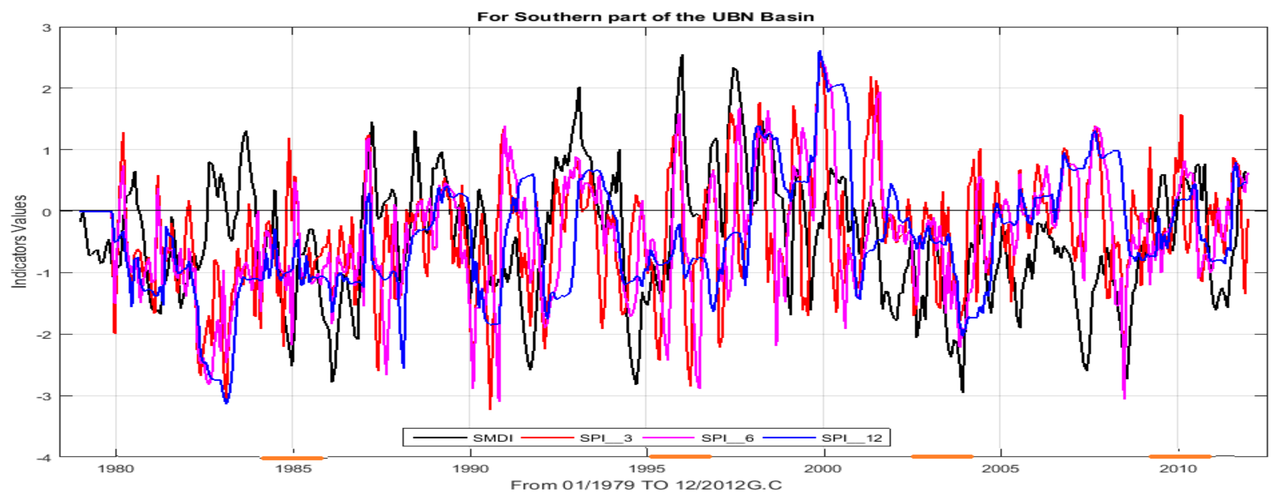
Probability of Capturing Drought for Mehal Meda Station Grid (07,12)									
Data Type	ECMWF Data set			Biased Corrected ECMWF Data set			Observed PPT Data Set		
	SPI_3	SPI_6	SPI_12	SPI_3	SPI_6	SPI_12	SPI_3	SPI_6	SPI_12
Drought Categories									
Extremely Wet	1.96	2.45	1.23	1.23	1.72	1.23	0.62	0.62	0.62
Very Wet	3.19	3.68	4.17	4.66	4.66	2.70	2.78	4.32	5.86
Moderately we	7.84	6.13	9.31	8.09	8.09	10.78	9.57	9.26	9.26
Mildly wet	42.16	43.38	42.40	38.24	36.52	39.46	45.06	44.14	37.65
Mild drought	30.39	28.92	28.43	33.58	32.84	29.66	27.47	26.85	28.40
Moderate drought	6.37	8.09	5.39	5.39	8.58	7.11	8.33	9.26	13.58
Severe drought	5.15	3.43	4.41	5.39	3.92	5.39	2.78	2.16	3.09
Extreme drought	2.94	3.92	4.66	3.43	3.68	3.68	3.40	3.40	1.54

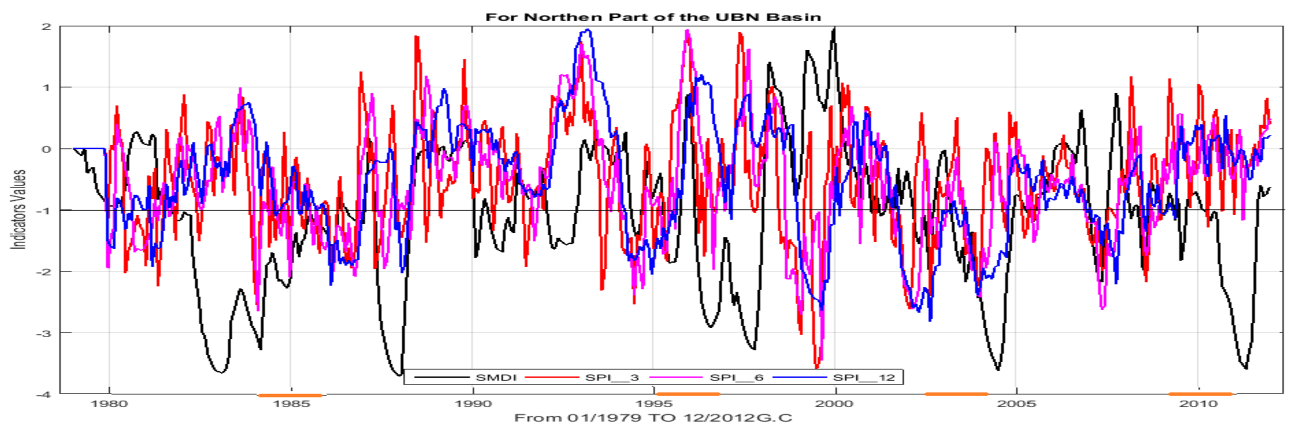
Probability of Capturing Drought for Combolcha Station Grid (08,12)									
Data Type	ECMWF Data set			Biased Corrected ECMWF Data set			Observed PPT Data Set		
	SPI_3	SPI_6	SPI_12	SPI_3	SPI_6	SPI_12	SPI_3	SPI_6	SPI_12
Drought Categories									
Extremely Wet	1.96	2.94	2.94	1.72	2.21	0.98	1.23	0.93	0.62
Very Wet	3.19	2.94	3.92	3.43	4.17	3.68	2.16	3.40	5.86
Moderately we	8.58	5.39	7.35	9.56	7.11	7.84	7.72	11.11	9.26
Mildly wet	40.93	45.59	40.93	35.54	37.99	38.97	45.68	37.96	36.11
Mild drought	30.88	26.72	30.64	34.07	33.82	33.82	31.17	34.26	32.72
Moderate drought	6.37	9.07	5.88	8.09	7.84	8.09	3.40	5.86	8.95
Severe drought	4.90	3.92	4.66	4.66	2.94	1.96	5.25	2.78	4.01
Extreme drought	3.19	3.43	3.68	2.94	3.92	4.66	3.40	3.70	2.47

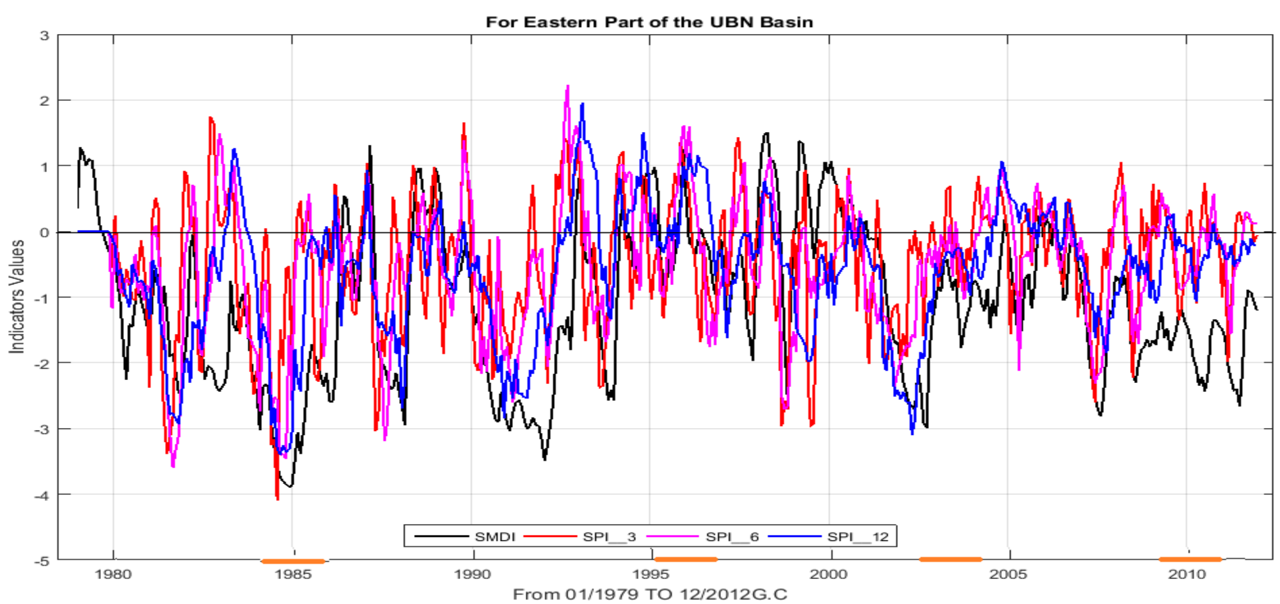
Probability of Capturing Drought for Pawi Station Grid (09,06)									
Data Type	ECMWF Data set			Biased Corrected ECMWF Data set			Observed PPT Data Set		
	SPI_3	SPI_6	SPI_12	SPI_3	SPI_6	SPI_12	SPI_3	SPI_6	SPI_12
Drought Categories									
Extremely Wet	2.45	2.70	4.17	2.21	3.68	2.70	1.85	2.78	0.93
Very Wet	3.68	4.66	2.45	5.39	3.92	6.62	4.94	2.47	6.79
Moderately we	10.29	7.60	5.88	8.09	7.84	7.84	6.79	8.02	8.64
Mildly wet	33.82	34.80	42.40	31.13	31.86	29.66	40.43	41.05	37.96
Mild drought	34.80	35.05	29.66	36.76	37.75	42.40	32.41	33.02	33.95
Moderate drought	9.31	9.07	8.33	10.54	8.82	4.41	8.95	4.94	4.32
Severe drought	3.68	3.92	4.66	4.66	3.92	2.94	2.78	3.09	4.32
Extreme drought	1.96	2.21	2.45	1.23	2.21	3.43	1.85	4.63	3.09

Annex D Regional Analysis of drought indices

Time Series Plot for Drought Indices







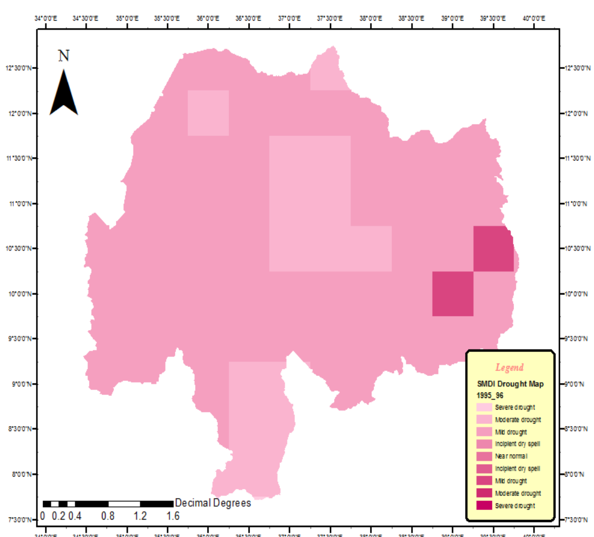
Characteristics of the Historic Drought Events

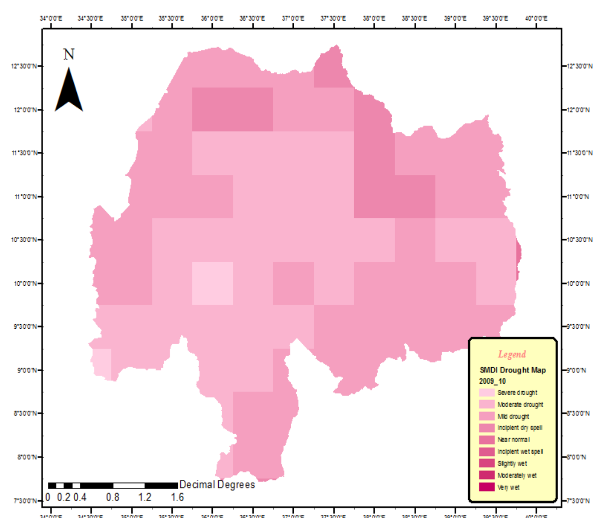
Characteristics of the historic drought events for Southern Part of UBNB				
Data Type	**ECMWF Data set**			
Drought Index	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**
Historic drought events in the year 1984-1985				
Mean Intensity, *M*	-1.41	-0.89	-0.94	-1.37
Duration, D (months)	30.00	13.00	12.00	67.00
Severity, S	-42.37	-11.60	-11.33	-91.98
Maximum intensity, Mmax	-2.79	-2.21	-2.18	-3.15
Historic drought events in the year 1995-1996				
Mean Intensity, *M*	-1.45	-1.31	-1.15	-0.83
Duration, D (months)	18.00	8.00	10.00	47.00
Severity, S	-26.01	-10.49	-11.55	-39.08
Maximum intensity, Mmax	-2.83	-2.43	-2.43	-1.64
Historic drought events in the year 2003-2004				
Mean Intensity, *M*	-1.30	-0.73	-0.87	-0.86
Duration, D (months)	37.00	11.00	29.00	34.00
Severity, S	-48.22	-8.05	-25.16	-29.40
Maximum intensity, Mmax	-2.95	-1.71	-2.22	-2.03
Historic drought events in the year 2009-2010				
Mean Intensity, *M*	-1.21	-0.53	-0.73	-0.59
Duration, D (months)	36.00	7.00	22.00	17.00
Severity, S	-43.49	-3.73	-16.04	-9.96
Maximum intensity, Mmax	-2.73	-0.95	-3.06	-0.82

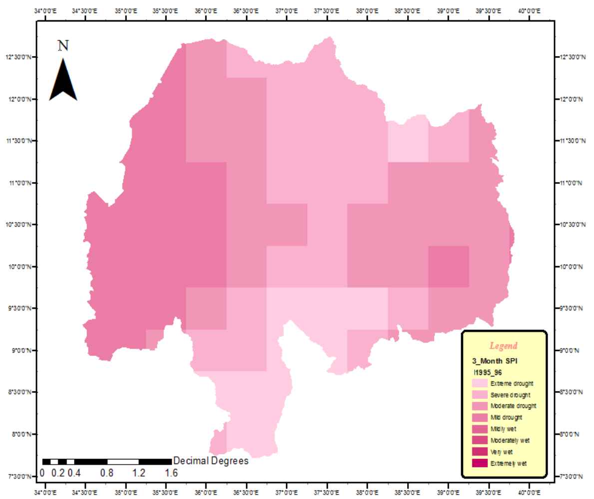
Characteristics of the historic drought events for Eastern Part of UBNB				
Data Type	**ECMWF Data set**			
Drought Index	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**
Historic drought events in the year 1984-1985				
Mean Intensity, *M*	-2.34	-1.47	-1.64	-1.61
Duration, D (months)	50.00	10.00	23.00	27.00
Severity, S	-117.13	-14.74	-37.68	-43.36
Maximum intensity, Mmax	-3.89	-2.47	-3.47	-3.39
Historic drought events in the year 1995-1996				
Mean Intensity, *M*	-0.58	-0.57	-0.92	-0.23
Duration, D (months)	6.00	6.00	11.00	4.00
Severity, S	-3.48	-3.44	-10.12	-0.90
Maximum intensity, Mmax	-0.90	-1.19	-1.76	-0.32
Historic drought events in the year 2003-2004				
Mean Intensity, *M*	-1.28	-0.56	-1.07	-1.14
Duration, D (months)	47.00	5.00	30.00	44.00
Severity, S	-60.09	-2.78	-32.20	-50.24
Maximum intensity, Mmax	-2.98	-1.59	-2.36	-3.09
Historic drought events in the year 2009-2010				
Mean Intensity, *M*	-1.64	-0.91	-0.89	-0.81
Duration, D (months)	63.00	7.00	8.00	32.00
Severity, S	-103.52	-6.37	-7.12	-25.79
Maximum intensity, Mmax	-2.82	-2.22	-1.72	-1.85

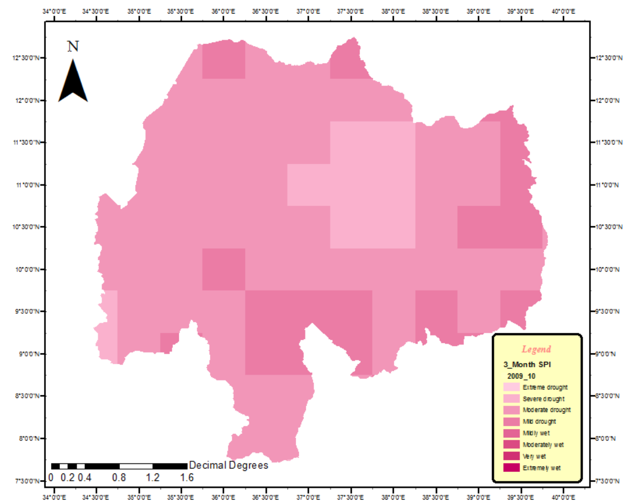
Characteristics of the historic drought events for Northern Part of UBNB				
Data Type	**ECMWF Data set**			
Drought Index	**SMDI**	**SPI_3**	**SPI_6**	**SPI_12**
Historic drought events in the year 1984-1985				
Mean Intensity, *M*	-1.89	-1.16	-1.25	-0.99
Duration, D (months)	72.00	25.00	38.00	41.00
Severity, S	-136.16	-29.08	-47.37	-40.42
Maximum intensity, Mmax	-3.66	-1.98	-2.65	-2.24
Historic drought events in the year 1995-1996				
Mean Intensity, *M*	-1.06	-1.19	-1.16	-1.32
Duration, D (months)	19.00	18.00	25.00	23.00
Severity, S	-20.16	-21.45	-29.08	-30.43
Maximum intensity, Mmax	-1.88	-2.55	-2.40	-2.05
Historic drought events in the year 2003-2004				
Mean Intensity, *M*	-1.24	-0.83	-1.27	-1.48
Duration, D (months)	71.00	11.00	44.00	51.00
Severity, S	-88.03	-9.10	-55.90	-75.43
Maximum intensity, Mmax	-3.62	-2.41	-2.61	-2.82
Historic drought events in the year 2009-2010				
Mean Intensity, *M*	-1.44	-0.81	-0.98	-0.91
Duration, D (months)	51.00	11.00	10.00	46.00
Severity, S	-73.68	-8.89	-9.79	-42.06
Maximum intensity, Mmax	-3.60	-2.18	-1.75	-2.21

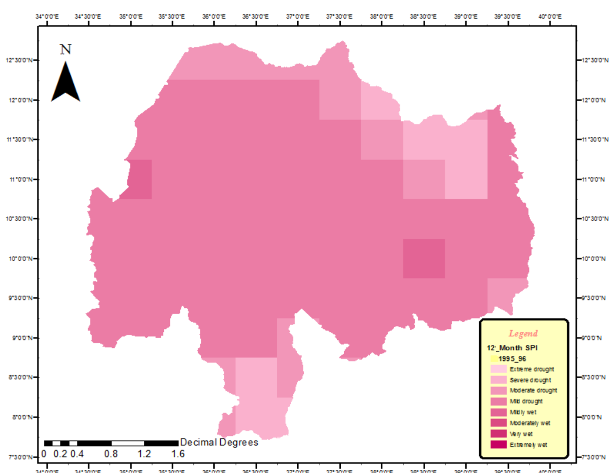
Drought Map

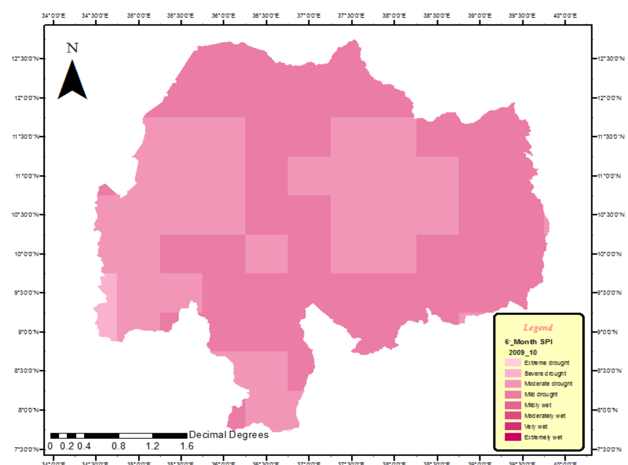


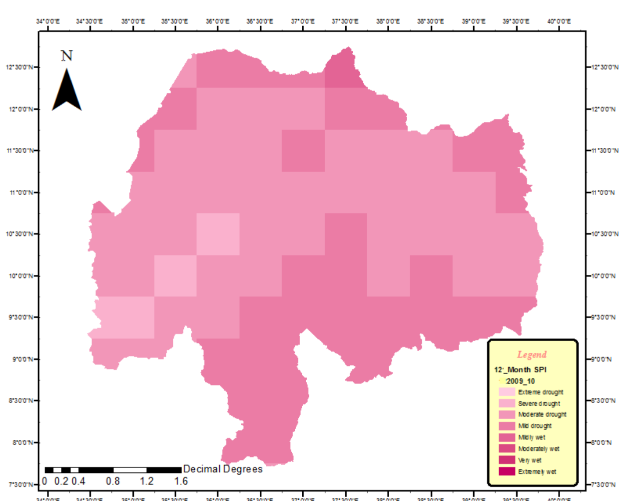


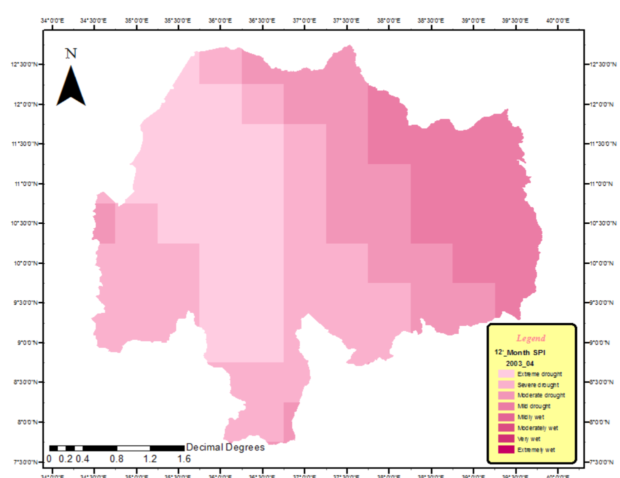

N
Legend
3_Month SPI
I1995_96
Extreme drought
Severe drought
Moderate drought
Mild drought
Mildly wet
Moderately wet
Very wet
Extremely wet
Decimal Degrees
0 0.2 0.4 0.8 1.2 1.6

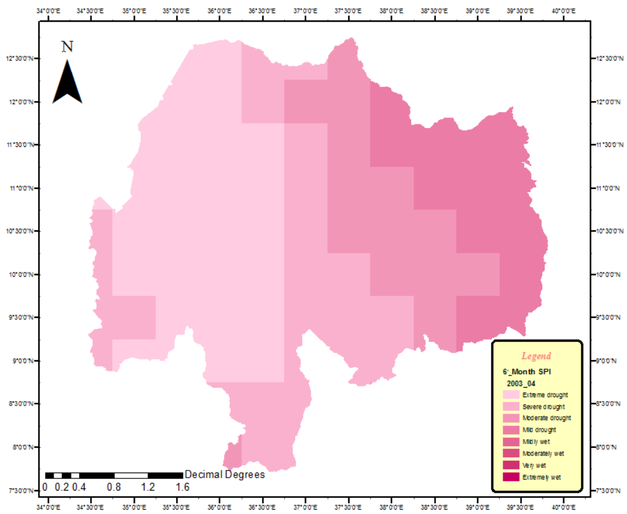

N
Legend
3_Month SPI
2009_10
Extreme drought
Severe drought
Moderate drought
Mild drought
Mildly wet
Moderately wet
Very wet
Extremely wet
Decimal Degrees
0 0.2 0.4 0.8 1.2 1.6

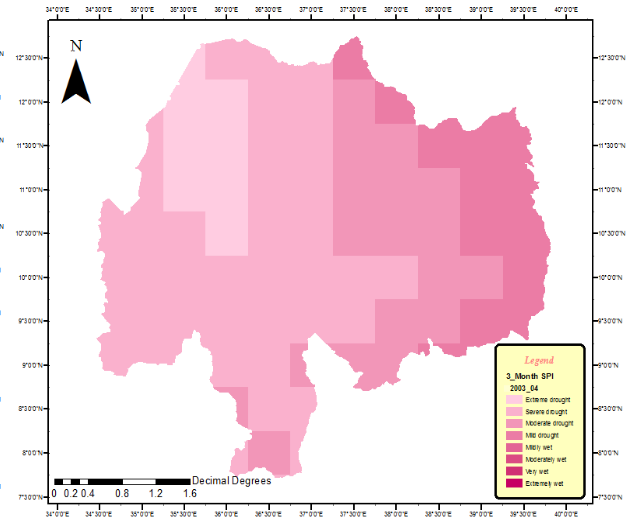

N
Legend
12_Month SPI
1995_96
Extreme drought
Severe drought
Moderate drought
Mild drought
Mildly wet
Moderately wet
Very wet
Extremely wet
Decimal Degrees
0 0.2 0.4 0.8 1.2 1.6

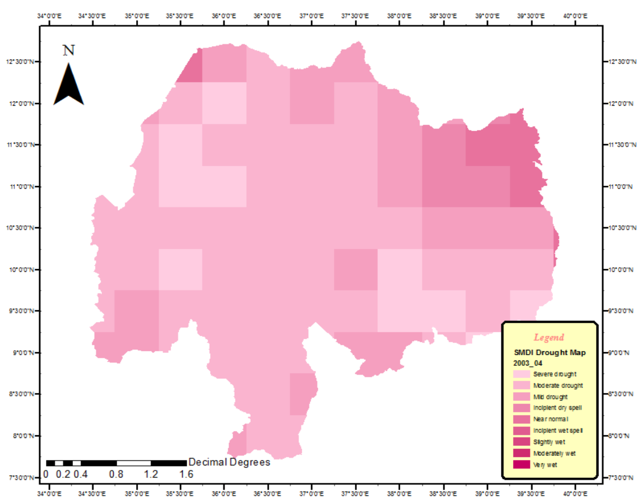

N
Legend
6_Month SPI
2009_10
Extreme drought
Severe drought
Moderate drought
Mild drought
Mildly wet
Moderately wet
Very wet
Extremely wet
Decimal Degrees
0 0.2 0.4 0.8 1.2 1.6


N
Legend
12_Month SPI
2009_10
Extreme drought
Severe drought
Moderate drought
Mild drought
Mildly wet
Moderately wet
Very wet
Extremely wet
Decimal Degrees
0 0.2 0.4 0.8 1.2 1.6


N
Legend
12_Month SPI
2003_04
Extreme drought
Severe drought
Moderate drought
Mild drought
Mildly wet
Moderately wet
Very wet
Extremely wet
Decimal Degrees
0 0.2 0.4 0.8 1.2 1.6


N
Decimal Degrees
0 0.2 0.4 0.8 1.2 1.6
Legend
6_Month SPI
2003_04
Extreme drought
Severe drought
Moderate drought
Mild drought
Mildly wet
Moderately wet
Very wet
Extremely wet


N
Decimal Degrees
0 0.2 0.4 0.8 1.2 1.6
Legend
3_Month SPI
2003_04
Extreme drought
Severe drought
Moderate drought
Mild drought
Mildly wet
Moderately wet
Very wet
Extremely wet


N
Decimal Degrees
0 0.2 0.4 0.8 1.2 1.6
Legend
SMDI Drought Map
2003_04
Severe drought
Moderate drought
Mild drought
Incipient dry spell
Near normal
Incipient wet spell
Slightly wet
Moderately wet
Very wet