# Precipitation Extremes and Their Pattern in the Central Highlands of Ethiopia: SPI Based Analysis

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**Abstract**
Precipitation extremes are the most important occurrences that need to be studied with maximum possible care as they are always related with damages of any kind. Extreme precipitation deficit is the most notable among the occurrences of the extreme climate events in Ethiopia. However, the other extreme is also essential in understanding the precipitation and the effect of climate variability in Ethiopia. Accordingly, the present study critically focused on examining the occurrences of both extremes for detecting and monitoring extreme drought and wet conditions in the central highlands of Ethiopia. A standardized precipitation Index has been employed on a thirty years monthly precipitation record. The results indicated that the long term precipitation analysis based on SPI showed that there has been relatively some deficit precipitation amounts observed in the third decade of the study period. A total of 17 extreme dry conditions occurred in this particular decade and the same decade had comparable occurrences of 16 extreme wet ones in the district The other two decades had 3 and 9 extremely deficit precipitations conditions with their respective orders, decade first and second. Similarly in thirty years of monthly total precipitation record, the SPI detected that there were 10 and 3 extreme precipitation surplus in the first and second decades respectively.
**Keywords:** Extremes, SPI

## 1. Introduction

Seasonal variations and atmospheric pressure systems contribute to the creation of three distinct seasons in Ethiopia: Kiremt (June to September), Bega (October to February) and Belg (March to May). The Kiremt is the main rainy and Belg is the short lasting one while the dry season is attributed to Bega (Selshi and Zanke, 2004). The country usually receives its highest rainfall (50-80%) when the rainfall low pressure center/trough is established in the northern equatorial region following the sun's apparent movement towards the northern hemisphere. Some areas in the eastern and northern parts of the country also receive short(Belg) rain from as early as February to May as a result of penetration of rain bearing winds in to Ethiopia during this period (Cmberlin and Philippon, 2001).

Rainfall is highly variable both in amount and distribution across regions and seasons (Tesfaye, 2003, Tilahun, 1999: Mersha, 1999). Some climate extreme phenomenons have been observed in recent years of 1980s. Out of the many reflections of those events, precipitation extremes are usually associated with physical and then socio economic damages whenever they occur. The occurrences of those events are typically reflected through damaging floods and severe droughts of different types. The most notable occurrences of precipitation extremes in Ethiopia are related with droughts but some experiences of the extreme wet events causing floods and some damages: lose of life, infrastructural collapses have also been reported (Wing et.al. 2008).

During the last centaury, Ethiopia's climate variability and subsequent agricultural as well as socioeconomic crises attracted strong global attention. There have been substantial evidences reporting the shortfalls of precipitation and its space-time variability in Ethiopia had lead to recurrent and historic shortfalls in agricultural production, which claimed tens of thousands of human life and animal lives (Mahdi and Sauernborn, 2002; Wolde-Mariam, 194; Degefu, 1987; Hurni, 1993). During those years, the country suffered significant production deficit of about 20 % in the agricultural sector, resulting in a decrease of total annual production by about one million tones (Mahdi and Sauerborn, 2002).

The central highlands of Ethiopia received long term average summer rainfall of 660mm in 100 years period of observation, with standard deviation of 162mm and a variability coefficient of 24%. A minimum rainfall of 355 mm and a maximum of 1594 mm were recorded for the summer period; with an extreme average of 619mm. Rainfall followed a clearly decreasing trend for most of the areas the central highlands of Ethiopia, with some exceptions like in this particular district (Bishoftu) which was observed to experience an increasing one (Mahdi and Sauerborn, 2002).

However detailed analysis and temporal characterization of the extreme dry and wet events has not been worked out with sufficient amount in the central highlands of Ethiopia. The reasons are mostly related with availability and continuity of weather data for the region. For the regions with sufficient and complete data set, a kind of work will help in identifying different forms of drought: meteorological, agricultural and hydrological and subsequently the results will be used in the decision making and early warning systems.

In this regard, some drought indices have been developed for detecting, monitoring and evaluating drought occurrences and events based on long climatic and physical data. Drought indices are the functions of several hydro meteorological variables (e.g., rainfall, temperature, stream flow, snowmelt, etc...). There exist some different indices that measure precipitation deficiency in a given time period from historical average. Most frequently used index of this type is standardized precipitation index-SPI (McKee et.al., 1993). SPI represents the meaning of precipitation amount during specified time period in relation to the normal precipitation for that period.

The main advantage this index is its standard nature and flexible time scale of calculation. It also helps to identify the initiation, termination and duration of both the dry and wet events in a defined period of time.

The purpose of this study was to analyze the occurrences, duration and extent of the extreme precipitation events for a selected district in the central highlands of Ethiopia for two crop growing seasons.

## 2. Materials and Methods

The data used in this study was collected from a site located at $38^0 51'43.63''$E and $8^0 46'16.20$ in the South East of the capital of Ethiopia, Addis Ababa.

Precipitation data of monthly values has been organized and summarized in a suitable format for calculation. The time series of monthly precipitation data of 30 years (1978-2007) was then made to fit the gamma distribution function:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} \ell^{\frac{-x}{b}} \quad (1)$$

Where:

$\alpha > 0$, is a shape parameter

$\beta > 0$, is a scale parameter

X is the precipitation amount

$$\Gamma(\alpha) = \int_0^{\infty} y^{a-1} \ell^{-y} dy \quad (2)$$

Where, $\Gamma(\alpha)$ is the gamma function

The values of alpha and beta ($\alpha$ and $\beta$) in the function were estimated using the following equations;

$$\overset{\lambda}{\alpha} = \frac{1}{4} A\left[1 + \sqrt{1 + \frac{4A}{3}}\right] \quad (3)$$

$$\beta = \frac{\bar{X}}{\overset{\lambda}{\alpha}} \quad (4)$$

$$A = \ln\left(\bar{X}\right) - \frac{\sum \ln x}{n} \quad (5)$$

Where,

X is the precipitation amount and,

$\bar{x}$ is the mean precipitation of the series.

The resulting parameters, alpha and beta, were then entered into excel program of gamma distribution function to obtain the cumulative probabilities of each of monthly rainfall record for the selected station describing the district. Since the gamma function is not defined for zero values and the series of the data contained many zeros, the cumulative probability of each rainfall event was then estimated through the following equation:

$$H(x) = q + (1 - q)\, G(x) \quad (6)$$

q is the probability of zero which was estimated as the proportion of zeros in the rainfall data series.
The SPI was then computed as (Abramowitz and Stegun 1965)

$$Z = SPI = -\left[ t - \frac{c_0 + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right] \quad (7)$$

For 0 < H<(x)≤ 0.5

$$Z = SPI = +\left[ t - \frac{c_o + c_1 t + c_2 t^2}{1 + d_1 t + d_2 t^2 + d_3 t^3} \right] \quad (8)$$

For 0.5 < H(x) < 1
Where,

t= $\sqrt{\ln \frac{1}{(H_{(X)})^2}}$ for 0<H(x) $\leq$ 0.5 and

t= $\sqrt{\ln(\frac{1}{(1 - H(x))^2}}$ 0.5<H(x) <1

$C_0$ = 2.515517 $d_1$= 1.432788
$C_1$ = 0.802853 $d_2$= 0.189269
$C_2$ = 0.010328 $d_3$= 0.00130

The cumulative probability was then transformed in to standard random variable, Z being described as the SPI values for each of the precipitation events of desired time scale.
Four time scales have been used to analyze the occurrences of the extreme precipitation events: one- month, three month, six-month and twelve-month or SPI-1, SPI-3, SPI-6 and SPI-12 respectively. The first two were used to describe the moisture conditions while the latter two for evaluating the hydrological conditions in the study area. The dry and wet classification has been based on the works of Vermes (1998).

**3. Results and Discussions**

The district had more percentage of occurrences of precipitation values in the near normal range in all the time scales used for this study reaching as low as 66% and as high as 74% for SPI-3 and SPI-1 respectively (Figure 1). The same figure also indicated that the occurrences of the extremes (both dry and wet) are kept minimum: less than 5% in all the time scales for each of the SPI category.
More specifically extreme precipitation deficit was observed to last from March 1995 to August 1995 on SPI-6 time scale and the same occurred from August 1995 to March 1996 and another continuous extreme dry condition appeared from September 1996 to February 1997 on 12-Months time scale. There were no continuous occurrences of extreme dry conditions observed in the shortest time scales, SPI-1 and SPI-3 (Figure2). The above results clearly illustrates that the year1995/96 has been significantly affected with reasonable hydrological drought conditions. This could have been due to lower and decreasing trend of annual rainfall values persisted from 1994 to 1997 in the district. Similarly, a continuous extreme precipitation surplus was also observed from June to August of the year 2002. The reasons for this is probably linked to a sharp increase in the annual rainfall series during this period after a prolonged decline in the late 1990's
The long term precipitation analysis based on SPI showed that there has been relatively some deficit precipitation amounts observed in the third decade of the study period. A total of 17 extreme dry conditions occurred in this particular decade and the same decade had comparable occurrences of 16 extreme wet ones in the district (Figure 3). This is in agreement with the results from Seleshi and Demaree (1995) stating that it was only after the 1990s that the central highlands experienced excessive years with rainfall higher than the long term averages. The other two decades had 3 and 9 extremely deficit precipitations conditions with their respective orders, decade first and second. Similarly in thirty years of monthly total precipitation record, the SPI detected that there were 10 and 3 extreme precipitation surplus in the first and second decades respectively.
A correlation analysis was done among the SPI out puts of different time scales to see the strength of one explains the other. Accordingly the results obtained showed that the shorter time scales (SPI-1 and SPI-3) had good correlation with each other while the longer ones did the same (Table2). Thus the results from SPI-3 are used to describe the precipitation conditions of shorter period (Soil moisture conditions) and the SPI-12

 

represents the longer period (Hydrological conditions) for monitoring and detecting the dry and wet events in the district. Similarly, the months of March and June, the beginnings of short rainy and the main rainy season respectively, and that of August for its high rainfall period were selected to describe the status of the particular seasons.

Accordingly, the year 1995 experienced two extreme dry conditions occurred in March and August in the 3 and 12 –Month time scales respectively. The month of June had extreme precipitation deficit in the years: 1992 and 1992 in the shorter time scale, SPI-3. The 12-Monthe time scale detected another extreme precipitation conditions in the year: 1996. The extreme surplus precipitation condition appeared in the months of June and August of the year 2002 (Figure 4)

To Summarize, These results in general put in picture that there has no been significant rainfall deficiency causing any of the drought reflections (meteorological, hydrological...) for most of the years in the study period. This study calls for substantial and critical examinations of monitoring and evaluation of extreme precipitation conditions based on different precipitation and drought indices, like PDSI (Palmer's Drought Severity Index) for comparisons and better explanations of precipitations conditions.

## 4. Conclusions

The standardized precipitation index (SPI) has been proven to detect the extreme precipitation conditions in the study area. The tool is extremely important in areas where hydrological data is very limited as it only consumes precipitation data. Thus, the use of the index is helpful in most parts of Ethiopia which have only ordinary weather stations. It will also be encouraging to compare the results of the index with some other ones in areas where data availability is less critical. Therefore the authors of this study would recommend that the present results are supported with the analysis obtained form other precipitation and drought indices.

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Figures and Tables

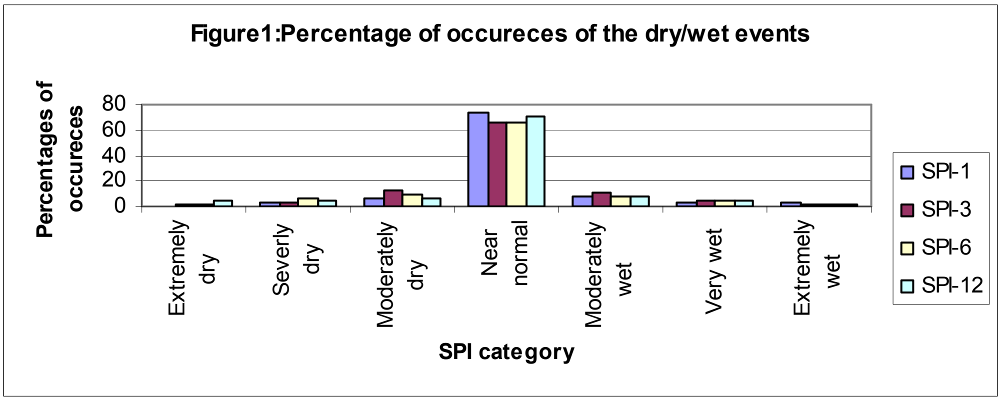

Figure1:Percentage of occureces of the dry/wet events

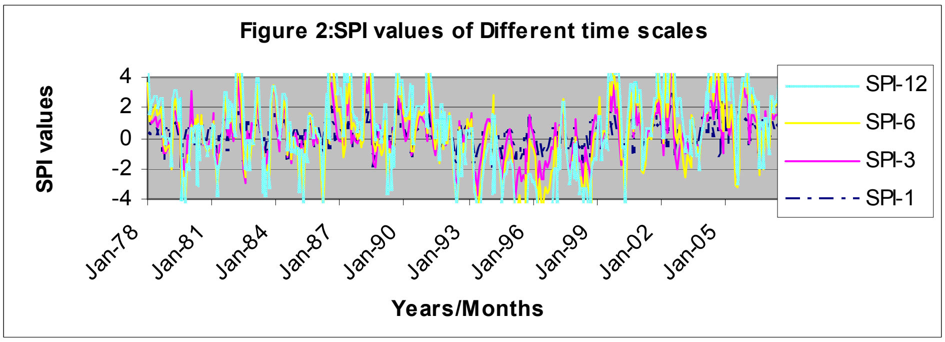

Figure 2:SPI values of Different time scales

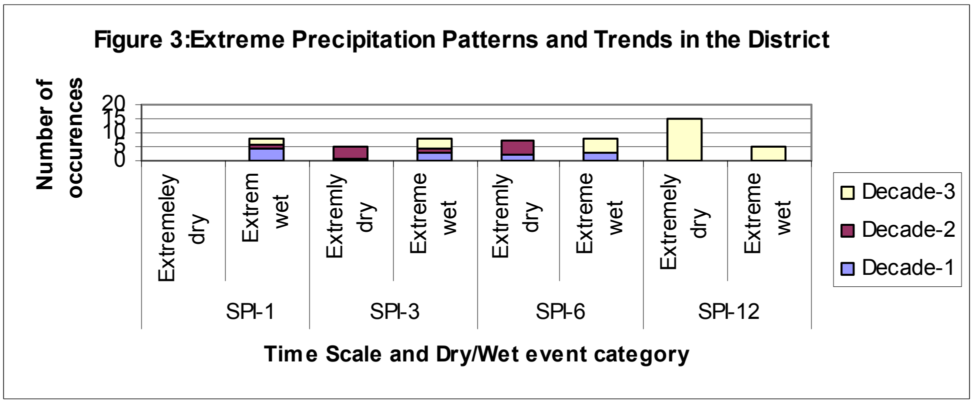

Figure 3:Extreme Precipitation Patterns and Trends in the District

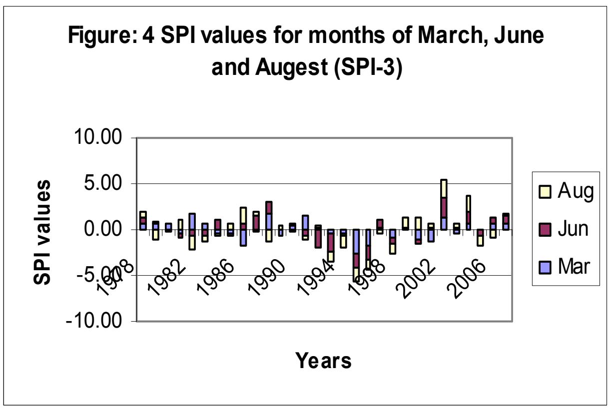

Figure: 4 SPI values for months of March, June and Augest (SPI-3)

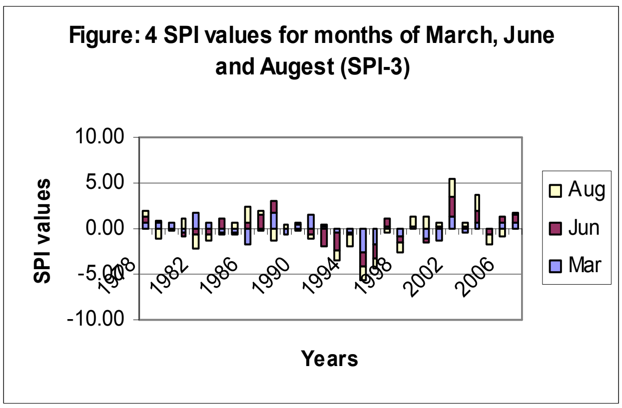

Figure: 4 SPI values for months of March, June and Augest (SPI-3)

Table 1 Classification of SPI values and corresponding Probability of occurrences

| SPI classes | Probability | Period classification |
|---|---|---|
| SPI<-2 | 0.0228 | Extremely dry |
| -2<SPI<-1.5 | 0.0441 | Severely dry |
| -1.5<SPI<-1 | 0.0918 | Moderately dry |
| -1<SPI<1 | 0.6827 | Near normal |
| 1<SPI<1.5 | 0.0918 | Moderately wet |
| 1.5<SPI<2 | 0.0441 | Very wet |
| SPI>2 | 0.0228 | Extremely wet |

Table 1 Cross correlation between the SPI values

| | *SPI- 1* | *SPI-3* | *SPI-6* | *SPI-12* |
|---|---|---|---|---|
| SPI-1 | 1 | | | |
| SPI 3 | **0.581497** | 1 | | |
| SPI- 6 | 0.377551 | **0.654795** | 1 | |
| SPI-12 | 0.276422 | 0.464935 | **0.680436** | 1 |