Interactive Drought Monitoring Information System: A Case Study on Standardized Precipitation Index for Ethiopia

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Abstract

Drought has the effect of creating inconvenience on most of the creatures on the surface of the earth, particularly human beings. It has long been recognized as one of the most insidious causes of human misery and being the natural disaster that annually claims the most victims. Ethiopia has experienced at least five major national droughts since 1980, along with literally dozens of local droughts.

The current drought monitoring mechanism in Ethiopia is the conventional method that uses meteorological data. It is not adequate to monitor drought using only weather or meteorological data called point data which is data that is used to represent the entire "Woreda" or district. Meteorological data is cumbersome to process. Currently there is no framework that serves as a guideline for drought monitoring for Ethiopia. Remote sensing based decadal Tropical Applications of Meteorological Satellite (TAMSAT) rainfall estimate data was used to develop decadal Standardized Precipitation Index (SPI) based drought monitoring system and moreover a framework was identified. Interpolating of the SPI was done to cover all locations. A total of 2812 points were used to develop the tool and interpolation of these SPI values was done using a script written in Matlab. The output from the script was maps that show drought information. On the maps continuous SPI datasets values that show continuous drought severity information was produced from the points data and this will help decision makers to get reliable information on drought so that they will make on time and accurate decisions.

Keywords: Drought; Framework; Interpolation; Point data; SPI

1. Introduction

Drought has the effect of creating inconvenience on most of the creatures on the surface of the earth, particularly human beings; due to the severity or impact it posed on the living conditions. Its ability to cause widespread misery and inconvenience is actually increasing from time to time in rapid way without a well-known fashion or pattern [1]. Drought definitions vary from region to region and may depend upon the dominating perception or related with whether the drought is operational or conceptual and the task for which it is defined; either for academic study or a drought-relief plan [2]. As described in [3] operational definitions are formulated in terms of drought index which is used in this paper.

Drought has been a recurring phenomenon in Ethiopia for millennia, having been recorded at least as early as 253 BC, and frequently since then [4]. It creates great impact on the economy consequently on crop failure and famine in Ethiopia, especially in the 1973-1986. The impact was shown on the agricultural sector, non-agricultural sectors, and macro-economic level of the country. Drought was one of the major problems of Ethiopia since 253 BC [4]. Table 1 shows the impact of drought in Ethiopia [5].

Table 1: The impact of drought in Ethiopia

Type of Poverty	*People in Poverty (%)*
Observed poverty	47.3
Predicted Poverty with no drought shocks	33.1
Predicted poverty with no shocks of any kind	29.4

The problem of drought in the country is not only reflected in agriculture, but also in non agricultural sectors like industrial production which declined during 1973-1974 [4]. Nomadic and transhumant pastoralism is the most efficient form of land use for parts of arid and semi-arid lands, where crop production is very risky due to high climatic variability [6].

Despite the important contribution that pastoralism makes to African economies, particularly in Ethiopia, due to lack of enough rainfall the sector is not giving its potential value. This is caused mainly by the recurring drought and lack of mitigation options in Ethiopia.

The current drought monitoring mechanism in Ethiopia is the traditional method that uses meteorological data. It is not adequate to monitor drought using only meteorological data. Additionally, gathering meteorological data is a cumbersome process [7]. Therefore, in the country lack of up-to-date information on state of drought is seen as a fundamental problem. This is because there are no sufficient tools for drought monitoring. In addition, currently there is no framework that serves as a guideline for monitoring drought using precipitation data.

The purpose of this work is that even though meteorological drought cannot be avoided but its impact can be greatly influenced by timely and effective intervention by the development of timely drought monitoring mechanisms. The mechanisms include the development of drought monitoring procedures like framework and drought severity indicative tool. In order to be able to predict drought conditions, it is necessary to capture historical data sets which are the critical parameters considered as the input for the calculation of the Standard Precipitation Index (SPI). Hence, the main aim of this research is to develop rainfall based drought monitoring system using satellite rainfall estimate data (RFE). The specific objectives of the research are to develop 1) a framework for drought monitoring information system using precipitation data, and 2) tool for drought monitoring using Standardized Precipitation Index.

In line with the above objectives, the research questions of this work are: 1) what is the appropriate framework for monitoring drought using precipitation data? and 2) what is the appropriate tool for realizing drought using precipitation data?

2. Literature Review

Among the disturbing things or disasters, drought can take the higher rank. This is because, in contrast to most of the accidents in which there are possible ways of controlling, it is not an easy task to control drought. A disaster can be described as an event, concentrated in time and space. Among all the hazards, drought is quite different. First, it is a creeping hazard, so-called because droughts develop slowly. A broad definition of drought is a deficiency of precipitation over an extended period of time, usually a season or more, which results in a water shortage for some activity. However, in terms of typologies, droughts are classified as meteorological, agricultural, hydrological, and socio-economic. Meteorological drought is a natural event that results from climatic causes, which differ from region to region. The rests highlight the interaction between the natural characteristics of meteorological drought and human activities. Second, droughts are not constrained to a particular tectonic or topographic setting and their impact can extend over very large regions. It is a long term environmental degradation and often difficult to tell where and when drought ends [8].

Droughts are caused by situations with temporarily less than normal water availability. One thing all droughts have in common is that they are caused by a deviation from normal conditions. The deviations can be in different forms and their effects vary accordingly. The effects of drought can be divided into primary and secondary effects. Primary effects of drought result from a lack of water and the results are loss of crops, livestock, and other animals. The most serious impacts result in famine. Secondary effects include major ecological changes and increased flash flooding [1].

In general, globally and especially in developing countries like Ethiopia without having proper strategies, drought is one of the significant natural disasters in terms of spatial extent, duration of exposure, mortality, and long-term socioeconomic and environmental implications, posing a serious impediment even to the achievement of the Millennium Development Goals (MDGs).

The physical, social, and economic situations in Ethiopia have contributed to the degradation of resources. There are different types of land cover formed by both human activities and natural factors over the last centuries [9]. Tatem *et al*. [10] noted that accurate information on land cover is required for both scientific research and undertaking management interventions.

The following methods are used to carry out drought assessment in which the first four are the conventional methods while the last one is said to be the modern method. They are: 1) ground field surveys, 2) remote reporting systems, 3) use of baseline data, 4) over flights, and 5) remote sensing. Conventional methods of drought monitoring suffer from limitations in reliability but satellite sensors have the capability to provide both spatial and temporal information of drought conditions such as the effects seen on vegetations called vegetation stress. This shows that a comprehensive and very descriptive study on droughts can be conducted using satellite sensors in a better way [11].

There are several factors to look into when choosing a remote sensing system for a particular application. These include spatial resolution, spectral resolution, radiometric resolution, and temporal resolution [12]. Temporal resolution is defined as the frequency at which images are recorded or captured in a specific place on the earth [13]. The more frequently it is captured, the better the temporal resolution is said to be.

Efforts have been made by different researchers or institutions to monitor drought using different techniques or data. Based on the time scale, there are two basic techniques commonly used to monitor drought. The earliest one was called the Palmer Drought Index (PDI) which is used as an indicator of drought severity, and a particular index value is often the signal to begin or discontinue elements of a drought contingency plan. This index was developed in 1965 and called the Palmer Drought Severity Index (PDSI) [14]. Variations of the index include the modified PDSI, the Palmer Hydrologic Drought Index, and the Z index. However, spatial and temporal comparisons can be misleading and lead to erroneous conclusions by users of the Palmer indices.

In addition to the Palmer index, a new one, called the Standardized Precipitation Index (SPI), was developed to give a better representation of wetness and dryness than the Palmer indices [14]. It was designed to be an indicator of drought that recognizes the importance of time scales. It is essentially a standardizing transform of the probability of the observed precipitation. McKee *et al*. [15] developed the SPI based on precipitation data. The SPI is calculated by fitting historical precipitation data to a Gamma probability distribution.

The Gamma distribution is frequently used to represent precipitation because it provides a flexible representation of a variety of distribution shapes while utilizing only two parameters, the shape and the scale [16]. In addition to the Gamma parameters, a third parameter describes the probability of zero rainfall during the interval. Hence, Gamma based distribution was used in this research.

Getachew *et al*. [7] suggested that, it is possible to use MeteoSat Second Generation (MSG) and historical National Oceanic and Atmospheric Administration (NOAA) data with some calibration and validation to identify and predict drought. NOAA is owned by the US government whereas MeteoSat Second Generation (MSG) is the new European system of geostationary meteorological satellites

The Tropical Applications of Meteorological Satellite (TAMSAT) generates 30 years time series of rainfall estimates for Africa based entirely on data from the MeteoSat satellite calibrated against local gauges. It is produced by the TAMSAT group at Reading University in the United Kingdom [20]. These estimates are combined with the observations from over 600 rain gauges. The result is a unique high-quality dataset. Hence in this paper due to its high accuracy, the TAMSAT based decadal (10 days cumulative) data is used to develop interactive drought monitoring system for Ethiopia using Standardized Precipitation Index.

Conceptually a framework is a set of policies widely accepted enough to serve as the guiding principles of doing a task within a particular discipline. In the area of software development, it is about the use of proven components to build a piece of software. Frameworks increase productivity and reduce the development costs through large-scale reuse. In Ethiopia there is no framework in the area of drought monitoring. Hence, in this study a new framework is developed to serve as a guideline for drought monitoring in the country. So, it is the base for the tool that shows information on drought using ten days (decadal) satellite based rainfall estimate (RFE) data.

The proposed framework is a three-layered approach with the following elements. These are the Data Input, Execution of SPI, and Information Presentation layers. From each layer, a unique task is expected and the lower layers deliver their tasks to their immediate upper layers. The flow or interaction between the elements and sub elements are illustrated in Figure 1. The Data Input Layer is the layer where the raw data is accepted and preprocessing tasks are carried out. In this study, in order to develop rainfall based drought monitoring system, satellite based rainfall estimate (RFE) was the source of the data. To make the data suitable and deliver to the next immediate layer for processing, the RFE data was converted to point data using software called Igore. In the Execution of SPI Layer processing of the data is done to have a big picture on the status of drought. In this study, as depicted in Figure 1 by sub elements of the layer by using the points data that were created in the lower, computation of the SPI values were done. The other unique task that was done in this layer is the extension of SPI values in order to show drought intensity using interpolation to make the SPI values continuous rather than point values. The Information Presentation Layer is the users' layer in which information seekers get reliable information about the drought status to go for further decisions. In this study, interactive Graphical User Interface (GUI) tool was developed. By use of the GUI, information seekers will be able to get drought severity status by virtue of the popup menu.

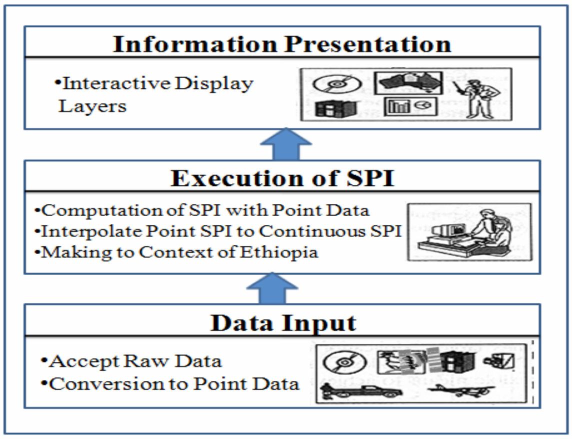

Figure 1: Three-Layered Approach Framework

3. Material and Methods

The study area for this research was Ethiopia. Ethiopia occupies the interior of the Horn of Africa, stretching between 3° and 14° N latitude and 33° and 48° E longitude, with a total area of 1.13 million km^2 [17].

Generally, data is information stored according to specific rules. The rules enable an interpreter to extract information from the data. Because this study was primarily focused on the effect of precipitation deficits on agricultural drought, the SPI was selected representing climatic data input and the rainfall climatic data for the SPI derivation was obtained from satellite rainfall estimates (RFE). RFE was used because the number of rain gauges in Ethiopia is very small to describe the whole country, and they are unevenly distributed. Currently there are more than ten satellite rainfall products at different spatial and temporal resolutions [18]. The RFE data for this research was obtained from Tropical Applications of Meteorological Satellite (TAMSAT), which is produced by the TAMSAT group at Reading University in the United Kingdom [18]. TAMSAT generates 30 year time series of rainfall estimates for Africa based entirely on data from the MeteoSat satellite calibrated against local gauges. The detailed descriptions of these products are presented in Dinku *et al.* [19] and the basic methodology of the cold cloud statistics procedures is simple.

For this research, RFE products from years 1983 to 2006, which were accumulated to 10-daily totals, were obtained from TAMSAT with spatial of 10km. There are three 10-day (decadal) composites per month; the first is for days 1 through 10, the second is for days 11 through 20, and the third is for the remaining days. Then, these decadal (10 days) values were summed and monthly values were taken. The 24 years (from 1983 to 2006) TAMSAT data is a raw rainfall estimate called RFE data. Preprocessing tasks have been done on the RFE data. One of these is the conversion of RFE data to point data with their respective latitude and longitude. Software called Igore was used for this purpose. Figure 2 shows the general procedures.

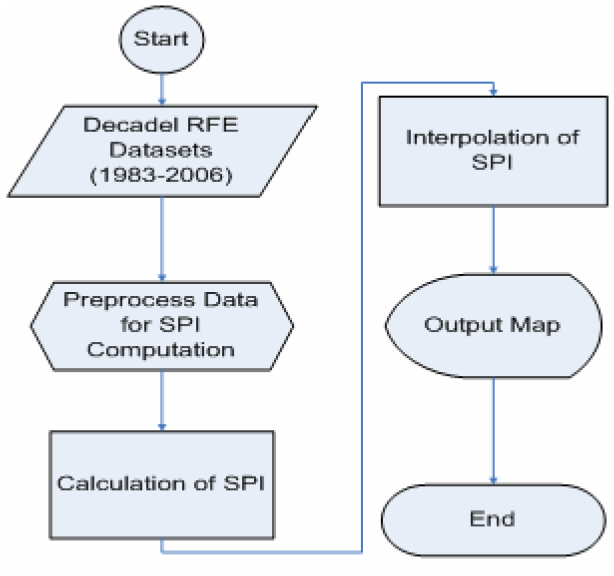

Figure 2: Overall Approaches of the Study

In this study more focus was given on the SPI. From the remote sensed historical data of 24 years which was collected by TAMSAT, points' data were created. There are 2812 points data that represent the entire country and they are 10km apart from their nearest. Earlier rainfall estimate data from 1983 to 2006 was used as input to the SPI program. It is more appropriate that for efficient computation of SPI, data for at least greater than 20 consecutive years is required. Input data was arranged in four column format: yyyy mm dec & pppp where, yyyy = year, mm = month, dec=decade, pppp = precipitation. A total of 2812 input files were created and one by one decadal SPI was computed for each point on time scale 3.

The SPI can be calculated for time scales that are important to the water analyst. Moving total time series are constructed from the observed precipitation data and then used for the SPI computation. For example, if the observed data consist of a time series of monthly precipitation amounts, and the analyst is interested in 3-month events, then a new time series is constructed by summing the first three monthly amounts, then summing the amounts in months 2, 3, and 4, etc. The 3-month SPI is then calculated from this new time series.

The first step in the calculation of the SPI is to determine a probability density function that describes the long-term series. Once this distribution is determined, the cumulative probability of an observed precipitation amount is computed. The inverse normal (Gaussian) function is then applied to the probability. The result is the SPI. SPI values are positive or negative for greater or less than median precipitation. The SPI was found to be a better drought monitoring index because of the following factors. 1) It is an index based on the probability of precipitation for any time scale. 2) Can provide early warning of drought and helps to assess drought severity. 3) It is less complex than the Palmer. 4) One number has historical context.

Since the SPI is equal to the Z-value of the normal distribution, McKee *et al.* [14] proposed a seven-category classification for the SPI: extremely wet ($z > 2.0$), very wet (1.5 to 1.99), moderately wet (1.0 to 1.49), near normal (-0.99 to 0.99), moderately dry (-1.49 to -1.0), severely dry (-1.99 to -1.5), and extremely dry (<-2.0). In summary, the SPI allocates a single numeric value to the precipitation (-3 to 3), which can be compared across regions with different climates.

In the study, for the data that were collected from the 1983 to 2006 of rainy seasons, SPI was calculated for the month August decadal one. Clearly, the result obtained from this is, August first decadal SPI using the 2812 points.

Given data that results from an experiment, there exists a function that passes through the data points and perfectly represents the interest at all non-data points. With interpolation, we seek a function that allows us to approximate values while passing through the original data set. Some of the concerns to take into account when choosing an appropriate algorithm are: a) How accurate is the method? b) How expensive is it? c) How smooth is the interpolant? and d) How many data points are needed? There are four commonly used interpolation methods: Piecewise constant, Linear, Polynomial, and Spline interpolation

Spatial interpolation is the process of estimating a value intermediate to the values of two or more known points in space. Depending on the spatial attributes of the data, accuracies vary widely among different interpolation methods. With respect to SPI, spatial interpolation can be described as the estimation of SPI at points that are not sampled. In this study, due to its ease to work with, the linear interpolation technique was used to interpolate the point SPI values using a script written in Matlab. Matlab was used because it has an interactive environment that enables us to perform computationally intensive tasks than with traditional programming languages such as FORTRAN, C++, etc. Further, it has the capability to provide us facilities to develop algorithms, data analysis, and visualization.

4. Analysis and Results

After preprocessing of the rainfall estimate data (RFE) to the point data, decadal based SPI calculating tool was written using the C language from these points using the SPI method discussed.

Three drought years are presented for demonstrating the concepts developed in this paper. The drought years used for this analysis were the years 1984, 2002, and 2003. For this purpose, five regions: Tigray, Amhara, Oromia, Afar, and Somali, are taken as samples for discussions in order to show the droughts intensity in Ethiopia. The year 1984 was described to be one of the worst droughts in Ethiopia [20]. Using the methods indicated above, the RFE data was used for producing the continuous drought extent of Ethiopia in 1984 for drought season of June to September. In 1984, the drought status in Tigray was severe in the northern, central, and eastern parts of the region in June and July. In August and September, the eastern part of this region was in relatively moderate drought severity and the northern and central parts were still in severe drought status. Figure 3 shows the drought extent of June 1984.

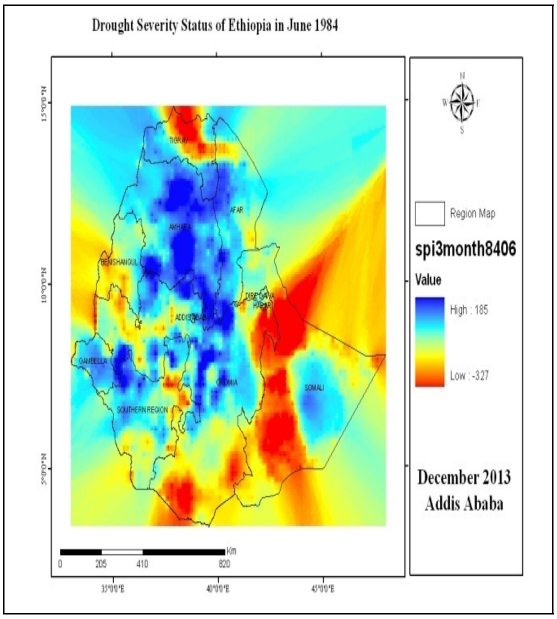

Figure 3: Drought extent of June 1984

As already discussed in SPI computation procedures section, the value of SPI ranges from -3 to 3 with seven categories. In this work, the SPI calculating tool produced a minimum value of -2.8 while the maximum value is 2.45, with standard deviation of 0.86 and an average SPI value of -0.1 for the first decade of August.

5. Conclusion and Future Work

Drought is one of the leading problems facing Ethiopia and its severity was observed in the country since 253 BC. This paper aims to provide new approaches to deal with the drought problem by producing continuous drought severity information using satellite rainfall estimate data. Using the framework as a reference, decadal SPI computing tool was developed. Using the tool, the 24 years historical TAMSAT RFE data was processed for the first decade of August. Since SPI output values from the tool were point values, interpolation was used as a technique to make the SPI values continuous and by doing so continuous SPI values were produced that show continuous drought severity information for the study area. Hence, the research questions of the study were addressed, consequently the two objectives were properly met and interesting results were found.

In the study, from the range of years (1983 to 2006) in which data were collected, three years (1984, 2002 and 2003) were selected and analyzed in detail for the selected season (rainy season from June to August) taking five regions (Tigray, Amhara, Oromia, Afar, and Somali) for discussion in the analysis of drought.

The scope of this study was showing continuous drought information for the study area and this was achieved by producing continuous SPI values from the points SPI. In the future the following must be done.

- Extension of the SPI tool has to be done in order to make the tool to accept and process continuous datasets.
- Accurately assessing impacts and trends requires both spatial and temporal analysis involving the development of detailed water level maps at various scales.

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