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# GIS-based climate variability and drought characterization in Ethiopia over three decades

K.V. Suryabhagavan

*School of Earth Sciences, Addis Ababa University, P.O. Box 1176, Addis Ababa, Ethiopia*

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ABSTRACT

The climate variability and drought frequency over potential crop growing regions of Ethiopia during 1983–2012 were analysed. Data from 87 weather stations across the country were used for this analysis. Ethiopian agricultural activities are highly dependent on the long rainy season (June–September) rainfall, which accounts for 70% of the total annual rainfall. There was no significant change in rainfall during annual and the bimodal seasons during this period of study. However, there was significant change in the rainfall coefficient of variation. STARDEX precipitation indices provided a measure of intensity, frequency and proportion of total rainfall. Ninetieth percentile of rainfall, number of rainy days with rainfall >10 mm/day and the greatest 10 d total rainfall were increased over time at most of the stations. Among the major droughts, 1984–'85 drought was reported as the most severe drought with peak negative SPI value −3.68 in Wollo. The longest duration of drought lasted for 63 months in Borena Zone in southern Ethiopia during 1983–2012 period. Extreme maximum temperature (90th percentile) has increased over 45% of the weather stations, while, extreme minimum temperature (90th percentile) has increased 53% of the weather stations. Extreme maximum temperature events have been increasing during the seasons in Ethiopia, which is the real concern for agricultural and livestock activities, as these sectors significantly contribute to about 50% of GDP for the country. However, given the increasing response capacity of the government, as observed during 2002–'03 drought, environmental disaster is expected to be under control over time.

## 1. Introduction

Climate change and variability in the Sub-Saharan Africa has considerable impact on agriculture, human health, livestock and the economy (Lipp et al., 2002; Haines and Patz, 2004; Confalonieri et al., 2007; Oscar et al., 2015). According to the Intergovernmental Panel on Climate Change (IPCC, 2014), there is significant warming occurring in the Sub-Saharan African countries. Whilst this warming is not uniform throughout the region, there is an observed increase in the number of warm spells and a decrease in extremely cold days. This has major implications for the agricultural sector, and will be critical for developing adaptive strategies to overcome this problem. Climate risk is a characteristic feature of Ethiopian agriculture, particularly in drought-prone areas. Agriculture is the mainstay of Ethiopian economy, which contributes for about 49% of Ethiopian GDP (Gross Domestic Product), generates more than 80% of the foreign exchange, and employs about 80% of the population (CSA, 2014). Ethiopian GDP is highly sensitive to variability of rainfall over time and space. Despite high contribution to the overall economy, agriculture in Ethiopia is challenged by many organizational, climatic and edaphic factors, of which climate related catastrophes such as drought, floods and irregularities in seasonal rainfall amount and distributions are the major ones (Deressa, 2007; Jaewon et al., 2015). The threats associated with climate variability in the region have been recognised since the 1960s and several efforts are under way to develop both mitigation and adaptation strategies to cope with this risk, though the outcomes are variable. Climate variability plays an important role in year-to- year variability in crop production and on the overall economy of the nation (Ngetich et al., 2014). Vulnerability of crop production to climate variability and changes can be decreased with crop specific climate information and use of such information in crop management decisions. Climate information has shown potential for improving resilience of agriculture to climate shocks. Despite of remarkable advancements in agricultural research in the past in many parts of the globe, climate remains as one of the critical factors challenging crop production in semi-arid regions of Ethiopia.

During the 1970s, 1980s and 1990s droughts in Ethiopia made massive economic loss and unparalleled human sufferings (Degefu, 1987; Berkele, 1987; Giorgis, 1987; Mishra and Cherkauer, 2009). Most devastating Ethiopian droughts were associated with failure of

*E-mail address:* drsuryabhagavan@gmail.com.

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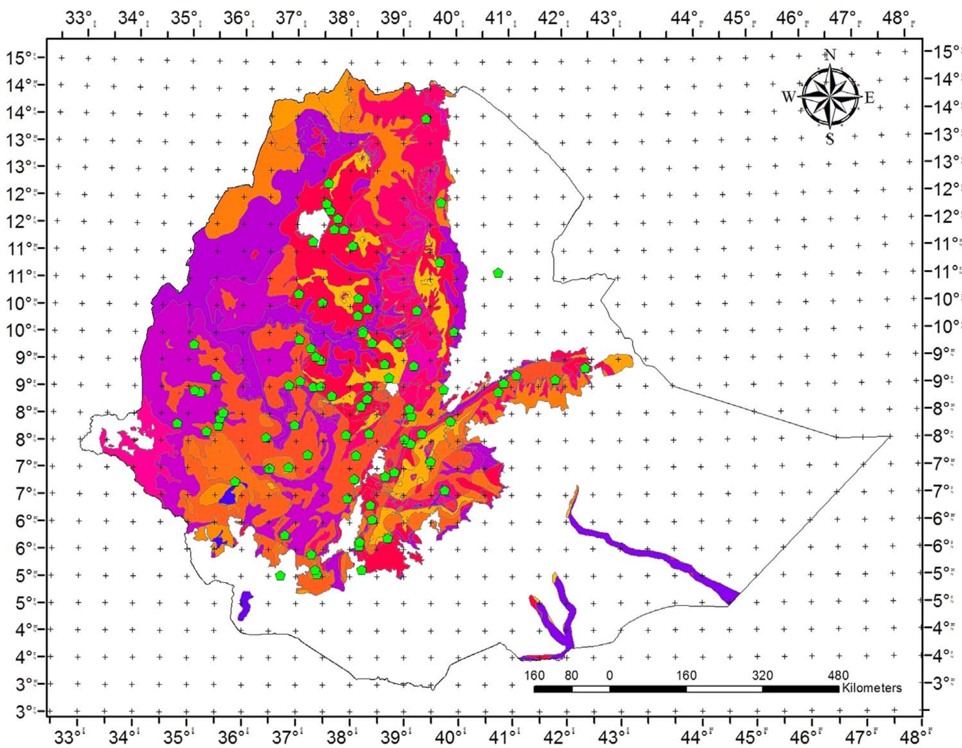


**Fig. 1.** Map displaying potential cropping area and locations of weather stations over Ethiopia.

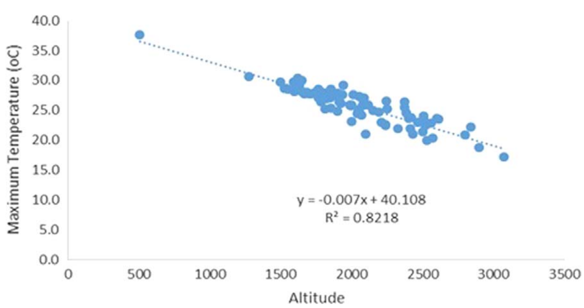


**Fig. 2.** Temperature variations over Ethiopia with changes in altitude of weather stations.

major rains (*Kiremt*, June–September) that account for 65–95% of the total annual rainfall, depending on the location. Fundamental understanding of *Kiremt* and the short seasonal rainfall (*Bleg*, March–May) depending on the regions and topography, for improving agricultural productivity in water scarce areas of Ethiopia was the motivation of the current study. Preliminary studies were undertaken to address the possible potential impacts of climate variability and changes on Ethiopian Agriculture (NMSA, 2001; Kidane et al., 2006; Deressa, 2007) and water resources (Kinfe, 1999; Deksyos and Abebe, 2006; Lijalem et al., 2006). These studies have analysed potential impacts of climate variability and changes on agriculture and suggested strategic crop adaptation measures.

Geographic information systems (GIS) and modeling have become critical tools in agricultural research and natural resource management (NRM), yet their utilization in the study area is minimal and inadequate. Utilization of GIS spatial-interpolation techniques such as inverse distance weighted (IDW) and Spline and Kriging interpolation techniques are some of the ArcGIS application tools essential for data reconstruction. To aid in understanding spatiotemporal occurrence and patterns of agro-climatic variables (e.g., rainfall), accurate and inexpensive quantitative approaches such as GIS modeling and availability of long-term data are essential. Most meteorological data in the study area are inconsistent, unrecorded, or missing, leading to more discrete and unreliable datasets for analysis. Besides the main stations themselves being several kilometres from the target area. These call for use of data reconstruction through interpolation.

Previous studies on drought were based on area average rainfall data for north central highlands of Ethiopia (Seleshi and Demaree, 1995; Osman and Sauerborn, 2002). These studies have revealed that the second half of the 20th century suffered predominantly with negative rainfall anomalies. Seleshi and Zanke (2004) studied rainfall variability over Ethiopia and illustrated that there was no significant trend in the rainfall and the rainy days. As per the available information, in Ethiopia, there were widespread droughts in frequency, severity and geospatial coverage occurred in 1965, 1969, 1973, 1983, 1987, 1989, 1997, 1998, 1999, 2003, 2005, 2008, 2009, and 2012, and over six million people suffered (Masih et al., 2014). It is the single most important climate related natural hazard impacting on the country from time to time. About a century ago, the frequency of drought occurrence in the country was once every 10 years (Gebrehiwot et al., 2011; Gizachew and Suryabhagavan, 2014; Seyoum Melese et al., 2016) but, at present drought has become more frequent. In response to the drought incidence, the Federal Government adopted its national Policy for Disaster Prevention, Preparedness and Management (Government of Ethiopia, 1993). According to this policy, each Woreda (Administrative district) is responsible to prepare drought contingency plans for local resilience (Hogg, 1997). As the economy of Ethiopia largely depends on rain-fed agriculture, frequent drought events result in severe economic losses, affects GDP growth, crop failure and severe impacts on livestock. According to Meze-Hausken (2004), many farms have shifted to more drought resistant crops in northern Ethiopia, as a consequence of the decline in rainfall during the past few decades. The impact of drought on water resources is also evident, particularly in the most populated area (the Great Rift Valley and the central Ethiopian highlands), where access to water supplies is limited (Funk et al., 2008). Even though some of the earlier studies (Hailemarian, 1999; Elisabeth, 2004; Zeleke et al., 2013; Birhanu et al., 2014) have assessed drought variability in Ethiopia, spatial and temporal variability of drought was not understood, especially at regional and sub-regional scales. Many such studies tend to focus on