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Agricultural Drought Assessment Using Remote Sensing and GIS Techniques: A Case Study of East Shewa Zone, Ethiopia

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Abstract

In dry land semi-arid areas of Ethiopia, including large parts of East Shewa Zone, agricultural drought is common, and farmers inhabiting the area experience extreme temporal and spatial variability of rainfall with longer dry spells in cropping seasons. This makes them vulnerable to the risk of agricultural drought. Thus, in order to adapt to the impact of agricultural drought, spatiotemporal variation of agricultural drought patterns and severity was assessed using different drought indices with the objective of assessing agricultural drought risk and preparing agricultural drought risk zone map. Indices-based results indicate that 2000-2005 cropping seasons experienced enhanced agricultural drought and yield reduction with observed spatial difference in severity level. The year 2002 was the most severe of all followed by 2000. The risk map indicates that East Shewa Zone is classified into slight, moderate and severe agricultural drought risk zones covering 17.18%, 41.32% and 41.50% of the total area, respectively.

Keywords: agricultural drought risk, GIS, remote sensing, rainfall variability, risk mapping, yield reduction

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Introduction

Climate has always been a dynamic entity, affecting natural systems through the consequences of climate variability and climate change. Frequent drought is an important aspect of climate variability and climate change that human being has been experiencing in recent decades. According to Segele and Lumb (2005: 89), Ethiopia has been experiencing severe drought over the last many decades, primarily due to the failure of its main (*kiremt*) rainy season. Areas affected by drought are increasing in Ethiopia due to climate change, climate variability and other human induced factors (WMO, 1986; NMSA, 1996). According to Wilhite and Glantz (1985: 10), drought can be classified into four, based on causative factors. *i. Meteorological drought* refers to a deficiency of precipitation, as compared to average conditions, over an extended period of time. It basically originates from the deficiency of precipitation and focuses on the physical characteristics of drought (Mokhtari, 2005) rather than impacts associated with shortage of precipitation; *ii. Agricultural drought* is defined as a reduction in soil moisture availability below the optimal level required by a crop during the different growth stages, resulting in impaired growth and reduced yields. It typically occurs after meteorological drought but before hydrological drought (Flood and Climate Basics, 2004); *iii. Hydrological drought* results when precipitation deficiencies begin to reduce the availability of natural and artificial surface and subsurface water resources. It occurs when there is substantial deficit in surface runoff below normal conditions; *iv. Socio-economic* drought occurs when human activities are affected by reduced precipitation and related water availability. This form of drought associates human activities with elements of meteorological, agricultural, and hydrological drought.

Agricultural drought produces a complex web of impacts that span many economic sectors. Agriculture is the primary economic sector affected by agricultural drought. Short term agricultural drought at critical growth stages has severe impacts on agriculture (Wu and Wilhite, 2004: 33). Agriculture remains by far the most important sector in Ethiopian economy. According to Sadoff (2006), 80% of Ethiopia's population subsists on rain fed agriculture, thus welfare and economic productivity are linked to the variable rain. This dependency on rain fed agriculture has made the country's economy extremely vulnerable to the impact of climate variability and climate change, usually manifested through rainfall variability and recurrent drought.

In dry land semi-arid areas of Ethiopia covering large part of East Shewa Zone, agricultural drought and crop failures have been common, and rain fed agriculture has yet to provide minimum food requirement for rapidly growing population. According to Reddy and Kidane Georgis (1993), dry land semi-arid areas, which cover about 46% of the total arable land in Ethiopia, contribute less than 10% of the total crop production in the country. This implies that rainfall is highly risky in terms of distribution, and the rate of evapo-transpiration is very high. Farmers inhabiting the area experience extreme temporal and spatial variability of rainfall in cropping season with frequent and longer dry spell affecting their agricultural productivity. The risks associated with agricultural drought are spatially variable; hence they require different adaptation strategies and options.

In order to adapt to the adverse impacts of agricultural drought, agricultural drought assessment and identification of risk zone have to be the primary tasks among others. Identification of agricultural drought risk zone is usually carried out by analysing of rainfall and evapo-transpiration data on long-time basis (Lemma, 1996: 1). This conventional method lacks identification of spatial variations (Jeyaseelan, 2004). Besides, collecting sufficient spatial and temporal data is difficult, especially in areas with rugged topography and less accessibility. The use of satellite data is, therefore, of paramount importance.

The advent of satellites has introduced an entirely new technology of satellite remote sensing and a whole range of its applications for the benefit of mankind. Currently, the use of remotely sensed data from satellite platforms for drought assessment has become quite common (Kogan, 1997; Alemayehu, 1999; Thenkabail et al., 2004: 23; Nageswara et al., 2005: 33; Chopra 2006; Beyene, 2007; Murali et al., 2008: 37). The use of satellite data using advanced techniques such as remote sensing and Geographic Information System (GIS) can be used for detecting and mapping agricultural drought prone areas. Agricultural drought risk mapping in turn is useful in the decision making process for drought monitoring and identifying appropriate sites for specific adaptation and mitigation actions. Hence, agricultural drought risk zone map produced from this study can be used by policy makers to prioritize their actions based on the risk level. It can also be used by researchers to generate agricultural technologies and information including selection of drought tolerant and adaptive crops, as well as generation of crop management and soil moisture conservation practices. Moreover, it may be helpful for development agents and Non-Governmental Organizations (NGOs) to facilitate scaling up of best technologies with success stories from similar risk zones elsewhere.

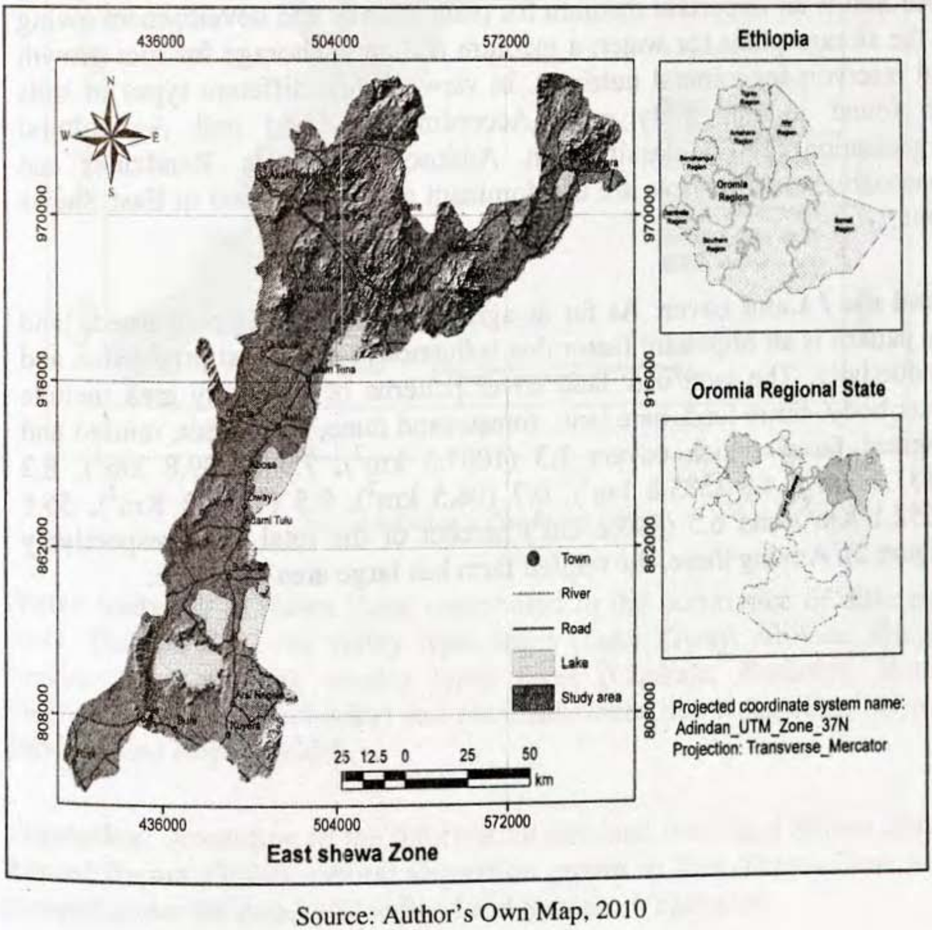
Since agricultural activities in the dry land semi-arid areas of Ethiopia in general and the study area, East Shewa Zone, in particular, are influenced and controlled by seasonal rain, the study of agricultural drought analysis was carried out season-wise using remote sensing image with the objectives of a) assessing agricultural drought risk using vegetation, climate and crop performance indices; b) estimating agricultural yield reduction due to moisture deficit; and c) preparing agricultural drought risk zone map showing the severity of drought condition at various levels.

Materials and Methods

Study Area

The present study was conducted in East Shewa Zone, Oromia Regional State of Ethiopia located at 38° 03' - 40° 05' E longitude and 7° 04' - 9° 10' N latitude, covering a total area of about 13,766.5 km^2 (Figure 1). The altitude of the study area ranges from 538 to 3,101m above sea level.

Figure 1. Location map of study area



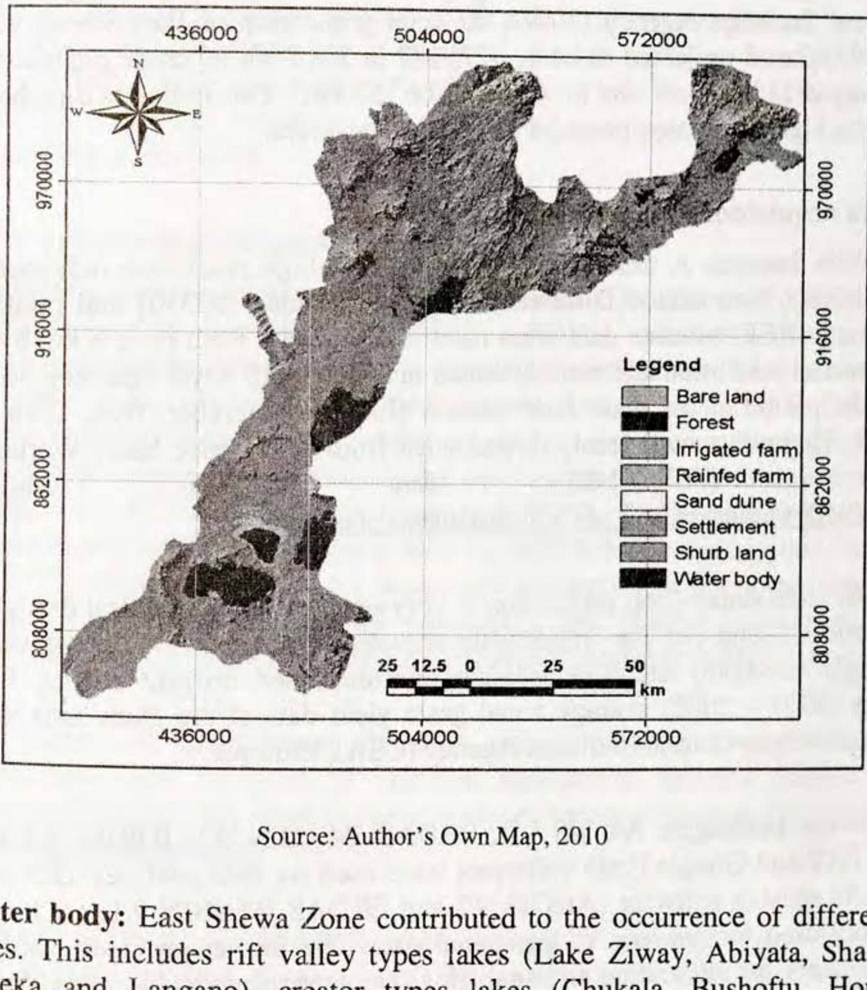
Source: Author's Own Map, 2010

Climate: East Shewa Zone is characterized by semi-arid and sub-humid climate based on the moisture index classification of climate (Lemma, 1996). Considering the long-term average seasonal (June – September) rainfall, the area receives 458 - 518 mm rainfall based on spatially interpolated rainfall data collected from National Meteorology Agency (NMA). Based on mean annual rainfall and temperature of the area, the major climatic classes of the zone are dry climate and tropical rainy climate. Dry climate includes the arid and semi-arid subdivision, while tropical rainy climate is characterized by tropical humid and sub-humid climate.

Soil: Soil is an important medium for plant growth and development owing to the storage place for water, a medium and an anchorage for root growth and reservoir for mineral nutrients. In view of this, different types of soils are found in the study area. According to Food and Agricultural Organization (FAO) classification, Andosols, Vertisols, Rendzinas and Phaeozems, and Fluvisols are the dominant soil types found in East Shewa Zone.

Land use / Land cover: As far as agricultural activity is concerned, land use pattern is an important factor that influences agricultural production and productivity. The land use/ land cover patterns of the study area include water body, shrub land, bare land, forest, sand dune, settlement, rainfed and irrigated farms which covers 7.3 (1007.3 km^2), 7.9 (1089.8 km^2), 8.2 (1131.6 km^2), 4.3 (585.8 km^2), 0.7 (96.5 km^2), 9.5 (1313.2 Km^2), 55.6 (7652.1 Km^2) and 6.5 (890.2 km^2) percent of the total area, respectively (Figure 2). Among these, the rainfed farm has large area coverage.

Figure 2. Land use/land cover map of the study area



Source: Author's Own Map, 2010

Water body: East Shewa Zone contributed to the occurrence of different lakes. This includes rift valley types lakes (Lake Ziway, Abiyata, Shala, Beseka and Langano), creator types lakes (Chukala, Bushoftu, Hora, Kuriftu, Green and Cheleleka) and manmade lakes like Koka (East Shewa Zone Annual Report, 2009).

Vegetation: According to the information obtained from East Shewa Zone Annual Report (2009), natural vegetation grown in East Shewa Zone are grouped under the Acacia Woodland and Savanna Vegetation.

Socio-economic conditions: Demographic data is very important in indicating the size and trends of population variables. According to the Central Statistics Agency (2007), the total population of East Shewa was 1,159,062 and projected to be 1, 477, 187 in 2015 while, crude population density is 120 per km^2 and projected to be 153 km^2. This indicates that there will be high population pressure on natural resources.

Data acquisition and software package

Satellite images: A time series advanced very high resolution radiometer (AVHRR), Normalized Difference Vegetation Index (NDVI) and rainfall estimate (REF) satellite data were used in this study. Both have 8 km by 8 km spatial resolution and were obtained in dekadal (10 days) time step basis for the period of the main rainy season (June – September) from 1996 to 2008. These data were freely downloaded from the Famine Early Warning System (FEWS-NET) data archive website: http://earlywarning.cr.usgs.gov/adds/datatheme.php.

Grain yield data: Crop production is very sensitive to agricultural drought. In order to find out the relationship between crop yield and the existing drought condition and thus validate satellite based drought events, five years (2004 – 2008) average zonal grain yield data of the study area was collected from Central Statistics Agency (CSA), Ethiopia.

Software packages: ArcGIS 9.2, ERDAS IMAGIN 9.1, IDRISI, LEAP, INSTAT and Google Earth softwares were used for data analyses. GIS and remote sensing software (ArcGIS 9.2 and ERDAS IMAGIN 9.1) are being widely used for analysis of geospatial data. The former provides suitable framework for integrating and analyzing remote sensing data acquired from the latter after being analyzed. IDRISI is primarily designed to process and analyze raster information (images comprising of pixels such as satellite data).

Livelihood Early Assessment and Protection (LEAP) is a software environment for drought indexing, designed specifically for the local Ethiopian context commissioned by World Food Program (WFP) in 2006

(Hoefsloot, 2008). One of the design goals of LEAP is a platform for calculation of weather based indices starting out with the calculation of crop water balance indicator, WRSI. INSTAT is a simple general statistics package that also includes a range of special facilities to simplify the processing of climatic data. Google Earth is widely used software that allows exploring, searching and discovering any location (with its spatial features) in the world.

Data processing and analyses methods

Satellite images processing: As the National Oceanic and Atmospheric Administration (NOAA) AVHRR NDVI satellite images are radiometerically corrected, only geometric corrections were done. All images were imported in generic binary format in ERDAS IMAGIN software and information related to image dimensions and projection parameters were incorporated in the row images. In order to transform the imported raw data into -1 to 1 range of NDVI, the formula (NDVI= raw data /250), provided with raw data by FEWS-NET was applied to each NDVI image. Thereafter, the study area was extracted for further analysis. Similar procedure except data conversion was applied to satellite REF images so as to make the input REF image for further analysis.

Analysis of agricultural drought using various drought indices: Spatiotemporal variation of seasonal agricultural drought patterns and agricultural drought severity were analysed seasonally using the following three drought indices:

NDVI anomaly: NDVI can be used as vegetative drought index to assess crop condition through analysis of NDVI anomaly (Murali et al., 2008: 37). It has been calculated using NDVI values. Maximum NDVI and long-term mean maximum NDVI in the growing season (June to September) were computed in order to derive seasonal NDVI anomaly. NDVI anomaly percentage was then derived using the formula (equation 1) for each grid cell in the study area.

$$\text{NDVI Anomaly } i = [(\text{NDVI max}_i - \text{Mean NDVI max}) / (\text{Mean NDVI max})]\ 100 \qquad (1)$$

Where NDVI max_i=Maximum NDVI in the growing season in i^{th} year and Mean NDVI max=long-term mean maximum NDVI in the growing season. The resulting NDVI anomaly assigned to the respective grid cell was reclassified into five drought severity classes based on Table 1.

Standardized Precipitation Index (SPI): SPI is an index that was developed to quantify precipitation deficit at different time scales, and can also help assess drought severity (McKee et al., 1993). SPI was calculated using the following formula:

$$SPI = (X_{ij} - X_{im}) / \sigma \qquad (2)$$

Where X_{ij} is the seasonal precipitation, X_{im} is its long-term seasonal mean, and σ is its standard deviation. SPI results computed from seasonal rainfall data were assigned to each grid cell of the study area, and reclassified based on drought severity classes (Table 1).

Crop performance index: Water requirement satisfaction index (WRSI) is an indicator of crop performance based on the availability of water to the crop during the growing season. It is also known as the crop specific drought index (Assefa et al., 2007: 7). The WRSI was generated by a crop water balance model using LEAP software. The most important input parameters of the model were satellite based RFE and spatially distributed potential evapo-transpiration images.

Besides, the model uses relevant soil information from FAO digital soil map and topographical parameters derived from digital elevation model (DEM). WRSI was calculated as the ratio of seasonal actual evapo-transpiration (AET) to the seasonal crop water requirement (WR) (equation 3).

$$WRSI = (AET / WR) 100 \quad (3)$$

Where WR was calculated from the Penman-Monteith reference crop evapo-transpiration (ET_o) using the crop coefficient (K_c) to adjust for the growth stage of the crop: $WR = ET_o(K_c)$. AET represents the actual amount of water withdrawn from the soil water reservoir where shortfall relative to potential evapo-transpiration (PET) was calculated by function that takes into account the amount of soil water in the reservoir. Soil water content was estimated through simple mass balance equation, where the total volume was defined by the water holding capacity (WHC) of the soil. WRSI was computed using LEAP software and imported into GIS environment. The WRSI result was then reclassified based on drought severity classes mentioned in Table 1 for each grid cell of the study area.

Table 1. Drought severity classification

	Drought severity classes				
Drought Indices	No drought	Slight drought	Moderate drought	Severe drought	Very severe drought
NDVI anomaly	Above 0	0 to -10	-10 to -25	-25 to -50	Below -50
SPI	Above 0	0 to -0.99	-1 to -1.49	-1.50 to -1.99	Below -2.0
WRSI	80 to 100	70 to 79	60 to 69	50 to 59	Below 50

Source: McKee *et al., 1*993; Hoefsloot, 2008; Murali *et al.*, 2008

In order to show spatial patterns and severity of drought, two drought and wet years were selected and analysed from each index, and then reclassified based on their respective drought severity levels.

Computation of yield reduction: The impact of agricultural drought on crop production can be largely expressed by yield reduction. In view of this, yield reduction due to water deficiency was computed using LEAP software. Yield reduction was calculated from water balance output combined with an empirical formula - equation 4 is developed by Doorenbosch and Kassam (Hoefsloot, 2008), and expressed in percentage.

$$100-((1-(1-A/B)\,K_y)\,100) \qquad (4)$$

Where A is the actual evapo-transpiration, B is the total water requirement without water stress. K_y is a crop dependent stress indicator determined by the authors. The major crops grown in the study area, maize, teff, wheat, sorghum, finger millet, haricot bean, chick pea, field pea, and lentil, were considered in computation of aggregated yield reduction.

Regression analysis of grain yield with drought indices output: The relationship between average SPI, NDVI anomaly and WRSI value from each seasonal year with corresponding grain yield anomaly were computed using INSTAT software to validate the derived indices output. In this regard, the average raster cell values of SPI, NDVI anomaly, and WRSI images were extracted using ERDAS IMAGIN software statistical information. Besides, different information related to agricultural drought hazard and their impacts on agricultural activities were collected from zonal and woreda agricultural and rural development, and early warning and food security offices through questionnaire. It was also used for the evaluation of the result obtained from satellite images.

Agricultural drought risk map: Agricultural drought risk map of the study area was produced from the seasonal frequency maps derived from each drought indices. In order to compute the frequency of drought occurrence, drought class image from each index was re-classed into Boolean image based on their threshold value, and 13 binary images were generated for each drought index. These binary images were added to obtain the frequency map showing the frequency of drought occurrence at each pixel level.

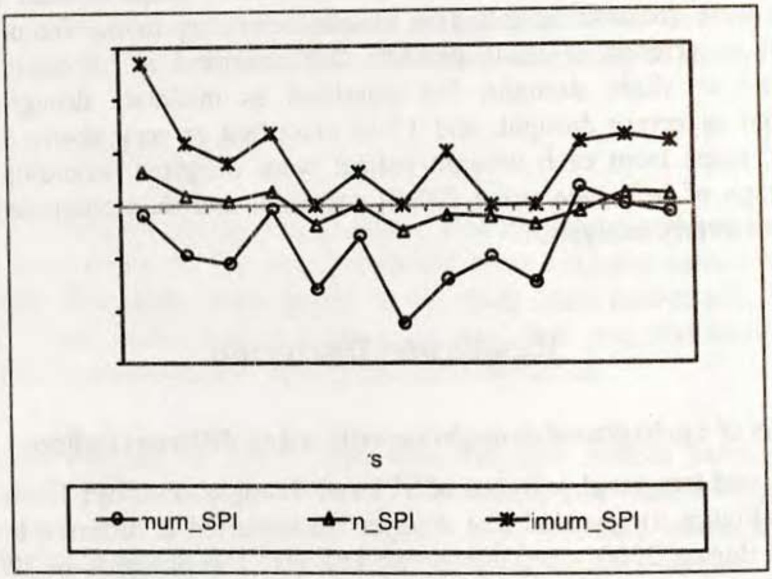
According to Lemma (1996: 1), the probability of drought occurrence in a given area can be classified into high, moderate and low drought probability zones when drought occurs in >50%, 30-50% and <30% of the years, respectively. Based on this criterion, the frequency maps of each drought classes were reclassified into five classes according to the frequency of drought occurrence in study periods: 0-2 classified as no drought; 3-4 classified as slight drought; 5-6 classified as moderate drought; 7-10 classified as severe drought; and 11-13 classified as very severe drought. Finally, maps from each drought indices were weighted according to the percentage of influence using IDRSI software, and then combined using weighted overly analysis.

Results and Discussion

Analysis of agricultural drought severity using different indices

Spatial and temporal patterns of SPI and drought severity: The analysis of SPI (Figure 3) revealed that drought has occurred at different levels of severity during 2000 - 2005 cropping seasons. The droughts in 2000 and 2002 were very severe compared to other years as explained by the SPI values that range from -1.6 to 0 and -2.25 to 0, respectively. McKee et al. (1993) and Sims et al. (2002: 29) explained that conditions of soil moisture are reacting to precipitation anomalies in relatively short time period and drought is happening every time when SPI is negative, while drought stops when SPI is positive. Hence, the result indicates that during these years, there was rainfall deficit in the growing season, and it, therefore, was the worst dry seasons.

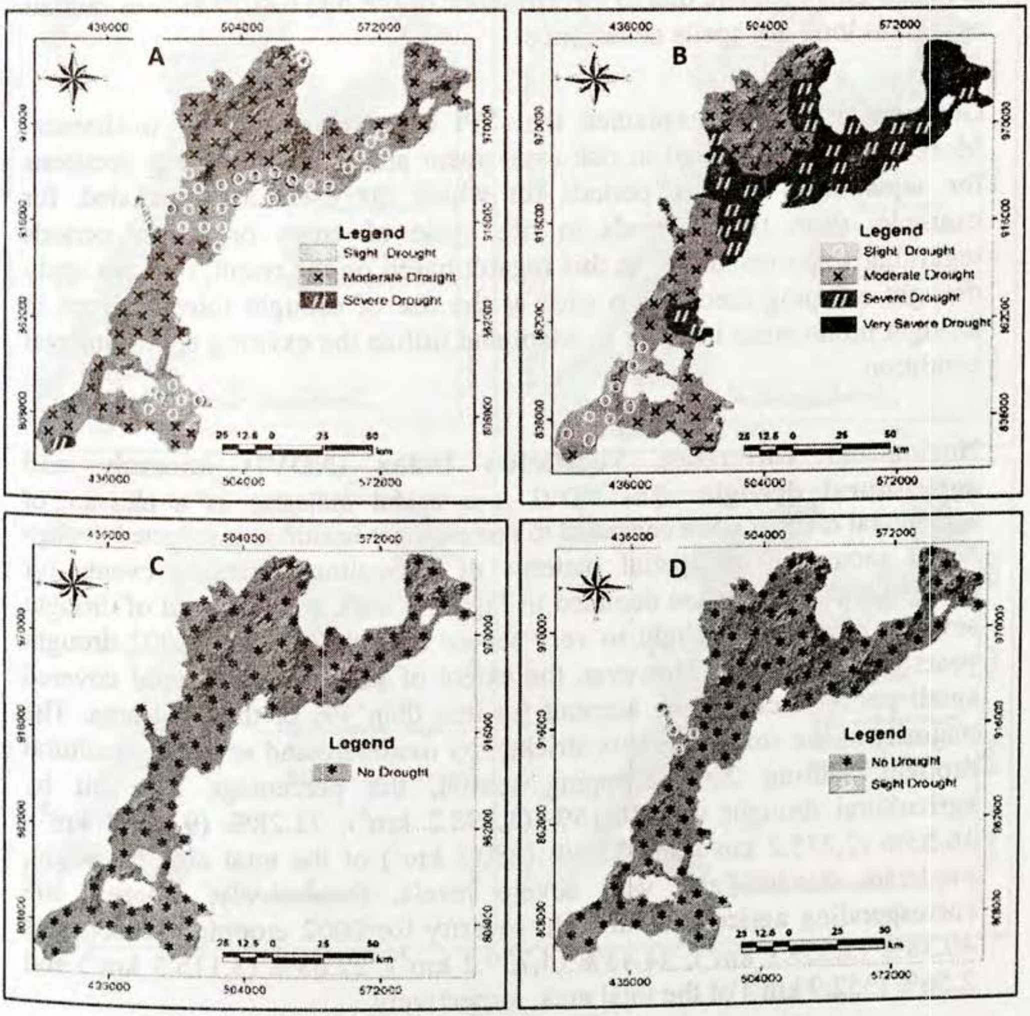
Figure 3.Temporal pattern of seasonal (June-September) SPI (1996-2008)



Source: Author's Own Figure, 2010

Spatial patterns of SPI for drought years (2000 and 2002) and wet years (2007 and 2008) was analysed and reclassified to show spatial trends of drought severity (Figure 4(a-d)). The whole area was hit by drought from slight to severe levels of severity during 2000 cropping season (Figure 4(a)) while in 2002 the range of severity was from slight to very severe drought levels (Figure 4(b)). This indicates that in the year 2002, there was a very severe drought in wider extent that accounts for 5.17% (711.5 km^2), 39.95% (5500 km^2), 46.04% (6,338.5 km^2) and 8.84% (1,216.5 km^2) of the total area hit by slight, moderate, severe and very severe drought, respectively. In 2000, the level of severity reduced to severe only in some pockets of the southern part covering 0.65% (89.2 km^2) of the total area while strike of moderate drought was expanding over majority of the East Shewa Zone covering 75.69% (10,420.1 km^2). In 2002, north eastern, eastern and central parts of the East Shewa Zone were more stricken by severe and very severe drought.

Figure 4. Spatial pattern of drought severity for drought years (2000 (A) and 2002 (B)) and wet years (2007 (C) and 2008 (D)) expressed in SPI index



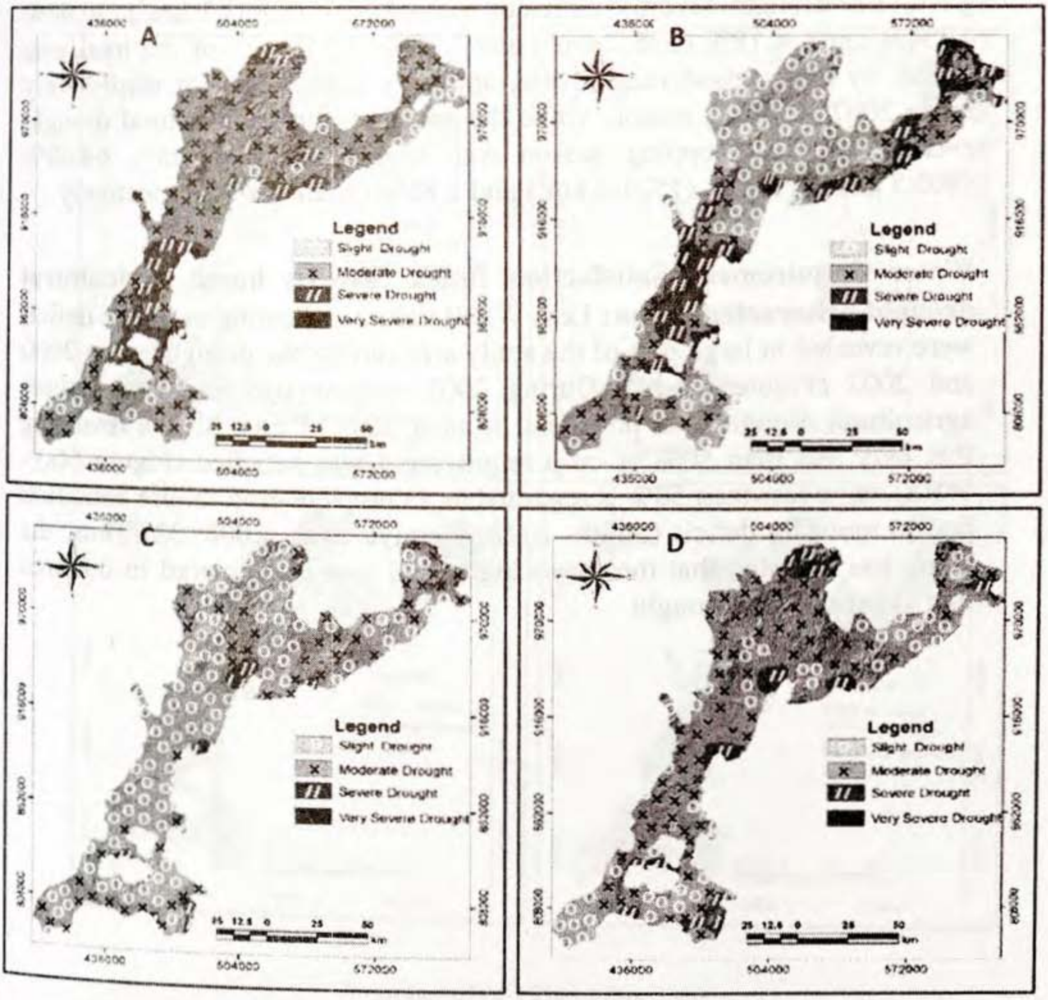
Source: Author's Own Map, 2010

As the maps in Figure 4(*c-d*) show, 2007 and 2008 were very wet years in East Shewa Zone. The range of severity was from no drought to slight drought. Although good seasonal rainfall helped almost the whole zone to avoid drought during 2008 cropping season, some small pockets covering 2% (247.3 km^2) of the total area in the western part experienced slight drought. This could be due to the influence of the bad distribution of rainfall as well as long dry spells occurrence.

Guttman (1998: 34) explained that SPI has greater spatial consistence. Moreover, it can be used in risk assessment analysis and making decisions for adjustments to time periods for which the users are interested, for example, short time periods in life cycle of crops or longer periods regarding water resources. In this regard, based on the result, one can apply drought escaping mechanism such as the use of drought tolerant crops in drought prone areas in order to adapt and utilize the existing environmental condition.

Normalized Difference Vegetation Index (NDVI) anomaly and agricultural drought: The NDVI is a useful indicator as a measure of agricultural drought when compared to normal plant health. It is reflected through NDVI anomaly. The spatial patterns of agricultural drought events for drought and wet year are depicted in Figure 5(a-d), and the level of drought severity ranges from slight to very severe in both 2000 and 2002 drought years (Figure 3(a-b)). However, the extent of very severe drought covered small pocket areas which account for less than 4% of the total area. The majority of the study area was stricken by moderate and severe agricultural drought. During 2000 cropping season, the percentage area hit by agricultural drought was 10.15% (1,398.2 km^2), 71.28% (9,812.3 km^2), 16.53% (2,275.2 km^2) and 2.04% (280.8 km^2) of the total area for slight, moderate, severe, and very severe levels, respectively, whereas the corresponding agricultural drought severity for 2002 cropping season was 40.38% (5,559.1 km^2), 34.43% (4,739.2 km^2), 22.63% (3,115.3 km^2) and 2.56% (352.9 km^2) of the total area, respectively.

Figure 5. Spatial pattern of agricultural drought severity for drought years (2000 (A) and 2002 (B)) and wet years (2007 (C) and 2008 (D)) expressed in NDVI anomaly index

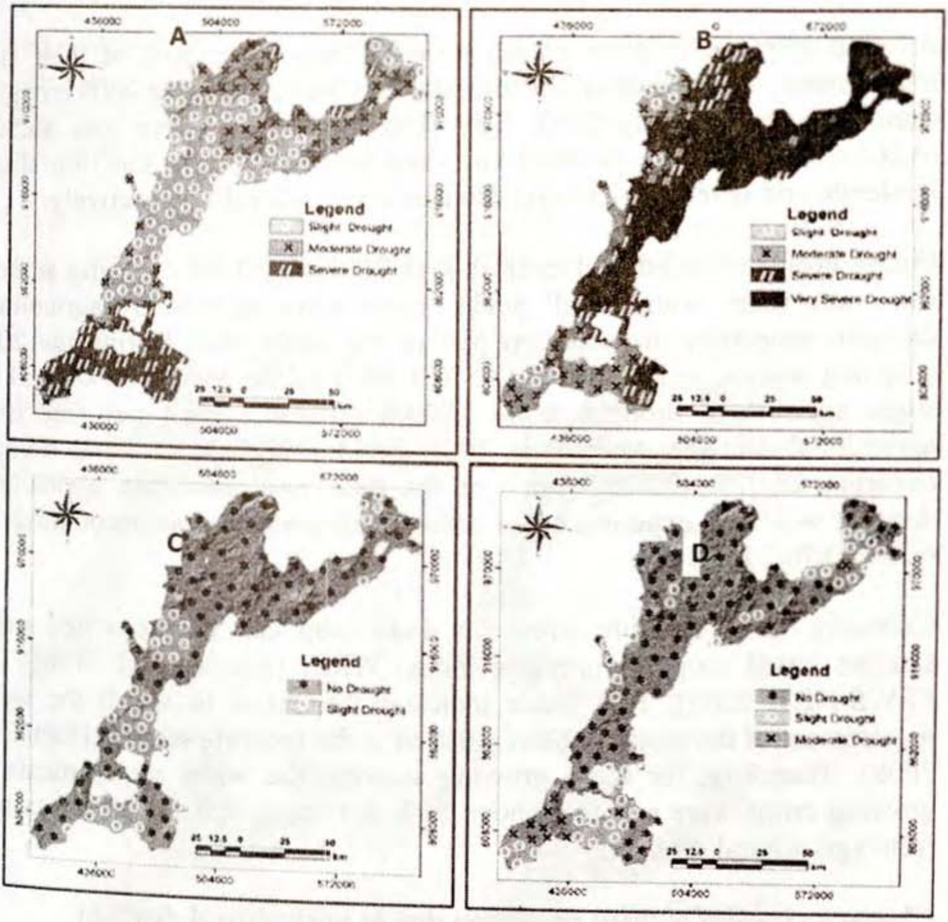


Source: Author's Own Map, 2010

It can be observed from the map depicted in Figure 3(c-d) that during the wet years, some very small pocket areas were hit by severe and very severe agricultural droughts while majority of the areas were under the influence of slight and moderate agricultural droughts. The percentage area of agricultural drought severity indicates that 64.32% (8,854.2 km^2), 30.90% (4,254.9 km^2), 4.18% (575.3 km^2) and 0.60% (82.1 km^2) of the total area was hit by slight, moderate, severe, and very severe drought respectively during 2007 cropping season, while the corresponding agricultural drought severity in 2008 cropping season was 22.41% (3084.6 km^2), 64.69% (8905.3 km^2), 11.07% (1524.0 km^2) and 1.83% (252.6 km^2), respectively.

Water Requirement Satisfaction Index (WRSI) based agricultural drought characterization: Less WRSI values indicating moisture deficit were revealed in large part of the study area during the drought years 2000 and 2002 (Figure 6(a-b)). During 2002 cropping season, very severe agricultural drought was prevalent in most parts of East Shewa revealing that only less than 50% of crop requirement was satisfied (Figure 6(a)). WRSI value less than 50% is regarded as a complete crop failure condition due to moisture deficit (Smith, 1992; Tsegaye et al., 2008: 32) Thus, the result has revealed that there was high yield loss encountered in the area due to agricultural drought.

Figure 6. Spatial pattern of agricultural drought severity for drought years (2000 (A) and 2002 (B)) and wet years (2007 (C) and 2008 (D)) expressed in WRSI index



Source: Author's Own Map, 2010

Large area coverage in north eastern, eastern and central part that accounts for 56.22% (7,739.6 km^2) of the total area was hit by very severe agricultural drought, whereas other parts of the area were stricken by severe, moderate and slight agricultural drought in the extent of 18.30% (2,519.2 km^2), 20.00% (2,751.6 km^2) and 5.48% (756.1 km^2), respectively.

As crop growing in most of the areas getting above 50% of their crop requirement, the level of agricultural drought was less during 2000 cropping season as compared to 2002. The percentage of the area was 45.52% (6,265.6 km^2), 29.71% (4,090.6 km^2) and 24.77% (3,410.3 km^2) for slight, moderate and severe agricultural drought severity levels, respectively.

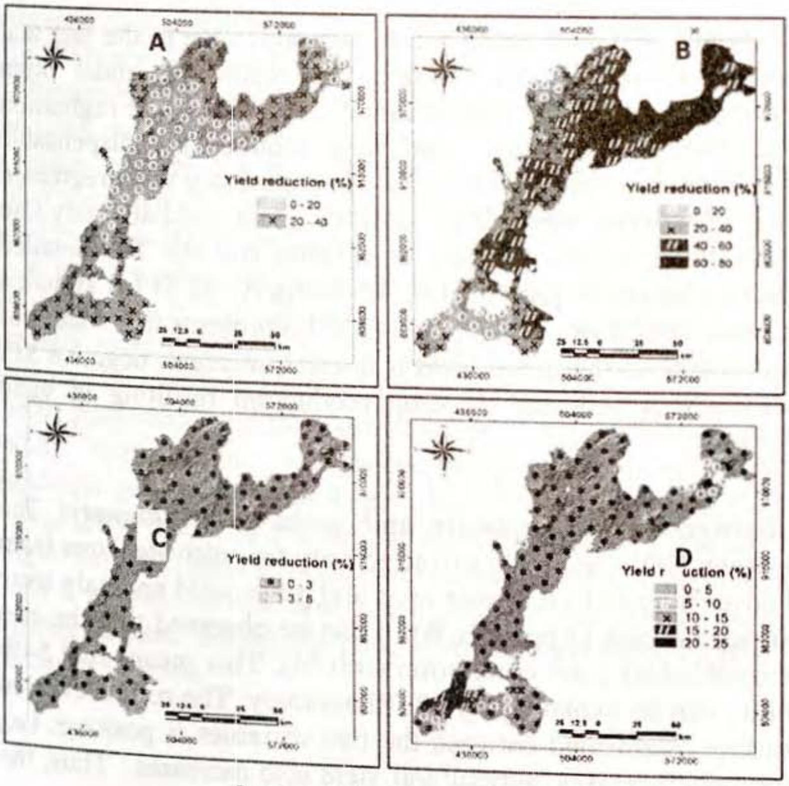
Figure 6(c-d) revealed that even though 2007 and 2008 cropping seasons were wet years, some small pocket areas were stricken by agricultural drought, especially the southern part of the study area. During the 2007 cropping season, only 23.76% (3,270.3 km^2) of the total area was hit by slight agricultural drought while 76.24% (10,496.2 km^2) was free from agricultural drought, whereas in 2008, besides slight agricultural drought covering 23.07% (3,175.3 km^2) of the total area, moderate agricultural drought was also experienced in some small pocket areas accounting for 6.36% (876.2 km^2).

Currently, crop moisture stress on grain crop can be monitored using satellite based crop performance index, WRSI (Victor et al., 1988: 39; FEWS-NET, 2009). This index indicates the extent to which the water requirement of the crop has been satisfied in the growing season (Hoefsloot, 2008). Therefore, for those growing seasons, the water requirements of growing crops were satisfied above 80% indicating that the area was free from agricultural drought.

Characterization of yield reduction due to agricultural drought

Similar to drought indices output, the highest yield reduction occurred in 2000 and 2002 cropping season. According to the result, in the 2002 cropping season, nearly all area was hit by agricultural drought, and agricultural yield reduction reached 80% (Figure 7(b)). During this season, eastern, north eastern and central parts of the East Shewa Zone encountered 60-80% yield reduction covering 26.52% (3,650.8 km^2) of the total area, while small areas in western and southern part encountered from 0 to 20% yield reduction covering 12.64% (1,740.1 km^2) of the total area. Similarly, 20 to 60% yield reduction was encountered in 60.84% (8,375.6 km^2) of the total area. In 2000 cropping season, the level of yield reduction was 40% (Figure 7(a));.0-20% and 20-40% yield reduction cover 42.78% (5,889.3 km^2) and 57.22% (7,877.2 km^2) of the total area of East Shewa. Kindye and Walker (2004: 29) explained that the reduction of crop performance and yield result from mismatches between water supply and demand. Thus, moisture deficit significantly influenced the growth and development of crops and the ultimate yields.

Figure 7. Spatial pattern of yield reduction for drought years (2000 (A) and 2002 (B)) and wet years (2007 (C) and 2008 (D)) cropping seasons



Source: Author's Own Map, 2010

Spatial pattern of yield reduction for the wet years (2007 and 2008) is shown in Figure 7(*c-d*). The level of yield reduction was very low (<30%) in most parts, while in small pocket areas around north eastern part of the zone the reduction was 3-6% covering 0.23% (31.7 km^2) of the total areas in 2007 cropping season. In 2008 cropping season, 20-25% yield reduction was observed in small pocket area covering 2.06% (283.6 km^2) of the total area in the southern part of the zone, although the dominant part remains under low level of yield reduction. This may be attributed to mismatch between seasonal rainfall and crop requirement during the critical growth stage.

Evaluation of indices-based results of agricultural drought using grain yield and ground-based information

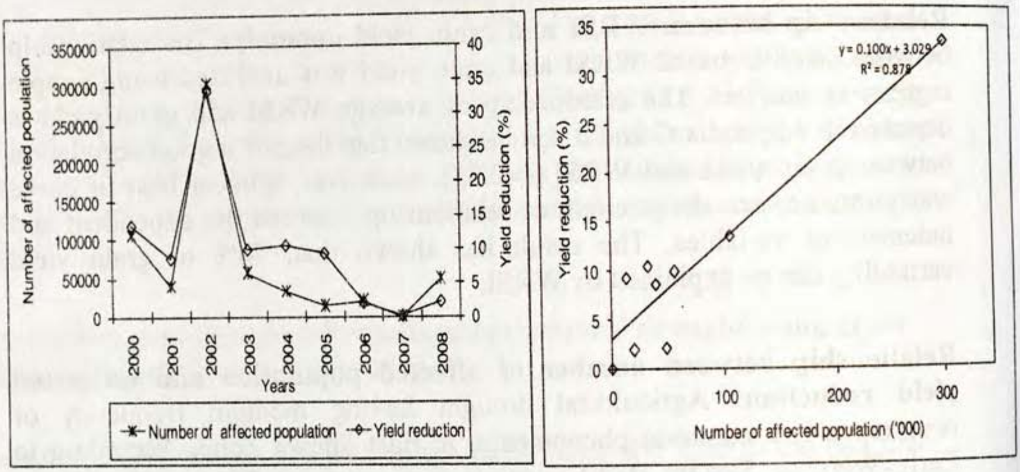
Relationship between SPI and grain yield anomaly: Due to the fact that crop production is a function of rainfall, crop failure is most often associated with moisture deficit or agricultural drought. Thus, the regression analysis between drought index and grain yield anomaly is indispensable for validation. In view of this, SPI and grain yield anomaly were regressed and the result has shown that when SPI is positive, grain yield anomaly also turns positive revealing a good positive correlation ($r=0.8$). The detailed result of regression analysis is presented in Appendix A. As SPI is an index that represents water deficit or excess, positive SPI represents that water has been available to plants so that grain yield is normal, whereas, negative SPI or rainfall deficiency is reflected on crop production resulting in yield reduction.

Relationship between NDVI anomaly and grain yield anomaly: The relationship between NDVI anomaly extracted only for cultivated area from land use/ land cover map of East Shewa zone and grain yield anomaly were analyzed. From scatter plot (Appendix B), it can be observed that the two variables have established good correlation ($r=0.74$). This means that 54% of yield variability can be explained by NDVI anomaly. The result revealed that the relationship established between the two variables is positive; i.e., when NDVI anomaly increases, agricultural yield also increases. Thus, the strength of the index to explain the existence of agricultural drought through agricultural yield is relatively good.

Relationship between WRSI and grain yield anomaly: The relationship between satellite based WRSI and grain yield was analyzed using simple regression analysis. The relationship of average WRSI and grain yield is depicted in Appendix C and it can be shown that there is a good correlation between grain yield and WRSI (r=0.87). Moreover, a linear best fit curve was plotted to see the strength of relationship between the dependent and independent variables. The result has shown that, 76% of grain yield variability can be explained by WRSI.

Relationship between number of affected population and estimated yield reduction: Agricultural drought having medium frequency of occurrence is a common phenomenon in East Shewa Zone. According to Early Warning System (EWS) reports from national Disaster Prevention and Preparedness Commission (DPPC), late onset and early cessation of the main rainy season, erratic distribution of rainfall and extended dry spells are the main weather related problems that cause agricultural drought. Furthermore, reports show that even though there was agricultural drought from the year 2000 through 2005 cropping season, the 2002 cropping season was the worst season that result in substantial yield reduction (EWS, 2003). As a result, the number of people affected by recurrent drought has increased significantly and the extents of food shortage and related problems have grown in East Shewa Zone (Figure 8). The number of affected population and the estimated yield reduction are highly correlated (r^2=0.8). Furthermore, information obtained from East Shewa Zone agricultural and rural development, and DPPC offices confirm that during the year 2000 and 2002 cropping seasons, there was severe agricultural drought in East Shewa Zone, and consequently, complete crop failure occurred in most of the area particularly, north eastern part of the area including Fentale, Bosset and part, of Adama and southern part, particularly Adamitulu Woreda.

Figure 8. Relationship between yield reduction and number of affected population



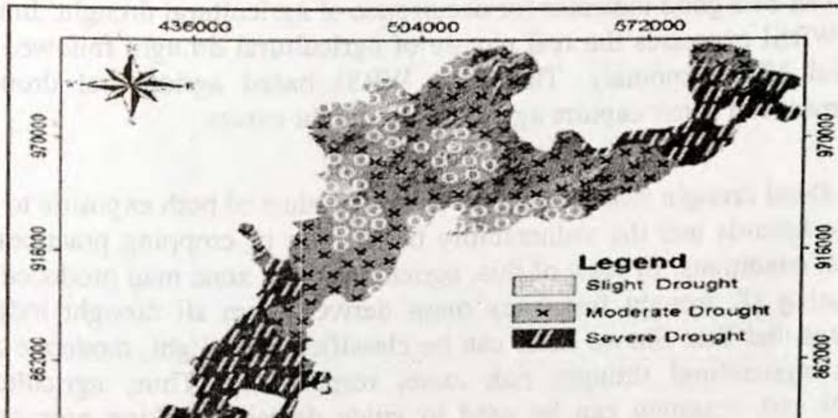
Source: Author's Own Figure Based on Model Output and East Shewa Zone DPPC Data, 2010

According to the information obtained from East Shewa Zone agricultural and rural development offices, agricultural drought mostly occurred as a result of mismatch of rainfall with crop requirement. Moreover, agricultural experts perceive that the length of growing period declined due to climate change and thus the production options of farmers was limited to short duration crop varieties. Irrigation practice has also been introduced as an option to reduce the impact of agricultural drought in the area. Besides, adverse weather condition as a result of rainfall variability, has increased pest infestations and crop diseases (like stem borer) reducing the crop quality and yield.

Classification of agricultural drought risk zone

According to the result derived from the integration of all drought frequency maps, East Shewa Zone is classified into slight, moderate and severe agricultural risk zones (Figure 9). The agricultural drought risk map (Figure 9) shows that the percentage area affected by slight, moderate and severe agricultural drought risk encompasses 17.18% (2,365.3 km^2), 41.32% (5688.3 km^2) and 41.50% (5,712.9 km^2) of the total geographical area of East Shewa Zone, respectively. The probability of occurrence of agricultural drought ranges from 15 to 30% for slight severity level, from 30 to 46% for moderate severity level and from 46 to 76% for severe severity level. Thus, the western and most of central part of East Shewa is categorized into slight and moderate drought probability zone while most of the north eastern and southern part is categorized into severe drought probability zone.

Figure 9. Agricultural drought risk map



Source: Author's Own Map, 2010

Conclusions

Using satellite data as an input parameter for drought indices, spatiotemporal variation of seasonal agricultural drought patterns and severity can be detected and mapped with the help of advanced techniques of remote sensing and GIS. The obtained result is in agreement with the ground based surveyed information. Hence, agricultural drought assessment using satellite data is of paramount importance in assessing the past and the current agricultural drought conditions, and generate baseline information that helps to monitor real time situation in the future for different adaptation options within relatively large geographical area and repetitive time scale coverage.

The comparative performance of the indices explaining the existence of agricultural drought revealed that WRSI, SPI and NDVI anomaly express 76, 64 and 54 per cent of variability of the grain yield, respectively. Thus, WRSI can be a good indicator for occurrence of agricultural drought. In this study WRSI expresses the real picture of agricultural drought followed by SPI and NDVI anomaly. Therefore, WRSI based agricultural drought assessment can better capture agricultural drought events.

Agricultural drought risk can be viewed as a product of both exposure to the climate hazards and the vulnerability of farming or cropping practices to drought conditions. In view of this, agricultural risk zone map produced by integrating all drought frequency maps derived from all drought indices indicates that East Shewa Zone can be classified into slight, moderate and severe agricultural drought risk zone, respectively. Thus, agricultural drought risk mapping can be used to guide decision making process in drought monitoring and to reduce the impact of drought on agricultural production and productivity. It can also be used in identifying appropriate sites for specific adaptation and mitigation actions.

Based on the findings of the study, prioritization and implementation of site specific adaptation and/or mitigation projects should be made based on such identification of risk levels of specific locations. Since agricultural drought severity levels vary spatially, selection of agricultural technologies and information (drought tolerance crops, the type of crop variety and soil moisture conservation practices) should also be made to fit in to the agricultural drought severity levels.

Finally, the methods as well as results of agricultural drought assessment and risk mapping are believed to be very important for decision makers and stakeholders who have a stake in the study area. However, it is recommended that future studies should build up on this work by including real time seasonal rainfall forecasts as model parameter so that stakeholders can get early warning information that helps to take necessary adaptation measures and reduce the impact of agricultural drought.

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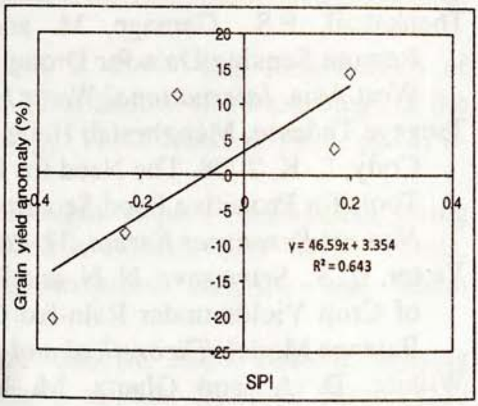
Appendices

Appendix A. Simple linear regression analysis between SPI and grain yield anomaly

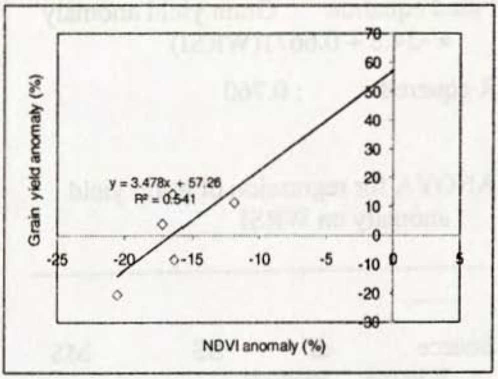
```
----------------- DETAILS OF THE FITTED LINE -----------------------

Fitted equation  : Grain yield anomaly =
3.355 + 46.59 (SPI)

R-squared        : 0.6438
```



```
ANOVA for regression of grain yield
  anomaly on SPI
-------------------------------------------------

Source      df     SS          MS
F value   Prob>F
-------------------------------------------------

Regression  1    541.992     541.99     5.42     0.1023
Residual    3    299.911     99.97
------------------------------------------------------------

Total       4    841.903
-------------------------------------------------------------------
```

Appendix B. Simple linear regression analysis between NDVI anomaly and grain yield anomaly

----------------- DETAILS OF THE FITTED LINE --------------------



Fitted equation : Grain yield anomaly
= 57.26 +
3.479(NDVI
anomaly)

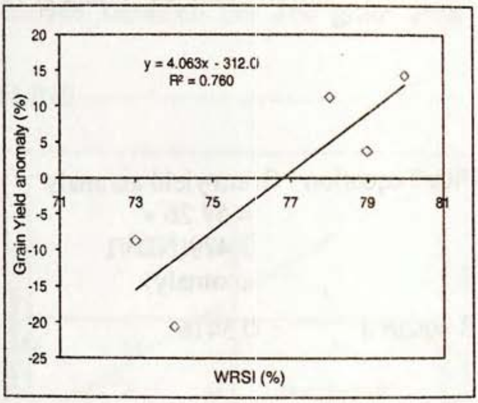
R-squared : 0.5416

ANOVA for regression of grain yield anomaly on NDVI anomaly

Source	df	SS	MS	F value	Prob >F
Regression	1	456.171	456.17	3.54	0.1563
Residual	3	386.124	128.71		
Total	4	842.294			

Appendix C. Simple linear regression analysis between WRSI and grain yield anomaly

----------------- DETAILS OF THE FITTED LINE -----------------



```
Fitted equation    : Grain yield anomaly
   = -34.8 + 0.6671(WRSI)

R-squared          : 0.760


ANOVA for regression of grain yield
   anomaly on WRSI

---------------------------------------------
   -----

Source       df      SS          MS
   F value   Prob>F

------------------------------------------------

Regression   1     17.2649     17.265    9.47     0.0542
Residual     3     5.46739     1.8225

-------------------------------------------------------------

Total        4     22.7323

-----------------------------------------------------------------
```