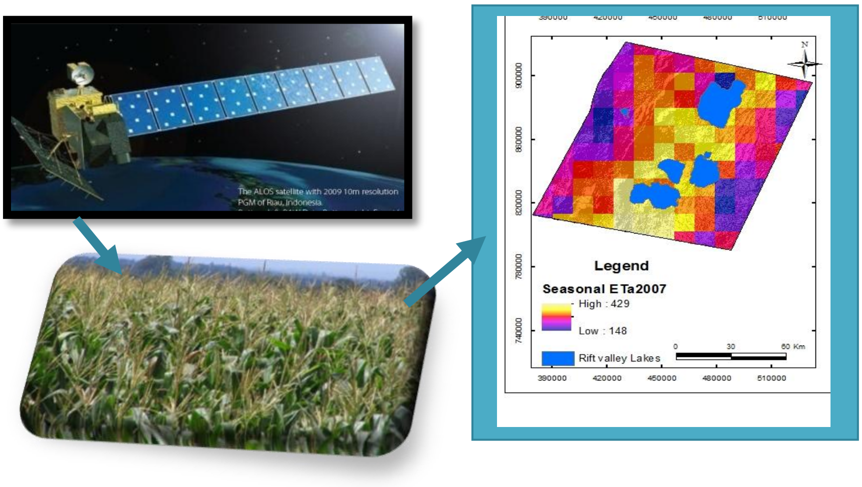
Addis Ababa University

School of Graduate Studies

Department of Earth Science

ESTIMATION OF ACTUAL EVAPOTRANSPIRATION AND ITS IMPACTS ON RAINFED AGRICULTURAL PRODUCTIVITY USING GEOSPATIAL TOOLS IN THE MAIN ETHIOPIAN RIFT



BY

DEBELE ABERRA

A Thesis submitted to the School of Graduate Studies in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Geoinformation Science

June 2012

Addis Ababa University

School of Graduate Studies

Department of Earth Science

ESTIMATION OF ACTUAL EVAPOTRANSPIRATION AND ITS IMPACTS ON RAINFED AGRICULTURAL PRODUCTIVITY USING GEOSPATIAL TOOLS IN THE MAIN ETHIOPIAN RIFT

A Thesis submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Geoinformation Science

BY: DEBELE ABERRA

ADVISOR: PROF. TENALEM AYENEW

CO-ADVISOR: DR. DAGNACHEW LEGESSE

Addis Ababa University

School of Graduate Studies

Department of Earth Science

ESTIMATION OF ACTUAL EVAPOTRANSPIRATION AND ITS IMPACTS ON RAINFED AGRICULTURAL PRODUCTIVITY USING GEOSPATIAL TOOLS IN THE MAIN ETHIOPIAN RIFT

BY: DEBELE ABERRA

A Thesis Submitted to the School of Graduate Studies of Addis Ababa University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Geoinformation Science

Approved by Board of Examiners:

Dr. SEIFU KEBEDE __________________________________

Chairman, Department

Graduate Committee

Prof. TENALEM AYENEW ________________________________

Advisor

Dr. DAGNACHEW LEGESSE ________________________________

Co-Advisor

Dr. SEIFU KEBEDE __________________________________

Examiner

Dr. K.V. SURYABHAGAVAN __________________________________

Examiner

Acknowledgments

Before anything, glory and thanks be to God who gives me full health, peace, knowledge and wisdom to accomplish this thesis work and He is still in my side throughout my life.

My deepest feeling of gratitude goes to my advisor prof. Tenalem Ayenew, for his invaluable advice, and constant encouragement helped me to complete this research work successfully and his admirable patience, and attractive spirit of friendship as unique personal possessions.

I would like to express my special and sincere appreciation to my co-advisor Dr. Degnachew Legesse for his guidance, constructive suggestions, review and constant follow-ups and supports throughout the research work.

I would like to take this opportunity to acknowledge Dr. K.V.Suryabhagavan, for his advice, humanity and support throughout my time in the Master of Science program at Addis Ababa University. At Addis Ababa University, I feel a deep sense of gratitude to all staffs of Department of Earth science and for providing a condusive working environment in the laboratory, I would like to thank Biniyam Tezera.

I am also grateful to the National Meteorological Agency (NMA), Central Statistics Agency (CSA) for providing me meteorological data, and crop production data, which helped me to carry out the research work.

I owe my great respect and love to Mr. Michael E. Budde for his suggestions and guidance. Nigussie Bekele, and Gossaye Bekele it is your kindness to support me from the very beginning and your good wish to see my upgrade, here is the fruit.

Contents

List of Figures

List of Tables

Acronyms

ALEXI	Atmosphere Land Exchange Inverse
AVHRR	Advanced Very High Resolution Radiometer
CSA	Central Statistical Agency
DISALEX	Disaggregated Atmosphere Land Exchange Inverse
EROS	Center for Earth Resources Observation & Science
ETa	Actual evapotranspiration
ETo	Potential evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
FEWS NET	Famine Early Warning System
GIS	Geographic information system
LSP	Land Surface Phenology
LULC	Land use land cover
METRIC	Mapping evapotranspiration at high resolution with internalized calibration
MODIS	Moderate Resolution Imaging Spectrometer
NASA	National Aeronautic and Space Administration
NDVI	Normalized Difference Vegetation Index
NOAA	National Oceanic and Atmospheric Administration
RFE	Rainfall Estimate
SEBAL	Surface Energy Balance Algorithm for Land
SEBI	Surface Energy Balance Index
SEBS	Surface Energy Balance system
TSEB	Two-Source Energy Balance models
WR	Water requirement
WRSI	Water Requirement Satisfaction Index
VegET	Vegetation Evapotranspiration

Abstract

Remote sensing based estimation of spatiotemporal patterns of vegetation water use has played significant roles in evaluation and monitoring of rainfed agriculture. Agriculture is the most vulnerable and sensitive sector that is seriously affected by the impact of climate variability and change, which is usually manifested through rainfall variability and recurrent drought in the Main Ethiopian Rift. The objective of this study is to estimate actual evapotranspiration for crop performance evaluation and monitoring for the study periods of 2001-2010 cropping seasons (June-September). Using VegET model that integrates commonly used water balance algorithms with remotely sensed Land Surface Phenology (LSP) parameter to conduct operational vegetation water balance modeling of rainfed systems at the LSP's spatial scale using readily available global data sets. The result confirmed that the lowest seasonal /driest seasons/ water use estimated in 2002, which is 192mm and followed by 2003, 2009 and 2001cropping seasons with 205,230, and 231 mm respectively. On the contrary, moisture deficit free seasons' were found during 2006–2008 and 2010 years with water use values ranges from 270-297 mm in depth. In the study area ETa and moisture availability (rainfall) have good positive linear relationship with coefficient of correlation (r=0.89). The result revealed that the highest yield reduction occurred during 2002 cropping season which is about 47% and then followed by 27%, 24%, 18%, and 18% in 2003, 2001, 2009 and 2005 cropping seasons respectively. The relationship between the water balance yield reduction estimation model and WRSI have good negative linear correlation determination coefficient (r=0.92). Finally, the VegET modeling approach was demonstrated to have a promising application for drought monitoring/crop performance/ and early warning applications at various spatial and time scales for rain-fed systems.

Key words: LSP, Main Ethiopian Rift, Remote sensing, VegET model, WRSI, Yield reduction estimation

1. Introduction

1.1. Background

Water is currently considered as strategic resource because it has significant roles economically, socially, politically and environmentally; subsequently, attracts attention of the whole society at large. Particularly, in developing countries, like Ethiopia, where human population is growing at rate of 2.6% (CSA 2007) and the demand for food and energy resources is also increasing at alarming rate, water resource management is critical. In order to satisfy these demand a number of irrigation schemes and hydropower projects have been developing in different part of the country and, hence their sustainability depend on how the water resources are properly managed. Water use strategy and water resource management requires scientifically sound information on water availability, which includes the quantification of spatial and temporal changes of water balance components like actual evapotranspiration (ETa).

ETa's dependence on land cover and soil moisture, along with its direct relationship with carbon dioxide assimilation in plants, makes it an important variable to monitor and estimate crop yield and biomass for decision makers interested in food security, grain markets, water allocation, and carbon sequestration (Gabriel Senay, 2008). Hence, the quantification of spatial and temporal vegetation water use has direct relationship with agricultural performance as the country's economy is largely based on rain-fed agriculture which is vulnerable to the amount and variability of rainfall.

In the components of the hydrological cycle, land surface evapotranspiration estimates are crucial for water balance studies. Also this is perhaps the most difficult component to estimate because of complex interactions between evapotranspiration (ET) and the components of the land-plant-atmosphere system.

Land surface evapotranspiration is governed by the conditions of the lower part of the atmosphere, the presence and the properties of the vegetation layer and the sub surface soil moisture conditions (Gieske, 2003). The condition of the lower part of the atmosphere depends on the supply of heat energy and the vapour pressure gradient, which, in turn, depend on meteorological factors such as temperature, wind speed, atmospheric pressure, and solar radiation. These factors also depend on other factors, such as geographical location, season, time of day, etc. All these factors make the evapotranspiration an entity which is highly variable in space and also with time.

During the past 20 years, the capacity of satellite remote sensing to monitor land surface processes has been developed to a great extent through a number of earth observation satellite programs, image acquiring, image processing and computing technologies. Space based information (earth observation, remote sensing) is one of the very few techniques that is ideally suited to assist the management of changing resources and earth surface monitoring (Neteler et al., 2004).

1.2. Statement of problems

Many methods for estimating ET exist, and most require extensive input data such as local meteorological parameters, surface properties and soil moisture availability. Such data from the ground observations are often scarce, especially, in developing countries, where meteorological stations are rare in spatial distribution and data types gathered.

ET estimated from meteorological stations gives point data and the discrete point data are to be interpolated to over the large area; however ground measurements of land surface fluxes are representative of a relatively small area (Bastiaanssen et al., 1998a). Meanwhile recently developed satellite remote sensing methods based on VegET and Surface energy balance techniques are capable of estimating surface fluxes from one pixel up to the regional scale with a certain degree of accuracy.

In Ethiopia, most agricultural activities are based on rain-fed and, hence, seasonal and annual ETa estimation will give more meaning rather than daily in operational manner, the newly developed VegET model can be used with readily available datasets. The satellite based methods would provide spatially distributed estimate of evapotranspiration that would greatly improve the resolution and certainty. Satellite images provide a powerful tool for the identification of crops and collecting information on Land Surface Phenology (LSP) rainfall amount and reference evapotranspiration (ETo) when used in conjunction with geographical information systems (GIS) have proved to be effective for land use and water management. The exchanges of radiative, heat and moisture fluxes affect the biosphere and various irrigation process, and estimation of crop water demand and also the rate of evapotranspiration.

1.3. Objectives of the study

General objective:

The general objective of the study was the estimation of actual seasonal evapotranspiration of the study area using VegET model and its significance in rainfed agricultural development.

Specific objectives:

- To determine crop/vegetation water use (ETa) using VegET model.
- To determine temporal and spatial crop water requirement.
- To evaluate relationship between ETa and rain-fed agricultural productivity.

1.4. Significance of the study

The use of satellite data using advanced techniques such as remote sensing and Geographic information system (GIS) can assist for distributed ETa estimation and its application in agriculture. Mapping Actual Evapotranspiration (ETa), Water Requirement Satisfaction Index (WRSI) and Aridity index in the aims to be useful in the decision making process for crop monitoring and identifying appropriate region specific adaptation and mitigation actions. Thus, WRSI map produced from this study can be useful on one hand for policy makers to prioritize their actions based on the risk level, on the other hand for researchers to generate agricultural technologies and information including selection of water stress 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 Organization (NGO) to facilitate scaling up of best technologies with success stories from similar water limited areas elsewhere.

2. Literature review

This chapter presents literature review related to remote sensing based estimation of Evapotranspiration (ET) and its components in wide range climatic conditions and geographic distributions. FAO 56 (2006) defined evapotranspiration as the combination of two separate processes whereby water is lost on the one hand from the soil surface by evaporation and on the other hand from the crop by transpiration. Factors that affect ET are weather conditions (solar radiation, air temperature, humidity and wind speed), crop or vegetation factors (crop type, variety and development stage), management and environmental conditions (soil salinity, land fertility, application of fertilizers, the presence of hard or impenetrable soil horizons, the control of diseases and pests).

There are a number of methods of determining ET stated in FAO 56 (2006): a) Energy balance and microclimatological methods which apply the principle of energy conservation. Which can be written in the form of equation as R_n-G-λET-H=0.

Where, R_n is the net radiation, H the sensible heat, G the soil heat flux and λET the latent heat flux. The various terms can be either positive or negative. Positive R_n supplies energy to the surface and positive G, λET and H remove energy from the surface. b) The Soil water balance: requires the measuring of various components of the soil water balance. c) Lysimeters-involve isolating the crop root zone from its environment and controlling the processes d) Pan Evaporation –developed for open water surfaces. f) ET computed from meteorological data using empirical and semi-empirical equations.

2.1. Remote sensing based Evapotranspiration

"Remote sensing is the science (and to some extent, art) of acquiring information about the Earth's surface without actually being in contact with it. This is done by sensing and recording reflected or emitted energy and processing, analyzing, and applying that information" (www.ccrs).

A tremendous remote sensing models of estimation of evapotranspiration have been developed, which are broadly based on either Water balance principles or surface energy balance.

2.1.1. VegET model

VegET is a new modeling approach that integrates Land Surface Phenology (LSP) and commonly used water balance modeling algorithms to estimate actual vegetation ET (water use) on a pixel-by-pixel basis in primarily non-irrigated crop and grassland environments for agro- hydrological applications. The key inputs data are:

- Rainfall data
- Reference ETo
- NDVI climatology
- Soil-water holding capacity

These data are readily available globally in different spatial and temporal resolutions.The primary objectives of VegET model are to estimate ETa and soil moisture to monitor crop and grassland performance for early assessment of yield and biomass production (Gabriel Senay, 2008).

VegET is a model recently developed for estimating actual evapotranspiration in non-irrigated cropland and grassland environments as an enhancement to the USGS/FEWS NET crop water balance model. VegET blends concepts from irrigation engineering with a remote sensing datastream to estimate actual ET quickly and accurately at low computational and data costs anywhere in the world (Gabriel Senay and Verdin, 2003).

According to Gabriel Senay (2007) a key innovation in the VegET model is the inclusion of the land surface phenology (LSP) parameter which describes the seasonal progression of vegetation growth and development. LSP can be observed by spaceborne sensors and is a key biogeophysical parameter that links the water and carbon cycles with anthropogenic activities, providing an important approach to change detection in terrestrial ecosystems. Moreover he did comparative analysis VegET and Simple Surface Energy Balance (SSEB) models as follows table 2.1.

Table 2.1 Comparison between VegET and Surface energy balance methods

	VegET	SEB
Modeling Approach	Water Balance	Energy Balance
Target Monitored/Output	ET, Soil Moisture, Runoff	ET
Spatial Resolution	Limited by LSP data MODIS: 250 m AVHRR: 1-8 km	Limited by Thermal data (MODIS/AVHRR: 1 km) Landsat: 60 m
Spatial Extent	Global: Potentially	Global: Potentially
Frequency of Product	Daily	8-day
Delay	1 day	About 2 weeks for MODIS
Period of Record	Limited by Rainfall data 1996–current: NexRad/Station Blend 1979–current: GPCP (Global Precipitation Climatology Project).	Limited by Thermal Data AVHRR:1989–current MODIS: 2000–current
Web access	VegET model output is NOT online yet, but comparable outputs from the USGS/FEWS NET site: http://earlywarning.usgs.gov/adds/	Product is not online
Geographic projection	Currently outputs are in lat/lon	Currently outputs are in lat/lon
GIS Environment	Yes	Yes
Description of product	Appropriate for rainfed agriculture or grassland environments.	Superior application in irrigated systems.
Challenge/Limitations For operational Implementation	No major limitation is anticipated to go operational on this model. Automation of the model can be setup within 3 months of time.	Cloud cover is an issue, but the 8-day product overcomes this problem compared to the daily products. Automation of data processing is not yet implemented. However, this can be achieved within a period of 1 year.

2.1.2. Surface Energy balance model

Remote sensing data provided by satellites are a means of obtaining consistent and frequent observation of spectral reflectance and emittance of radiation of the land surface on micro to macro scale (Bastiaanssen et al., 1998a).

It is based on the principle of energy conservation and it further divide in to single and double source energy balance models.The single source energy balance models: Surface Energy Balance Algorithm for Land (SEBAL), Mapping Evapotranspiration at high Resolution with Internalized Calibration (METRIC) , Surface Energy Balance Index (SEBI), and Surface Energy Balance system (SEBS) are typically single-source energy balance models based on the contrast between dry and wet limits to derive pixel by pixel ET from the relative evaporative fraction when combined with surface parameters derived from remote sensing data and a certain amount of ground-based variables measured at local and/or regional scale take in to account the growing conditions and do not require a satellite based crop classification.

Su (2002) developed the Surface Energy Balance System (SEBS) model to estimate land surface fluxes using remotely sensed data and available meteorological observations. It has the most important advantage of its inclusion of a physical model for the estimation of the roughness height for heat transfer which is the most critical parameter in the parameterization of the heat fluxes of land surface. SEBS variant was utilized to analysis the soil moisture status over the study area and the spatial-temporal distributions of actual ET were analyzed by combination of the up-to-date land cover map. SEBS requires three broad sets of information to enable the estimation of surface fluxes including; a) data on the land surface condition consisting of surface albedo, emissivity, surface temperature, fractional vegetation coverage and leaf area index, along with height of the vegetation; b) meteorological data including atmospheric pressure, air temperature, humidity, and wind speed at a reference height and; c) radiation data comprising downward solar radiation and downward longwave radiation. SEBS constrains the surface heat flux estimates by considering dry-limit and wet-limit conditions, thus differentiating the upper and lower boundaries on the sensible heat flux (H) estimation.

Surface Energy Balance Index (SEBI) is remote sensing based algorithm to estimate ET which was proposed by Menenti and Choudhury (1993), is based on the Crop Water Stress Index.

Bastiaanssen et al., (1998a) and Bastiaanssen et al., (1998b) formulated the Surface Energy Balance Algorithm for Land (SEBAL). SEBAL estimate the spatially distributed energy balance in composite terrain by means of remotely sensed data. It uses the relationship between visible and thermal infrared spectral radiances of the area with specifically large hydrologic contrast (dry and wet land surface types, vegetation cover is not essential) constitute the basic for the formulation of (SEBAL). The most important inputs data are images from any suitable satellite sensors and weather data (air temperature, relative humidity, and wind speed) and vegetation height. SEBAL algorithm i) estimate the spatial variation of most essential hydro-meteorological parameters empirically; ii) requires only field information on a short-wave atmospheric transmittance, surface temperature and vegetation height; iii) does not involve numerical simulation models; iv) calculates fluxes independently from landcover; v) can handle thermal infrared images at different resolution.

Since SEBAL is physical based method and handles climate changes, and therefore applicable in various climatic conditions as far as cloud free images and the drylands and wetlands are available. The SEBAL has internal "Self calibration'' process, this is done by utilizing two "anchors'' pixels to fix the boundary or extreme conditions for the energy balance. Those pixels are: "Cool" pixels represented by water bodies, wetlands and well irrigated crop surface with full cover and under this condition $T_s \cong T_a$ which implies that H$\cong$ 0. "Hot" pixels represented by drylands, bare agricultural fields and under this condition $T_s \gg T_a$ which implies that $ET \cong 0$; H$\cong R_n - G$. Where T_s *and* T_a stand for surface and air temperature respectively.

Many researchers have been tested the SEBAL model in many different part of the world having different climatic conditions and terrain composites. Among these, Tasumi et al., (2000) gave detailed computational steps and procedures of SEBAL model to estimate evapotranspiration in Bear River Basin of Idaho through remote sensing using ERDAS software. Tenalem Ayenew (2003) did evapotranspiration estimation using landsat TM spectral satellite data in the Ethiopian Rift and adjacent highlands. This study clearly revealed that the relationship between ET and elevation (rift, escarpment and highlands) and landuse/landcover. Similarly, Gao et al.,(2008) studied estimation of evapotranspiration using landsat TM data under complex terrain in the upper Chao river basin in Northern China and showed relationship between ET and landuse/landcover and terrain (slope, aspect and elevation). Later SEBAL modified to METRIC by researcher at University of Idaho (Allen et al., 2007a).

While the Two-Source Energy Balance models (TSEB): Disaggregated Atmosphere Land Exchange Inverse (DisALEXI) model does not require local data or identification of extreme conditions. Mecikalski et al. (1999) discussed in detailed the Atmosphere Land Exchange Inverse (ALEXI) method. The most important inputs data are a fraction vegetation cover (obtained from the Normalized Vegetation Difference Index [NDVI] estimated from the AVHRR data or other satellite sources), and the change in radiometric temperature of the land surface over approximately a four-hour time interval in the morning. Currently, this time-change (temporal resolution) information is only available from the NOAA- GOES (Geostationary Operational Environmental satellites). ALEXI is developed based on “two-Source Energy Balance’’ model (TSEB); the two sources being soil and vegetated components of a scene. The scale of ALEXI fluxes estimation have spatial resolution of 4-5km scale of GEOS thermal measurement required to compute time change in radiometric temperature.

2.2. Agriculture Sector in Ethiopia

Agriculture remains by far the most important sector in Ethiopian economy. The sector directly supports about 85% of the population in terms of employment and livelihood; contributes about 50% of the country’s gross domestic product (GDP); generates about 88% of the export earnings; and supplies around 73% of the raw material requirement of agro-based domestic industries. It is also the major source of food for the population and hence the prime contributing sector to food security. In addition, agriculture is expected to play a key role in generating surplus capital to speed up the country’s overall socio-economic development (CEEPA, 2006)

Ethiopia's natural resources basis the soil, the climate, the relative humidity, the vegetation types are the foundations of agriculture and could be over laid to give what is known as the agro-ecological zones. Ethiopia has 32 major agro-ecological zones and these different agro- ecological zones, extensive arable land and high population in rural areas make Ethiopia an agrarian country (CAADP, 2009).

However, the existences of climate variability influence agricultural sector on which majority of the population depend. According to FAO (2005) 80 percent of Ethiopia's population subsists on rainfed agriculture. The agricultural sector is nearly totally dependent on rainfall with only 2 percent of the total arable land being irrigated, thus welfare and economic productivity are linked to the variable rains. This dependency on rainfed agriculture has thus made the country's economy extremely vulnerable to the effect of climate variability and climate change. Frequent drought is an important aspect of climate variability and change that human being has been experiencing in current time. Consequently, area affected by drought is increasing in Ethiopia due to climate change, climate variability and other human induced factors (NMSA, 1996).

2.3. Application of remote sensing evapotranspiration in agriculture

Remotely sensed ET has paramount importance in water balance of large area, and it has strong link with agricultural productivity, besides its spatial resolution and extent, distributed model and make available real-time information for decision making purposes.

The most widely used crop water balance technique for operational monitoring is the Food and Agriculture Organization (FAO) water balance algorithm by (Doorenbos and Kassam, 1979) that produces the crop water requirement satisfaction index (WRSI). The WRSI shows the relative relationship (ratio/percent) between the supply (from rainfall and existing soil moisture) and demand (crop demand to meet its physiological needs) using observed data from the beginning of the crop season (planting) until a specified date throughout the growing season.

Because conventional agricultural production figures are typically unavailable until several months after harvest, simple physically based crop water requirement models have been devised for use with rainfall station data. These models, in turn, permit early estimates of crop yield and production through statistical relationships. The United Nations Food and Agriculture Organization (FAO) has developed the WRSI as an operational tool for estimating the agricultural consequences of rainfall in water- limited areas of the world (Frere and Popov, 1986). Moreover, Crop water accounting with the WRSI is done on a dekadal basis using sums of daily rainfall observations from a station representative of conditions in a crop-reporting district. The dekad is the basic 10 day time step of agrometeorological monitoring of crop water stress and each month of the year is divided into three dekads (Verdin and Klaver, 2002).

The performance of the crop during the growing season is one of the indicators of agricultural drought. Currently, crop moisture stress on grain crop can be monitored using satellite based crop performance index, WRSI (Victor et al., 1988; 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). WRSI can be related to crop production using a linear yield reduction function specific to a crop (FAO, 1977; FAO, 1979) and the reduction of crop yield due to water deficit is simulated from it. WRSI is currently operational as monitoring and forecasting tool for regionwide food security analyses in drought prone countries in Sub-Saharan Africa. Furthermore, Senay and Verdin (2002) evaluated the performance of the model using district level crop yield data from Ethiopia. Historical yield data from 1996-1999 were used to evaluate the performance of a seasonal WRSI for sorghum. WRSI values and reported district yield data were significantly correlated (r=0.77) and the model was particularly found successful in capturing the response of the crop during a relatively dry year.

Rainfed agriculture is always characterized by significant fluctuation in yield due to variation in moisture availability and other factors (fertilizer application, disease, pest control, seed varaity). Agricultural drought in general and extended intra-seasonal dry spell in particular, as moisture deficit can lead to crop failure. Agricultural drought is a permanent constraint to agricultural production in many developing countries, and an occasional cause of losses of agricultural production in developed ones (Ceccarelli and Grando, 1996). Application of satellite derived indices for assessment of crop growth conditions using geospatial rainfall estimate is well known in semi-arid countries. Tracking the spatial and temporal patterns of rainfall data from satellite with respect to crop and soil characteristics can reveal situation of yield reduction due to water deficits (Gabriel Senay and Verdin, 2002). Agricultural drought decreases grain yield through the reduction of various yield components of a crop. Water deficit is one of the most common environmental stresses that affects growth and development of plants (Aslam et al., 2006). Agricultural drought, or more generally, limited water availability is the main factor limiting crop production.

The Famine Early Warning System Network (FEWS NET) demonstrated a regional implementation of the FAO WRSI in a grid-cell modeling environment (Verdin and Klaver, 2002). Furthermore, Senay and Verdin (2003) enhanced the geospatial model by introducing the concept of maximum allowable depletion (MAD) and soil water stress factor, commonly used in irrigation engineering, for better estimation of ETa as a function of soil water content in an operational setup. The WRSI crop water balance index has been demonstrated to be a reliable tool for crop performance monitoring of large areas in an operational manner.

Accurate crop performance monitoring and production estimation are critical for timely assessment of the food security of several countries in the world. Since 2001, the Famine Early Warning Systems Network (FEWS NET) has been monitoring crop performance and relative production using satellite-derived data and simulation models in Africa, Central America, and Afghanistan where ground-based monitoring is limited because of a scarcity of weather stations. The commonly used crop monitoring models are based on a crop water-balance algorithm with inputs from satellite-derived rainfall estimates. These models are useful to monitor rainfed agriculture (Gabriel Senay et al., 2007).

2.4. Remote sensing to hydrologic modeling and monitoring

Remote sensing application to hydrologic modeling and monitoring, as well as water management in recent years are growing with emphases on water cycle research (precipitation, evapotranspiration and soil moisture), flood and drought hazard monitoring and evaluation, irrigation and drainage management, monitoring of ecologic environment related to water resources development and utilization. For hydrologic modeling, the time series of runoff, precipitation, and evapotranspiration are very important, which may be obtained by the station-based observation system. The model development based on surface station for a large river basin is almost impossible due to the scarcity of land surface observations and difficulties in representing hydrological processes at large scales.

Remote sensing may provide the required data, such as information on land use/cover, soil moisture, surface temperature, solar radiation, albedo, surface emissivity, green biomass and vegetation health conditions and topography, for hydrological modeling at local to global scales. Liu S.C and Zhang W.C. (2004) gave a review of application of remote sensing to the retrieval of precipitation, land use/cover, leaf area index, albedo, land surface flux and some indirect parameters in distributed hydrologic model, and proposed frame work for developing a distributed hydrological model by integrating GIS and remote sensing.

Engman and Schultz (2000) gave the advantage of remote in hydrology:

1. The ability to provide spatial data, rather than point data.
2. The potential to provide measurements of hydrological variables, such as soil moisture, and snow water content which are not available through traditional techniques.
3. The ability, satellite sensors, to provide long-term, global wide data, even for remote and generally inaccessible regions.

3. Materials and methods

3.1. Description of the study area

The study area is located in the Main Ethiopian Rift, Oromia and Southern Nations and Nationalities and Peoples' Administrative Regions. The Area is accessible via the main roads from Addis Ababa to Hawassa, and some 200km away to south-west from Addis Ababa and it is bounded with geographic coordinates of 37^{o}54'15"- 39^{o}17'00"E and 7^{o}9'10"- 8^{o}20'00"N. The study area including rift floor and its margins and it covers about 12464 km^2 area (figure 3.1). The Ethiopian Rift Valley, as part of the Great East African Rift Valley, splits the Ethiopian highlands into northern and southern halves, forming a floor in between occupied with the chain of lakes characterized by varied size, hydrological and hydrogeological settings.

The Main Ethiopian Rift Valley comprises Lakes: Ziway, Langano, Abiyata and Shalla and the highlands in both sides of the rift valley provide several perennial streams (Meki, Keter) that enter the lakes occupying the low-lying middle areas of the rift.

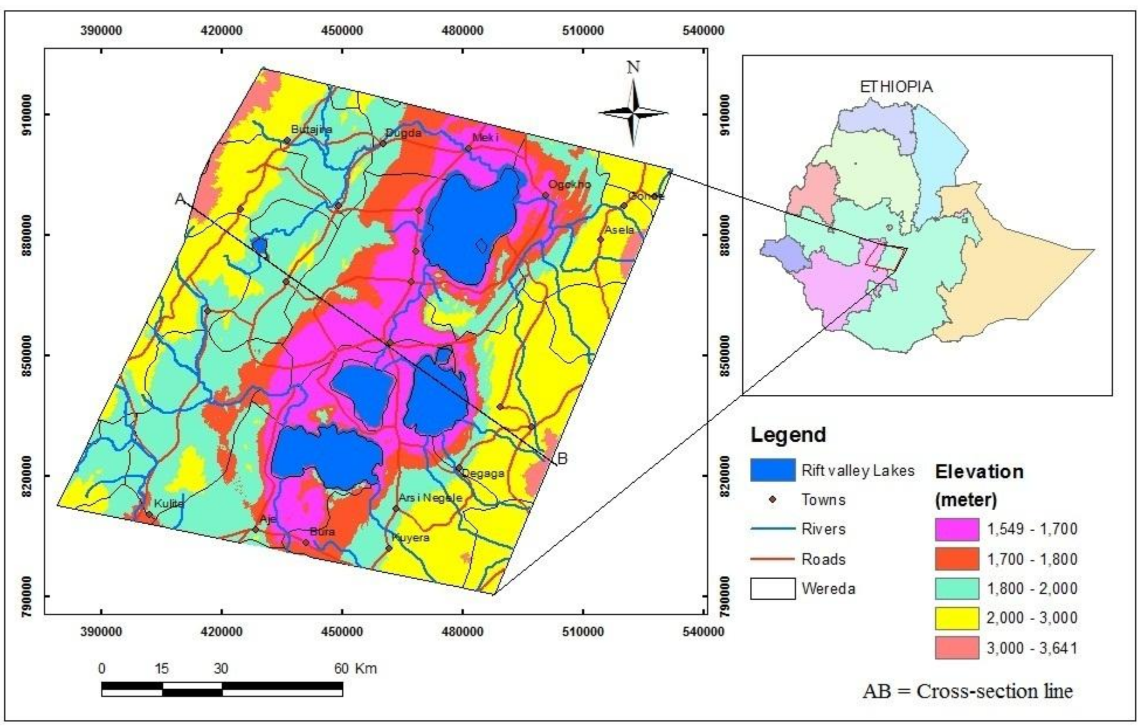


Figure 3.1. Location map of the Study area

3.1.1. Climatic characteristics

The climate of the study area is humid to sub-humid in the highlands and semi-arid in the rift floor. Mean annual temperature is about 15^0C in the highlands and around 20^0C in the rift. The average annual rainfall ranges from about 1150 mm in the eastern and western highlands to around 650 mm in the rift floor. At the top of large volcanic summits the annual rainfall can be as high as 1400 mm. The main rainy season is between June and September, while the dry period lasts from October to February. Temperature and rainfall show strong altitudinal variations (Tenalem Ayenew, 2003).

3.1.1.1. Temperature

The temporal distribution of temperature long term monthly mean in the Main Ethiopian Rift experiences the hottest month varies with meteorological stations and the coldest in December (fig.3.2). On the other hand, the spatial distributions largely vary depending on the altitude.

Regarding spatial distribution, the rift floor experienced higher temperature than both sides of edges of the escarpments because of topographic setting. It varies from 18.5-20.1^0C in the rift floor and 18.5-11.3^0C in the eastern and western edges of the escarpments (fig.3.3).

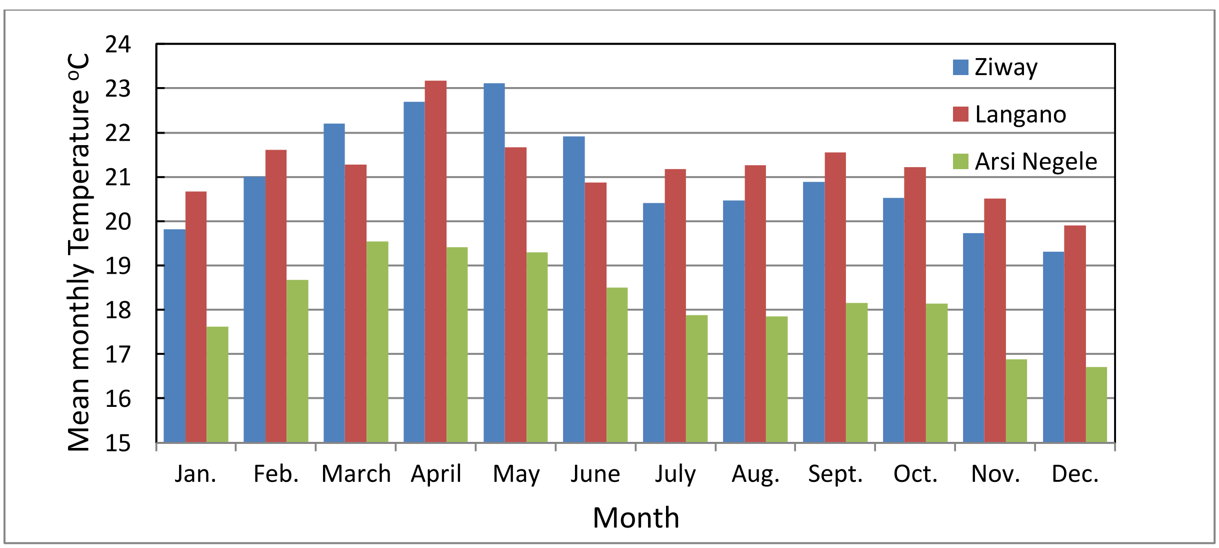


Figure 3.2 Distribution of mean monthly temperature

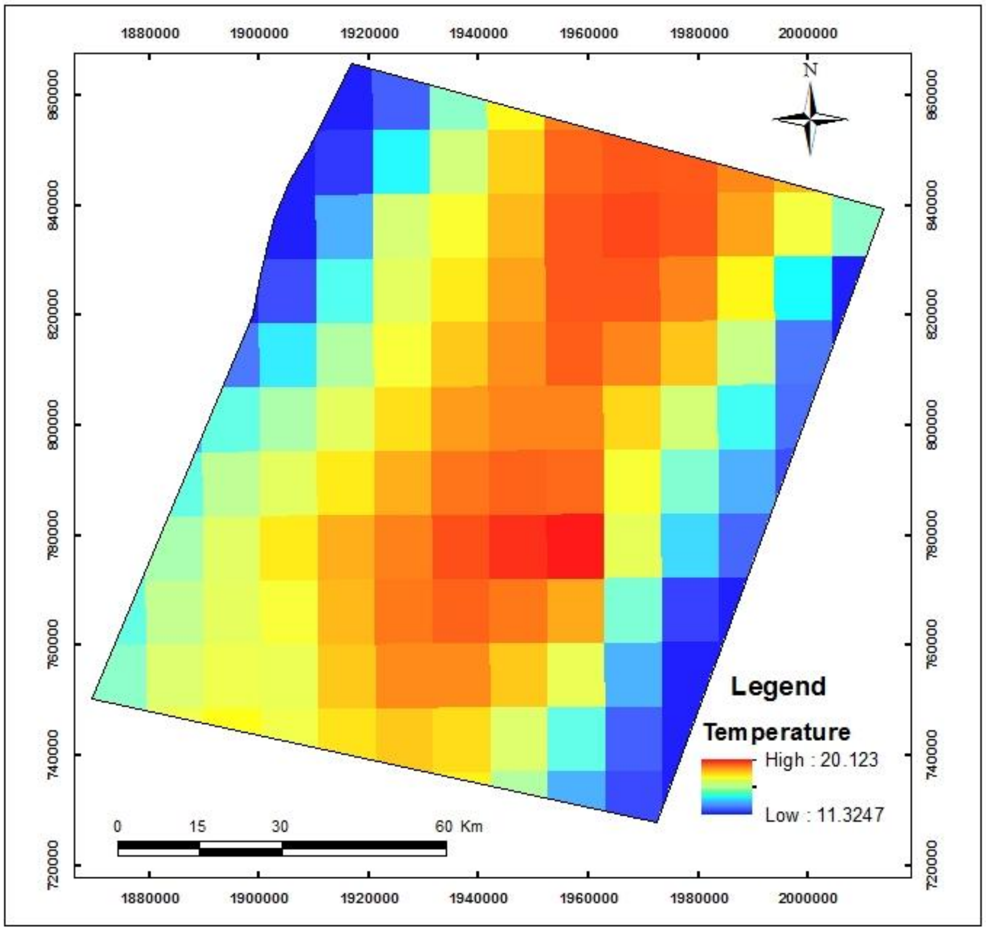


Fig. 3.3 Spatial pattern of long term seasonal (June – September) mean temperature (^{o}C)

3.1.1.2. Precipitation

The main Ethiopian rift is characterized by nearly bi-modal rainfall type, the shorter season, spring (Belg) (March, April and May months) and the longer season, summer (kiremt) which extends from June to September and the remaining months are characterized by low precipitation (fig.3.4). The annual distribution is varies 515mm/year in 2002 and 972mm/year in 2008 (fig.3.5).

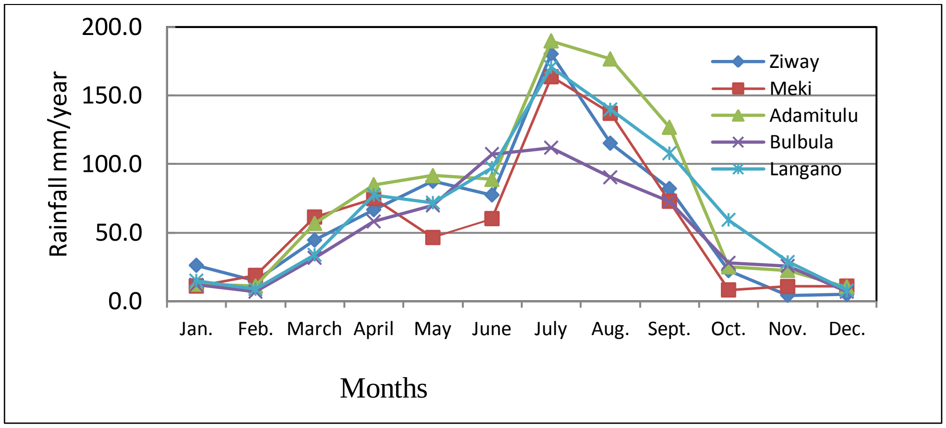


Fig.3.4 Distribution of mean monthly rainfall

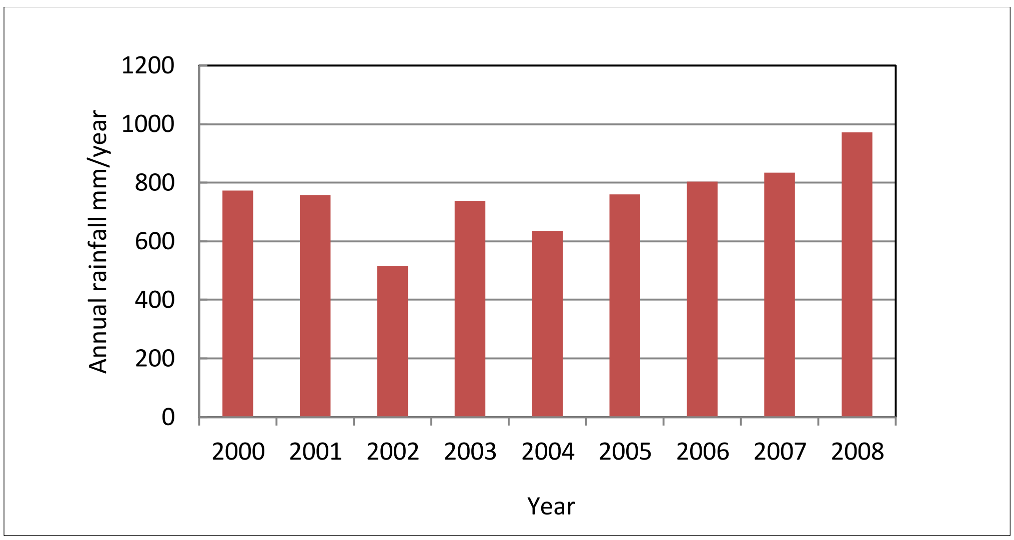


Fig.3.5 Distribution of annual rainfall (2000-2008)

3.1.1.3. Relative humidity

Relative humidity is the relative measure of the amount of moisture in the air to the amount needed to saturate the air at the same temperature (Shaw, 1988). It varies from time to time, depending on variation in rainfall, air temperature and wind speed. As Relative humidity rises, proportionately fewer of the water vapor molecules leaving the evaporating surface can be retained in the air, and so rate of evaporation, i.e., the total number of molecules leaving, minus the total number of molecules returning, is gradually reduced. The relative humidity data of years 2000 to 2007 was considered from Ziway meteorological station. The monthly average relative humidity revealed that the maximum and the minimum attained in months of August and February with values of 71% and 52% respectively. Throughout the months in the years, the monthly mean relative humidities were more the 50%.

Table 3.1 Monthly mean relative humidity

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
R.H (%)	57	52	53	57	59	62	70	71	67	55	54	56

R.H (%) = relative humidity in percentage

3.1.1.4. Wind speed

Presence of atmospheric turbulence can greatly increase the rate of evaporation by removing vapor from evaporating surfaces and giving space for fresh air capable of holding additional vapor in the atmosphere. In the study area, the Ziway meteorological station has records of wind speed at 2m above the ground surface (table 3.2).

Table 3.2 Monthly average wind speed

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
w.s (m/s)	1.4	1.4	1.3	1.3	1.5	1.9	1.8	1.6	1.1	1.2	1.5	1.5

w.s (m/s) = wind speed in meter per second

3.1.1.5. Sunshine hours

Since the evaporation requires continues supply of energy which is derived mainly from solar radiation, the solar radiation is a factor of considerable importance and it depends on sunshine duration of area under consideration. The sunshine duration data is available in Ziway meteorological station (table 3.3)

Table 3.3 Monthly average sunshine hours (hours/day)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
s.s (hrs)	9.5	9.4	8.3	8.4	9.2	8.4	6.4	6.6	7.0	9.1	10.2	10.1

s.s (hrs) = sunshine hours

3.1.2. Topography

One of the prominent aspects of Main Ethiopian Rift is the landscape. The topography greatly varies from low land (<1550m) in the rift floor to high land (2000m) at the margins. Besides that the Easter and western edges of the escarpments (plateaus) in the study area is ranges from above 2000m and the highest being 3640 meters above sea level. This big elevation difference within short distance contributes a lot for micro climate anomalies and plays enormous role in controlling factor on the surface and sub surface hydrological conditions. This abrupt elevation difference brought variation in weather conditions in the high lands and the valley floor.

The Main Ethiopian rift valley is low lying area surrounded by elevated and steep escarpments. The valley is surrounded by these escarpments in the eastern and western sides and the topographic cross-section of the rift from line AB is shown in Fig. 3.6.

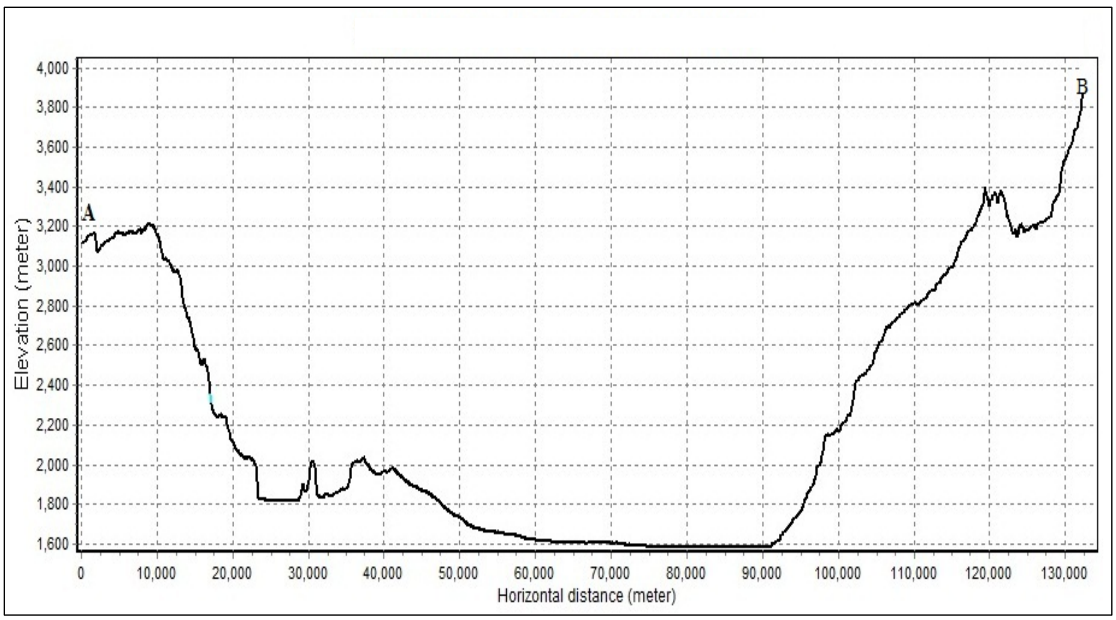


Fig.3.6. Topographic cross-section along line AB

3.1.3. Population

The Ethiopian population have annual rate of growth of 2.6% and of the total population 83 percent live in rural areas mainly subsisting on agriculture (CSA, 2007). The population projection figure in the rift area is estimated based on the results of the May 2007 National population and Housing Census of Ethiopia. Therefore, the projected figure for weredas included in the study area of the year 2011 is given in table 3.4. The dominant economic activity of the region is agrarian, and mainly relying on household labour. Agriculture production is aimed at self-subsistence and dependent on forces of nature. The main agricultural crops include teff, maize, wheat, barley, Sorghum, peas, bean and various types of oil seeds.

Table 3.4 Projected Population of 2010 in the main Ethiopian Rift (CSA, 2010)

Wereda	Population (p)	hectare (ha)	Population density (p/ha)
Siraro	163183	59935	2.72
Shala	167994	75825	2.22
Arsi- Negele	294212	128119	2.30
Munesa	187194	107159	1.75
Tiyo	94432	60538	1.56
Ziway Dugda	164389	92368	1.78
Adami tulu jido kombolcha	159468	109451	1.46
Sheshemene Zuria	276578	76788	3.60
Dugda Bora	66429	43567	1.52
Meskan	175113	44671	3.92
Merako	72870	25199	2.89
Dalocha	100989	35114	2.87
Alaba	262765	99466	2.64
Siltie	199770	51027	3.915
Lanfaro	131168	44599	2.94
Total	2,516,554	1,053,826	2.4

3.1.4. Soil characteristics

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. Soil distribution and characteristics vary by their parent materials, climate, vegetation and interaction among these factors and time. In view of this, different types of soils are found in the study area. According to Food and Agricultural Organization (FAO) cited in (Finance and Economic Development Bureau of Oromia, 2007), Andosols, Vertisols, Rendzinas and Phaeozems, and Fluvisols are the dominant soil type found in the main Ethiopian rift.

3.1.5. Geology

The major geological event in the study area is associated with the formation of Great Rift Valley and Rocks of the rift valley belongs to the tectonisms and volcanisms of Cenozoic Era. The geological and geomorphologic features of the basin in general are thought to have been associated with extensive volcanism and Cenozoic volcano-tectonic and sedimentation processes (Tenalem Ayenew, 2002a). The large part of the rift valley areas being characterized by lacustrine sediments and volcano-sedimentary rocks. Lacustrine sediments being the most common and form the second largest next to ignimbrites (Tesfaye Chernet, 1982). In East Shewa zone, tertiary volcanic covers southern, north eastern and north western part of the 20 zone forming about 59 percent of the zonal area. The later part of Cenozoic era, the quaternary period is characterized by the formation quaternary sediments and Volcanic. Quaternary sediments account for 19 percent of east Shewa zone covers the central and the lake region of the zone (Finance and Economic development Bureau of Oromia, 2007).

3.1.6. Land use/land cover

The landuse and land cover map of the study area was derived using Landsat TM images of Jan.30, 2011 with paths and rows (p168, r054& p168, r055& p169, r055). The land use/ land cover pattern of the study area includes rainfed farm (intensively cultivated and mixed cultivated /with woods), bushes,shrubs and grass lands, water body, forest, Swamps and wet lands, irrigated farms, degradede savanna and settlement (Figure 3.7).

Hence the dominant land was used for rain-fed agricultural practices and the least share occupied by settlement /towns and their areal coverage and percentage of landuse and landcover classes are given in table 3.5. The study area comprises three major rift valley lakes and their basic morphometric data as presented by (Tenalem Ayenew, 1998) is given table 3.6

Table 3.5 Land uses in the main Ethiopian rift

Land uses	Area (km^2)	Area (%)
Intensively cultivated	4984	40.0
Mixed cultivated/with wood	3839	30.8
Bushes, shrubs and grass	1959	15.7
water bodies	1095	8.8
Forest	160	1.3
Degraded savanna	110	0.9
Swamps and wet lands	132	1.1
Irrigated farm	135	1.1
Settlements	50	0.4
Total	12464	100

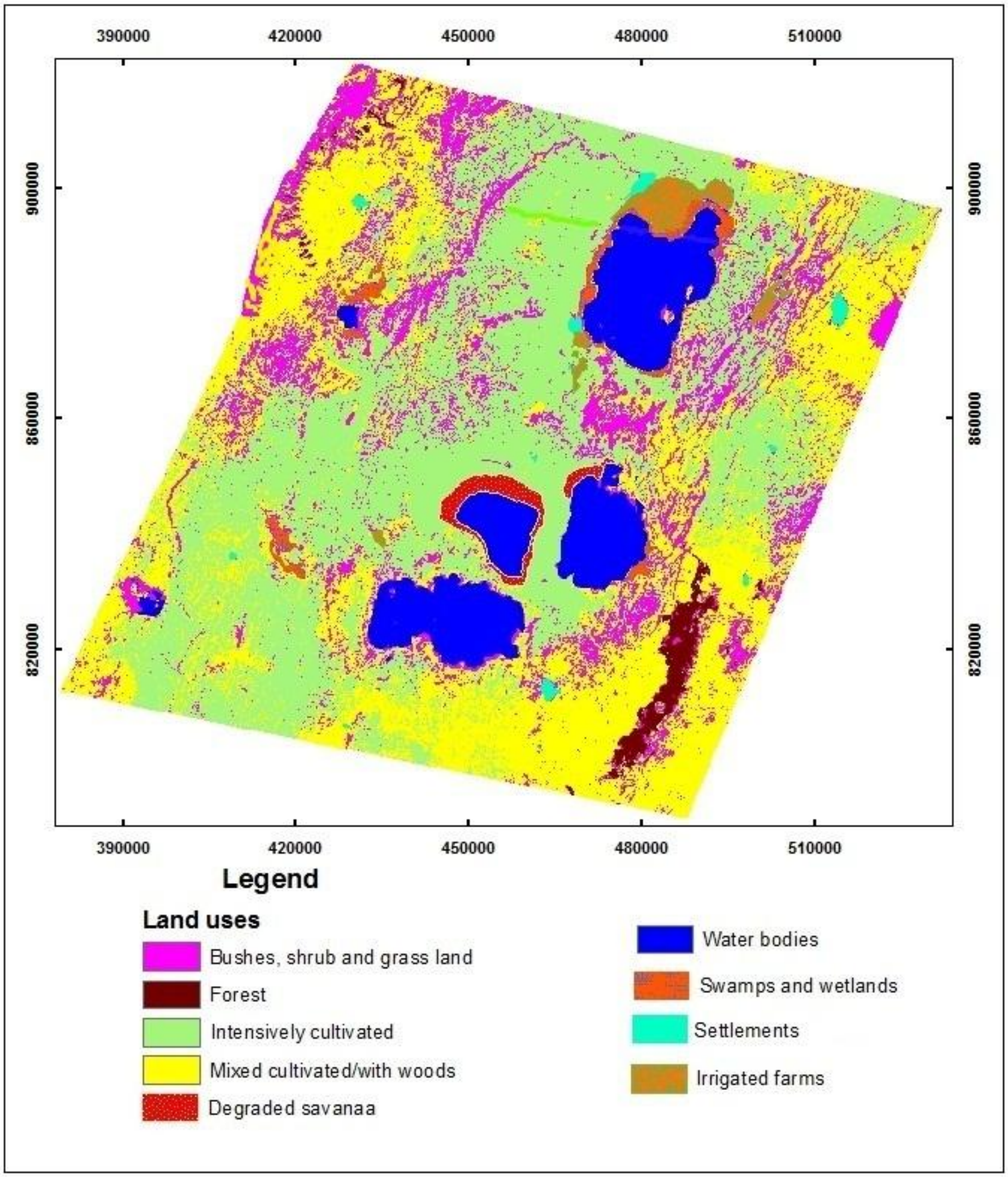


Fig 3.7 Land use land cover map of 2011

Table 3.6 Basic morphometeric data of the major lakes

Lakes	Altitude (m.s.l)	Lake area (km^2)	Catchment area (km^2)	Maximum depth(m)	Mean depth (m)	Volume (10^6m^3)
Abiyata	1580	180	10740	14.2	7.6	954
Langano	1585	230	2000	47.9	17	3800
Shala	1550	370	2300	266	8.6	37000
Zuway	1636	440	7380	8.9	2.5	1466

Source: Tenalem Ayenew (1998)

3.1.7. Agroclimatic Zone

According to Regional land Management Unit (RELMA) (2005) Ethiopia has remarkably diverse landscapes. Altitudes range from 120m below sea level (in the Denakil depression) up to 4620m above sea level (in the Semien mountaians). Day-time temperatures ranges from 2^{o}C and 43^{o}C.The soil vary in colour, texture, fertility and extent of degradation.The natural vegetation includes mountain steppes, savannah, woodland, forest and lowland scrub.

The two most important climatic factors from the agriculture point of view are temperature (which is determined by altitude) and rainfall. These have a major influence on what crops farmers grow, how they keep their livestock, how they manage their land.

In particular, the Main Ethiopia Rift (MER) is characterized by altitude ranges from 1500m to 2000m above sea level and Rainfall is less than 900mm/year and then which is categorized to weyna-Dega and Dry zone respectively. As a result the area is located in agroclimatic zone of Dry weyna-Dega zone. The dominant crops are wheat, teff and rarely maize.

3.2. Data acquisition and software package

Ten years time series climatology NDVI of Advanced Very High Resolution Radiometer (AVHRR) which embarked on NOAA satellite, reference evapotranspiration (ETo) and rainfall estimate (RFE) satellite data from 2001 to 2010 were used in this study. These data were downloaded from the Famine Early Warning System (FEWS-NET) archive website: http://earlywarning.cr.usgs.gov/adds/datatheme.php

Table 3.7 Description of the data used in this study

S.N	Data types	Temporal resolution	Spatial resolution	sources
1	Rainfall data (image)	dekadal	10km	Blend of NEXRAD of NOAA and station data
2	Reference ET (image)	dekadal	10km/100km	GDAS of EROS
3	Climatology NDVI	dekadal	8 km	AVHRR of NOAA
4	Soil-water holding capacity	-		FAO
5	IWMI Reference ET	dekadal	10km	IWMI
6	Temperature	dekadal	10km	IWMI
7	Meteorological data	-		NMA
8	Landsat images	-	30m	USGS data portal

Software package used are: ArcGIS10, ERDAS9.2, GeospatialWRSI3.0 and spread sheet

3.3. Methods

3.3.1. VegET model setup

VegET is a new modeling approach that integrates Land Surface Phenology (LSP) and commonly used water balance modeling algorithms to estimate actual vegetation ET (water use) in primarily non-irrigated crop and grassland environments for agro-hydrological applications. The model Produce daily ETa and soil moisture to monitor crop and grassland performance for early assessment of yield and biomass. Major inputs are precipitation (PPT), reference ET (ETo), WHC and Kcp. ETa is calculated as the product of ETo, soil stress coefficient (Ks) and phenology-based crop coefficient (Kcp) as shown in (eqn 1) and (fig.3.8).The model outputs are actual evapotranspiration (ETa) and runoff (Gabriel Senay, 2008).

$$ETa = Kcp * Kc * ETo \qquad (1)$$

Where ETa is actual evapotranspiration in mm; Kcp is LSP-derived crop coefficient (-); Ks is soil-water stress coefficient (-) and ETo is reference ET in mm.

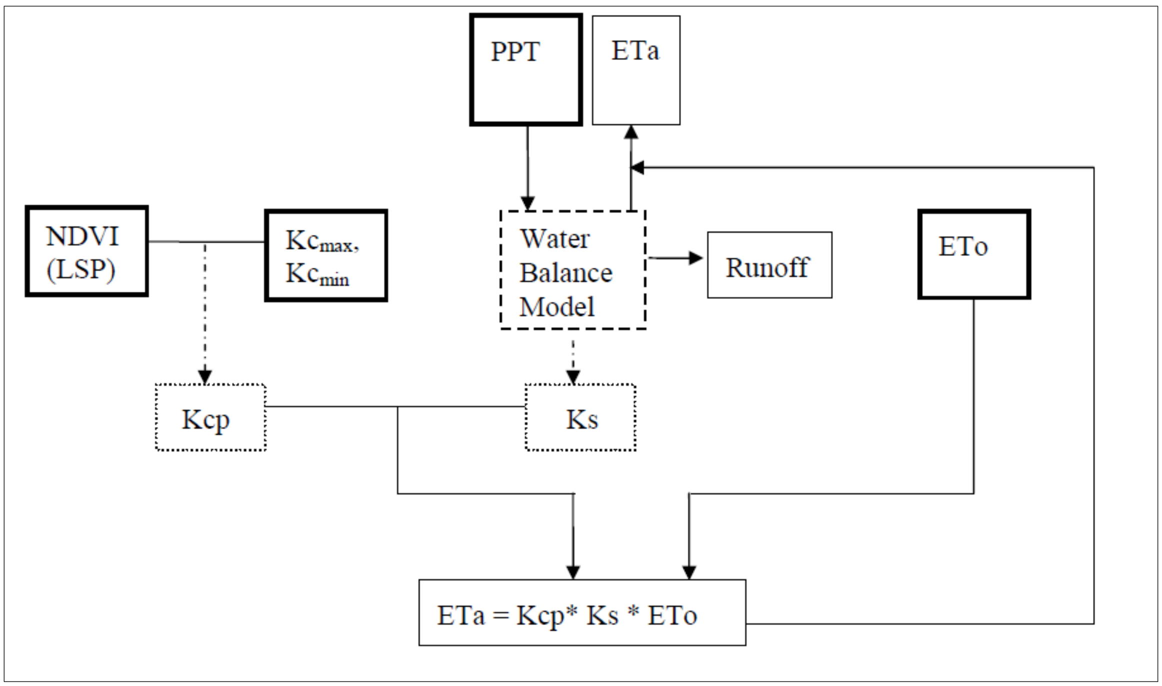


Fig 3.8. Methodology flow chart

3.3.1.1. NDVI Climatology

The NDVI climatology is defined as a "historical" average NDVI for a given time period. Historical is defined as the average of at least 5 years of NDVI data. Such data is available from AVHRR and MODIS for global applications. The terms Land Surface Phenology and NDVI climatology are used interchangeably. Land Surface Phenology (LSP): is defined as the seasonal spatio-temporal pattern of variation in vegetated land surfaces observed from remote sensing (De Beurs and Henebry, 2008). In this study, LSPs are simply represented by temporally smoothed (Long term average) climatology NDVI data sets. The smoothed NDVI climatology data sets are preferred to produce Kcp functions in order to avoid data noise from yearly NDVI data sets. Currently, NDVI climatology is available for global applications from different data sources such as the Global Inventory Monitoring and Modeling Studies (GIMMS) at a monthly scale at 8-km resolution. In this study, the dekadal maximum composite at 8 km is used. This data set is created by first compositing cloud-free weekly maximum NDVI values for each pixel from 2001 to 2010 years. The climatology was then created by averaging dekada maximum NDVI values of the 10 years. The weekly climatology NDVI were further interpolated to represent dekadal time periods to conform with other modeling procedures and availability of similar (dekadal) NDVI data sets for other regions of the world. A dekad is nominally composed of 10-day time periods in a month, except for the 3rd dekad of a month where it may assume values of either 8, 9, 10, or 11, depending on the month and year.

The AVHRR NDVI is calculated based on the red (0.58–0.68 μm) and near infrared (0.725–1.0 μm) reflectances of the NOAA AVHRR sensors as follows:

$$\text{NDVI} = \frac{\text{NIR} - \text{Red}}{\text{NIR}+\text{Red}}$$

NDVI values for vegetation typically range from about 0.05 to about 0.7, with higher values for denser vegetation. NDVI for bare soil and rock is usually near zero and NDVI for water and snow is typically negative.

3.3.1.2. Crop coefficient

To compare the differences between a generic cereal crop Kc and the spatially dynamic Kcp, a crop coefficient function was developed using the following assumptions. The study assumes a generic cereal crop with a growing length of 120 days. The growing lengths for the initial, vegetative, mature, and senescence growing stages are 0%, 16%, 26%, 40%, and 18% of cycle length respectively. The associated Kc values for the initial, mature, and senescence periods are 0.3, 0.3, 1.2, 1.2, and 0.25, respectively (Allen et al., 1998) and (Hoefsloot. 2010).

3.3.1.3. Soil-water stress coefficient (Ks)

Ks is determined from a soil water balance model similar to the one developed by Gabriel Senay and Verdin, (2003) for USGS/FEWS NET early warning applications using Equation 2 and 3. The dimensionless Ks coefficient varies from 0.0 to 1.0 depending on the soil water level in the modeling unit root zone (fig.3.9)

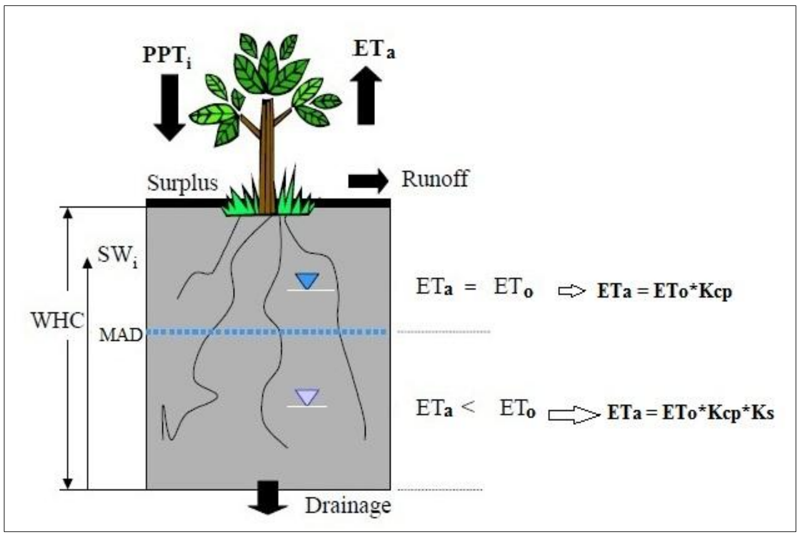


Fig. 3.9 Components a crop water balance model

$$Ks = \frac{SWi}{MAD}, \quad \text{if } SWi < MAD; \qquad (2)$$

$$Ks = 1.0, \quad \text{if } SW_i >= MAD \qquad (3)$$

SWi is soil water content of current time step in depth unit. MAD is the Maximum Allowable Depletion level of soil water content in the root zone, below which the vegetation ET is less than "potential" and will be constrained by the availability of soil water according to Equation 3. Although MAD varies by crop/vegetation type, a nominal value of 50% of the soil WHC can be used for most generalized crops such as cereals and natural vegetation.

The soil water level is determined using a dekadal soil water balance using Equation 4 where ETa is estimated iteratively employing Equations 1 and 2. The model estimates a combined runoff and deep drainage based on the principle of saturation excess where soil water in excess of the water holding capacity (WHC) of the soil is considered to be unavailable for plant–use in the root zone; thus SW_i is set to a maximum of WHC and a minimum of 0.0 during the modeling time-step. More detailed information is available on the setup and initialization of the soil water balance model for operational crop monitoring in (Gabriel Senay and Verdin, 2003).

$$SW_i = SW_{i-1} + PPT_i - ETa_i \qquad (4)$$

Where SW_i is soil water of current time step (mm); SW_{i-1} is soil water of the previous time step (mm); PPT_i is precipitation (mm) and ETai is actual ET (mm); "i" is the modeling time step.

The innovative approach in VegET is on the calculation of the Kcp (Figure 3.8). The Kcp is comparable to the Kc widely used by agronomists (Allen et al., 1998). The key difference is that Kcp is a parameter derived from remotely sensed data as opposed to site-specific field experiments. Kcp represents both the spatial and temporal dynamics of the landscape water-use patterns on a grid-cell basis. LSPs are characterized and converted into Kcp parameter functions.

3.3.1.4. Kcp Parameter Function

According to Gabriel Senay (2008) the Kcp parameter function is defined using NDVI climatology (LSP) and published crop coefficient minimum (Kc_{min}) and maximum (Kc_{max}) values. The Kc values provide the lower and maximum limits for the Kcp. The NDVI profile provides the temporal patterns of Kcp. Kc_{max} and Kc_{min} values can be defined under two conditions: 1) with the assumption that a specific crop/vegetation type will grow in a modeling cell (in this case, published values from FAO (Allen et al,. 1998) or other sources can be used), 2) with the assumption that the landscape ET is based on different land cover mixtures as captured by the NDVI profile; i.e., a modeling cell will include fractions of different vegetation types and bare cover. In the second case, Kc_{max} and Kc_{min} can be a composite value from a weighted average of the cover composition with each modeling cell. The percent cover fractions from the MODIS VCF data will be particularly useful for this application.

Equation 5 shows the formulation of the Kcp parameter as used in Equation 1 to estimate landscape ET, representing a spatial unit as determined by the resolution of the LSP data set (NDVI).

$$Kcp= \frac{Kc_{max}-Kc_{min}}{NDVI_{max}-NDVI_{o}} *(NDVI_{i}-NDVI_{o}) +Kc_{min} \qquad (5)$$

$$Kcp = Kc_{min} \quad \text{if } Kcp < Kc_{min} \qquad (6)$$

Where Kc_{max} is the maximum (mature) Kc value for a vegetation/crop type; Kc_{min} is the minimum (early stage) Kc value; $NDVI_{max}$ is the climatology maximum NDVI value in a year; $NDVI_{i}$ is the climatology NDVI value for a given period "i" (average weekly maximum value in this case); and NDVIo is the minimum reference NDVI value that is associated with the minimum Kc value, which varies depending on the value-range of NDVImax according to Equation 5 or 6.

NDVIo is calculated depending on the NDVImax for each pixel.

CASE 1: $NDVI_{max} > = 0.40$

$$NDVIo = 0.3 \qquad (7)$$

CASE II: $NDVI_{max} < 0.40$

$$NDVI_{o} = 0.33* (NDVI_{max} - NDVI_{min}) + NDVI_{min} \qquad (8)$$

$NDVI_{min}$ is the climatology minimum NDVI value from the weekly maximum NDVI composite data set.

The justification for establishing the NDVIo value is based on observations of the start of season in crop and grassland phenology. A value of close to 0.3 AVHRR NDVI generally corresponds to the start of the green-up period. This is generally true for areas with crop and grassland systems where the fraction of the vegetation coverage is relatively high. However, in sparsely vegetated areas the magnitude of the NDVI is so low that even the maximum NDVI is sometimes less than the minimum threshold level of 0.3 that is considered an indication of the start of season in predominantly cropland areas. To better handle sparsely vegetated areas, the NDVIo value is defined in relation to the maximum NDVI value for such regions. By visual inspection of several LSP profiles, pixels with NDVI maximum values less than 0.4 are considered sparsely vegetated. These areas were mainly concentrated in the arid and semiarid area.

For arid pixels, the NDVIo parameter will be calculated dynamically, as shown in Equation 7. The most useful information required is the timing and relative magnitude of water use. Although it is moved the NDVIo threshold value from 0.3 to some lower number, the timing and relative magnitude of water use will still be achieved. This is possible because the absolute NDVI magnitude of a pixel is a function of the percent vegetation cover, but the phenology (timing and relative magnitude of water use) is mainly captured by the temporal profile of the NDVI pattern.

Assigning a Kc_{max} value for Kcp during the peak NDVI is only appropriate if the objective is to simulate crop water use by assuming the entire modeling unit is composed of crop fields. Because crop makes good ground coverage (closed canopy) at maturity for most crops, the Kcp function assumes that maximum water use is achieved at maximum NDVI regardless of the magnitude of the maximum NDVI. The NDVI profile provides the timing and relative magnitude of water use. On the other hand, if the exercise is to simulate landscape water use by the natural vegetation, the maximum and minimum Kc (Kc_{max}, Kc_{min}) can be adjusted as an area-weighted value to reflect this based on information on percent ground cover from such data sources as MODIS VCF.

A justification of the 0.33 coefficient in Equation 7 is derived from the observation that 0.3 NDVIo value for crop/grassland areas also corresponds to approximately one-third plus the minimum NDVI of the range between the maximum NDVI (0.7) and minimum NDVI (0.1) generally found in crop and grassland systems (0.2 + 0.1). Thus, with a similar logic, the NDVIo for vegetation sparse regions is defined using Equation 7. These thresholds have been shown to produce reasonable results for the United States. However, sensor-specific adjustments may be necessary when using NDVI data sets from sources other than the AVHRR climatology. The main impact of the lower or higher NDVIo value is in the starting of vegetation growth simulation to the earlier or later part of the season, respectively. For example, a change from NDVIo of 0.25 to 0.3 may move the start of season by two weeks later. This kind of error is tolerable when the main objective is to monitor the performance of crops or vegetation at large spatial (> 5 km) and temporal (> monthly) time scales. This error is even more tolerable when the seasonal monitoring is compared with other years as an anomaly product. The Kcp function only uses these two parameters ($NDVI_{max}$ and NDVIo) to convert smoothed historical NDVI data sets from NDVI to Kcp according to Equation 5 or 6. For example, a generic cereal crop has a published Kc of 0.3 (Kc_{min}) at the early stage and 1.2 (Kc_{max}) for the mature stage. Both $NDVI_{max}$ and $NDVI_{min}$ (NDVIo) are calculated from $NDVI_i$

data sets where “i” represents a “historical” NDVI time step. $NDVI_i$ data sets are available at weekly or longer time steps.

3.3.1.5. Precipitation (RFE)

Rainfall Estimation (RFE) imagery is an automated (i.e., computer-generated) product which uses infrared data from the European Space Agency’s Meteosat satellite, rain gauge reports from the global telecommunications system, and microwave satellite observations within an algorithm to provide RFE in millimeters (mm) at an approximate horizontal resolution of 10km. RFE images prepared by Climate Prediction Center of the National Oceanic and Atmospheric Administration (NASA). The main use of these data is to provide input for hydrological and agrometeorological models as well as to provide climate information-e.g., to compare the current state of rainfall with previous time periods (Xie and Arkin, 1997).

3.3.1.6. Potential evapotranspiration (ETo)

Potential evapotranspiration (ETo) represents atmospheric demand for water from the Earth’s surface as a function of solar radiation, air temperature, wind, humidity, and atmospheric pressure (Allen et al., 1998). ETo is an essential dataset for calculating water cycle fluxes in hydrologic modeling. ETo data were calculated on global scale on a cell-by-cell basis according to the Penman–Monteith equation (Verdin and Klaver, 2002); (Gabriel Senay and Verdin, 2003). The model is run operationally at the USGS Center for Earth Resources Observation and Science (EROS). The ETo values were calculated from grids of the meteorological variables that the Penman–Monteith model requires. The meteorological data come from the Global Data Assimilation System (GDAS) dataset produced by the National Oceanic and Atmospheric Administration (NOAA) on a 1-degree by 1-degree grid.

The ETo was calculated using standard equation of FAO Penman-Montheith (Allen et al., 1998) described as follows: This equation can be applied to different vegetation and soil moisture conditions. By defining the reference crop as actively growing and well watered green grass surface with a height of 0.12 m having a surface resistance of 70 s/m and an albedo of 0.23.

$$\text{ETo} = \frac{0.408\Delta(R_n - G) + 900\gamma u_2(e_s - e_a)/T + 273}{\Delta + \gamma(1 + 0.34u_2)} \tag{8}$$

Where ETo reference/potential/ evapotranspiration [mm/month],

R_n Net radiation at the grass surface [MJ m^{-2} $month^{-1}$],

G Soil heat flux density [MJ m^{-2} $month^{-1}$],

T mean hourly air temperature [°C],

Δ Saturation slope vapour pressure curve at T [kPa $°C^{-1}$],

γ Psychrometric constant [kPa $°C^{-1}$],

U_2 Average hourly wind speed [m s-1],

$e_s - e_a$ Saturation vapour pressure deficit [kPa],

e_s Saturation vapour pressure [kPa],

e_a Average hourly actual vapour pressure [kPa].

3.3.2. Agricultural productivity

Crop productivity is the aggregated product of many variables: soil type, fertilizer and pest control utilization, management practices, weather conditions (temperature, humidity) and moreover, availability of water in the soil in plant roots zones. Currently, there are geospatial tools based index of monitoring and even predicting crop performance. There are two croping seasons in Ethiopia: the long “meher” (June to September) and short “belg” February to April. The meher season accounts 90%-95% crop production of the country (FEWS NET, 2001). Similarily, in the study region the meher season begins from June and extends to September.

3.3.2.1. Estimation of yield reduction due to moisture deficit

The impact of moisture deficit on crop production can be largely expressed by yield reduction. Yield reduction was calculated from water balance output combined with an empirical formula developed by Doorenbosch and Kassam (Hoefsloot, 2008).

100-((1-(1-ETa/WR) Ky) 100) (9)

Where ETa is the actual evapotranspiration, WR is the total water requirement without water stress. Ky is a crop dependent stress indicator determined by the authors.
The major crops grown in the area, teff, wheat, maize and sorghum and their respective Ky is 1.1499 for teff, wheat and barely, 1.25, 0.8999 for maize and sorghum respectively.

3.3.2.2. Water Requirement Satisfaction Index (WRSI)

WRSI is an indicator of crop performance based on the availability of water to the crop during a growing season (Gabriel Senay and Verdin, 2003). Studies by FAO, Doorenbos and Pruitt (1975), FOA (1986) have shown that WRSI can be related to crop production using linear yield–reduction function to specific to a crop. The most important input parameters of the model are satellite based rainfall estimate images and spatially distributed potential evapotranspiration images. Besides, the model uses relevant soil information from FAO digital soil map and topographical parameter derived from digital elevation model (DEM). WRSI was calculated as the ratio of seasonal actual evapotranspiration (ETa) to the seasonal crop water requirement (WR).

$$\text{WRSI} = \left(\frac{ET_a}{WR}\right) * 100 \qquad (10)$$

Where, WR is calculated from the Penman-Monteith reference crop evapotranspiration (ETo) using the LSP- based crop coefficient (Kcp) to adjust for the growth stage of the crop:

$$\text{WR} = \text{ETo} * \text{Kcp} \qquad (11)$$

The ETa represents the actual amount of water withdrawn from the soil water reservoir where shortfall relative to potential evapotranspiration (ETo) 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.

Table 3.8 WRSI based drought severity

WSRI (%)	Drought severity class
80-100	No drought
70-79	Slight drought
60-69	Moderate drought
50-59	Severe drought
<50	Very severe drought

After Gizachew Legese (2010)

3.3.3. Establishing drought index incorporating Evapotranspiration

Drought is a recurrent natural phenomenon associated with a deficit availability of water resources over a large geographical area and extending along a significant period of time (Rossi, 2000). This general definition adopted by engineers and scientists who are engaged in water resources management implies that drought is regional phenomenon characterized three dimensions: the severity or intensity, the duration and the extent. The most important parameters on which drought severity is dependent upon are:

- Precipitation (amount, regime, time distribution and intensity)
- Potential evapotranspiration (defined by solar radiation, air temperature, wind velocity, air humidity).
- Soil and vegetation cover characteristics (soil water retention capacity, soil infiltrabilty and surface albedo).

From these parameters the last is highly dependent on local conditions whereas the first and the second are related to climatic variability. In fact precipitation and potential evapotranspiration have been used for classifying bioclimatic aridity in a globally comparable way. In mathematical terms UNESCO (1979) and UNEP (1993) used an aridity /humidity classification system based on average annual precipitation (P) divided by the average annual PET (table 3.9). According to UNESCO (1979) and UNEP (1993) the PET was calculated based on the Penman formula which can be acquired from satellite images.

Table 3.9 Climate classes

Climate class	UNEP(1993) (penman method) P/PET	UNESCO(1979) (Penman method) P/PET	UNEP(1992) (Thornthwaite method) P/PET
Hyper-arid	<0.03	0.03	<0.05
Arid	0.03-0.2	0.03-0.2	0.05-0.2
Semi-arid	0.2-0.5	0.2-0.5	0.2-0.5
Dry sub-humid	0.5-0.65	-	-
Sub-humid	0.65-1.0	0.5-0.75	0.5-0.65
Humid	>1.0	>0.75	>0.65

3.3.4. Preprocessing of data

All images (NDVI, RFE, and ETo) were imported in generic binary format and information related to image dimension (number of rows, columns and bands), projection parameters (Spheroid name, datum name, latitudes of standard parallels, longitudes of central meridian, latitudes of origin of projection, false easting at central meridian and false northing at origin) were incorporated in the raw images. Originally, the data is projected using ALBERS Conical Equal-Area Projection and with the datum Clarke 1866 spheroid. Then the data is reprojected to Adindan UTM_Zone_37N.

As the NOAA-AVHRR NDVI satellite images are radiometerically corrected, geometric corrections were done. In order to transform the imported row data into -1 to 1 range of NDVI, the formula (NDVI= raw data /250) which is provided with row data by FEWS-NET was applied to each NDVI images. Thereafter, the study area was extracted and became ready for further analysis. For this study, a decade dekadal climatologic NDVI images were analysed and used as an input data to produce Kcp parameter on dekadal basis.

Prior to using these data for analysis, a downscaling of the GDAS 1-degree data was performed to produce a 10-km GDAS ETo. The approach utilized the International Water Management Institute (IWMI) historical (1950-2000) potential evapotranspiration (PET). The IWMI data set is based on data originally compiled at 16-km spatial resolution that has been disaggregated to 10-km. The downscaling technique utilized the 10-km historical IWMI PET data to create a fractional relationship, on a per pixel basis, between each 10-km IWMI pixel (X) and the corresponding 100-km IWMI pixel (Y) value (artificially created to simulate the 100-km GDAS). This fractional relationship was then applied back to the 100-km GDAS pixels to downscale these data to a spatial resolution of 10-km (Equation 12). The resulting 10-km ETo grids were used in this analysis (Figure 4). The downscaling method was developed and validated by the (Gabriel Senay et al., 2007) using similar IWMI data to develop the fractions over the conterminous US and the results compared favorably with station-based ETo in California. Thus, the method was proven to be an effective technique to downscale the Global GDAS ETo.

$$X / Y * \text{GDAS ETo} \tag{12}$$

Where, “X” represents 10-km IWMI PET and “Y” is the 100-km IWMI PET

4. Results and discussion

4.1. Estimation of seasonal actual evapotranspiration (ETa)

The VegET model, which principally based on water balance model, uses potential evapotranspiration, land Surface Phenology and soil water stress parameters to estimate vegetation water use. During VegETa estimation, the prevailing weather conditions influences potential evapotranspiration through variables such as temperature, solar radiation (sun hours duration), wind speed and relative humidity. In addition to weather variables, actual ETa is also affected by land cover type, land cover condition and soil moisture. The seasonal (June- September) ETa or crop/vegetation water use were shown as below table 4.1 and its spatial distribution were indicated in (fig.4.1), (fig. 4.2) and (fig.4.3).

According to the result, the area in the rift floor experienced higher crop/vegetation/ water use than both sides of the highlands. This was happened because of the land surface ETa is governed largely by Land Surface Phenolgy based derived coefficient (Kcp). Kcp parameter value was higher in the rift floor than in the highlands during the wet season; hence this resulted in higher ETa rate in the rift floor than in the highlands. This finding may contradict the perviously done research by Tenalem Ayenew (2003) which came up with higher ETa rate in the highlands than in the rift floor. Tenalem Ayenew (2003) carried out the daily ETa estimation using SEBAL model on Landsat TM image of 21 November 1989. However, during dry season (October, November and December) the Kcp coefficient is lower in the rift floor than in in highlands, especially during November month (dekad: 31, 32, and 33) it showed clear distinction between the rift floor and highlands. Hence, it resulted in lower ETa rate in the rift floor than the highlands. The mean, minimum and maximum crop water uses in study area were estimated as below table (table 4.1) for the year 2001 up to 2010. The minimum and maximum crop water uses were found in 2002 and 2006 years respectively.

Table 4.1 Seasonal (June – September) vegetation water use

Seasonal ETa	Min	Max	Range	Mean
ETa2001	101	360	258	231.2
ETa2002	84	378	294	191.7
ETa2003	77	343	266	204.9
ETa2004	126	415	288	260.1
ETa2005	96	393	298	236.8
ETa2006	141	427	285	286.2
ETa2007	148	429	280	297.4
ETa2008	117	418	301	269.7
ETa2009	80	403	323	229.6
ETa2010	142	410	268	283.6

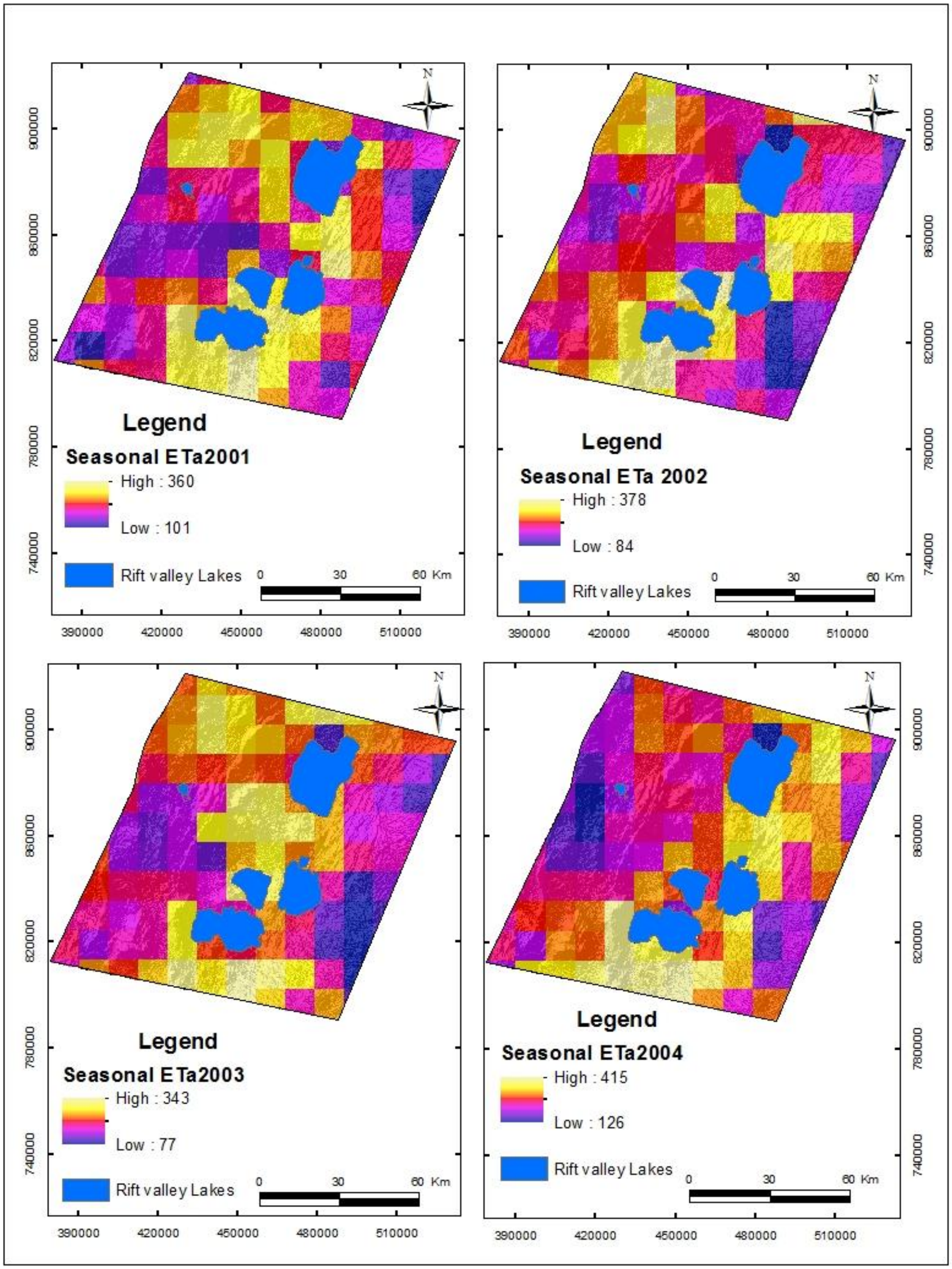


Fig.4.1 Spatial pattern of ETa (mm) for cropping seasons of years 2001 to 2004

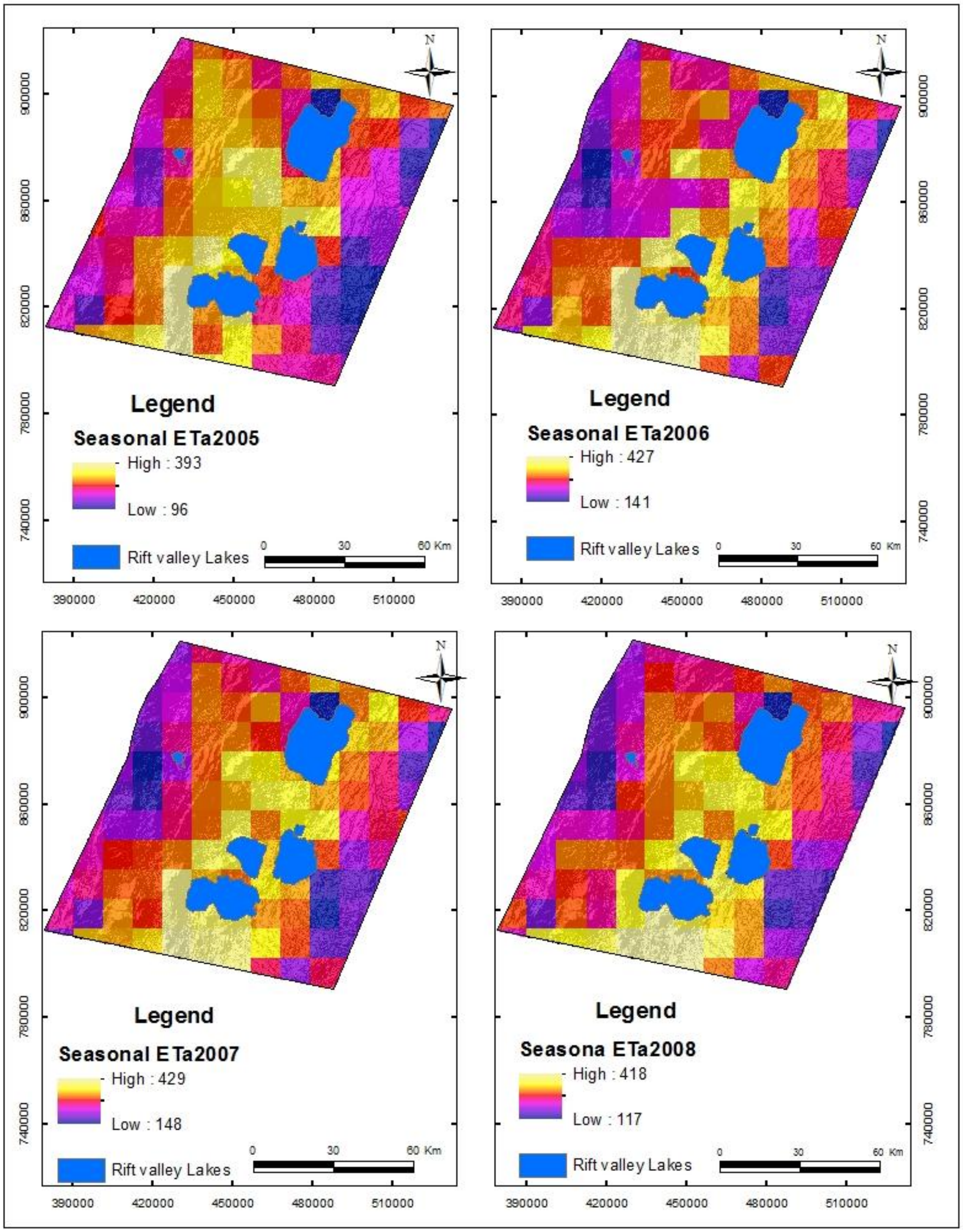


Fig.4.2.Spatial pattern of ETa (mm) for cropping seasons of years 2005 to 2008

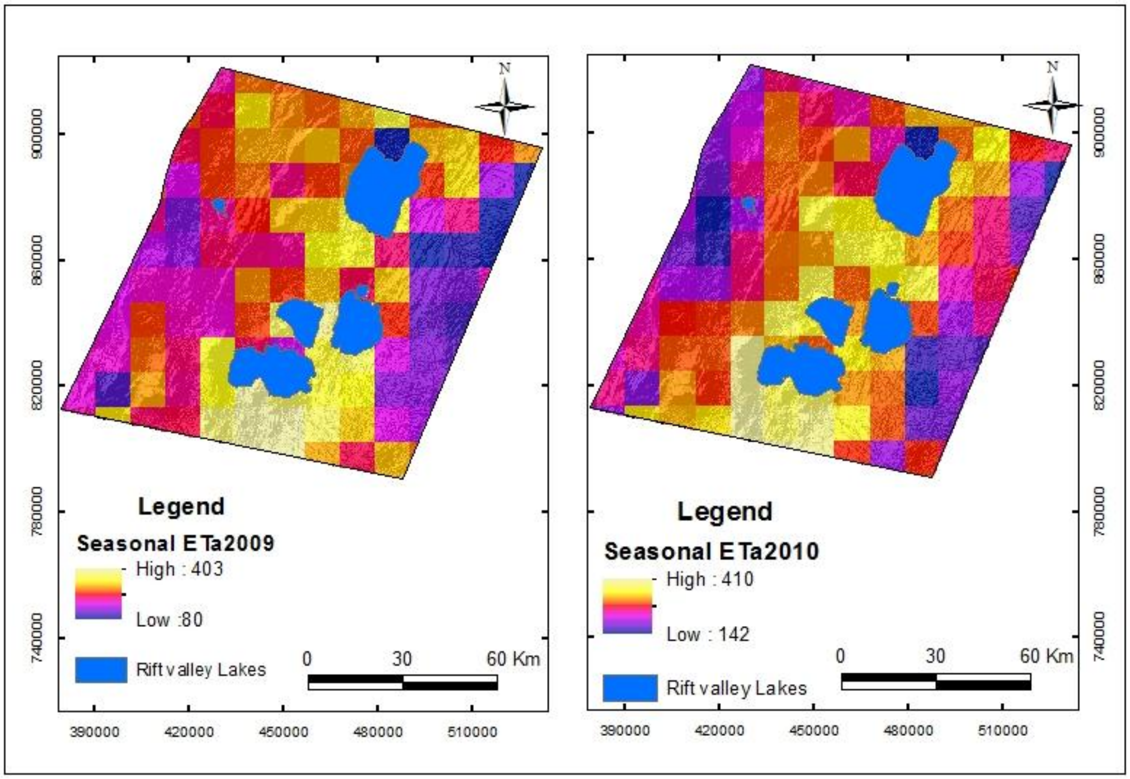


Fig.4.3.Spatial pattern of ETa (mm) for cropping seasons of years 2009 and 2010

4.2. Relationship between ETo, RFE and ETa

The dekadal Rainfall estimate (RFE), potential evapotranspiration (ETo) and Actual evapotranspiration (ETa) were summed to give of seasonal rainfall; Potential evapotranspiration and crop water use /ETa/ of the study area for the study period are shown in the fig 4.4. The seasonal Rainfall Estimate was plotted against seasonal actual evapotranspiration as shown in figure 4.5. The linear regression analysis showed that relationship between the amount of rainfall Estimate and crop water use of the region for a period of 2001-2010 have strong linear relationship with correlation coefficient (r =0.90) and this implies that 80% change in seasonal ETa can be described by the change in the amount of seasonal rainfall. On the contrary, the relationship between seasonal ETo and ETa had correlation coefficients (r≅ 0). It implies that seasonal ETa and ETo donot have significant positve or negative relationship. The percent of rainfalls that went to evapotranspiration ranges from 58% in 2007 to 99% in 2005 years respectively. Relatively high seasonal rainfall in 2006, 2007, 2008 and 2010 years in area resulted in high seasonal ETa values: 286.2mm, 297 mm, 269.7mm and 283.6 mm respectively.

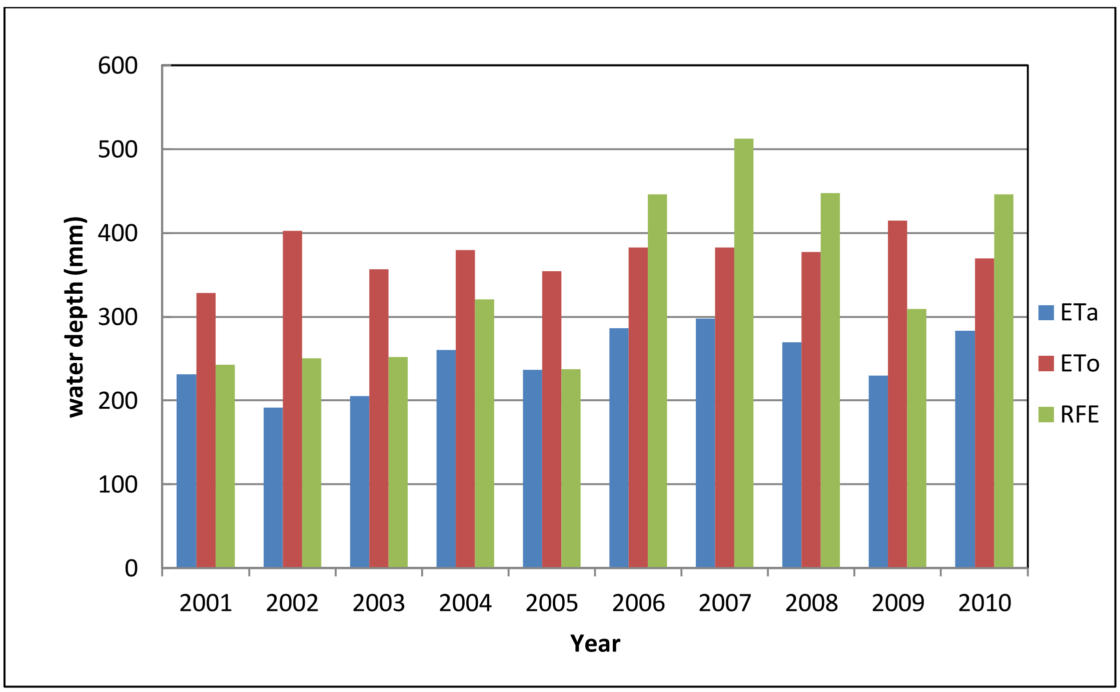


Fig.4.4 seasonal (June – September) RFE, ETo and ETa

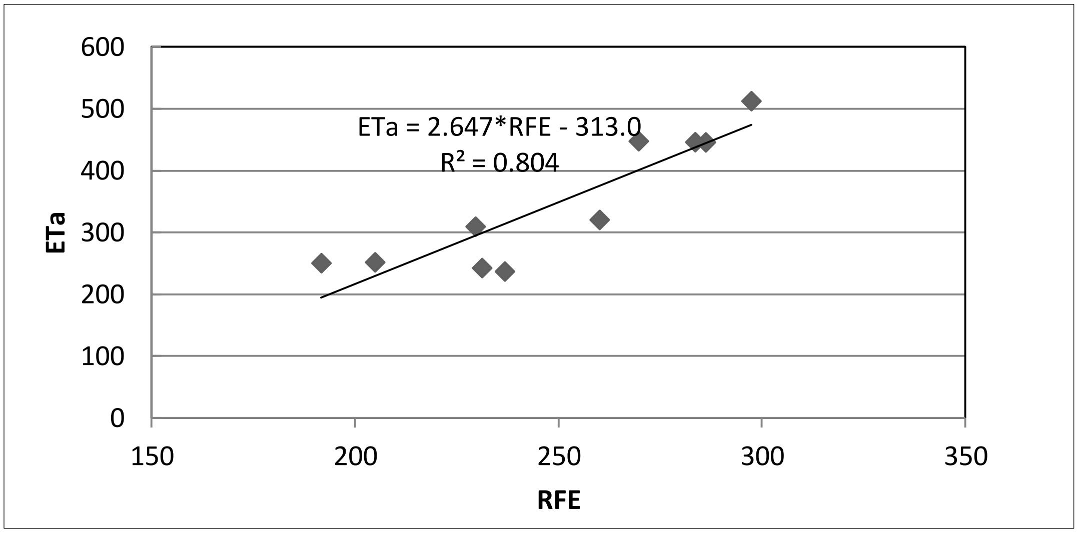


Fig .4.5 Relationship between seasonal (June to September) ETa and Seasonal RFE

4.3. Temporal and spatial seasonal Crop/Vegetation/ water requirement

The amount of water potentially required to meet the evapo-transpiration needs of the plant so that the plant does not suffer in its growth through short supply of water to produce the desired crop yield and quality and to maintain an acceptable salt balance in the root zone (Allen et al., 1998). Factors that influence vegetation water requirement are rainfall, temperature, stages of plant growth, growing season, humidity, wind speed and sunshine hours. For all years the rift floor experience high water requirement than edges of the escarpments and its surrounding highlands. The WR is the function of potential evapotranspiration and Land surface phenology and crop coefficient as indicated in eq.11.

As the fig.(4.6) depicts the extreme departure between temporal crop water use and crop water requirement occurred in 2002, 2003 and 2009 cropping seasons in turn these years were belongs to moisture deficit in the area. However, the temporal WR and ETa were in the same level in 2006, 2007, and 2010 cropping seasons and this implies that there was sufficient moisture in these years. The remaining years were found in between the moisture deficit and wet cropping seasons, which means slight to moderate moisture deficit in 2001, 2004, and 2005 cropping seasons.

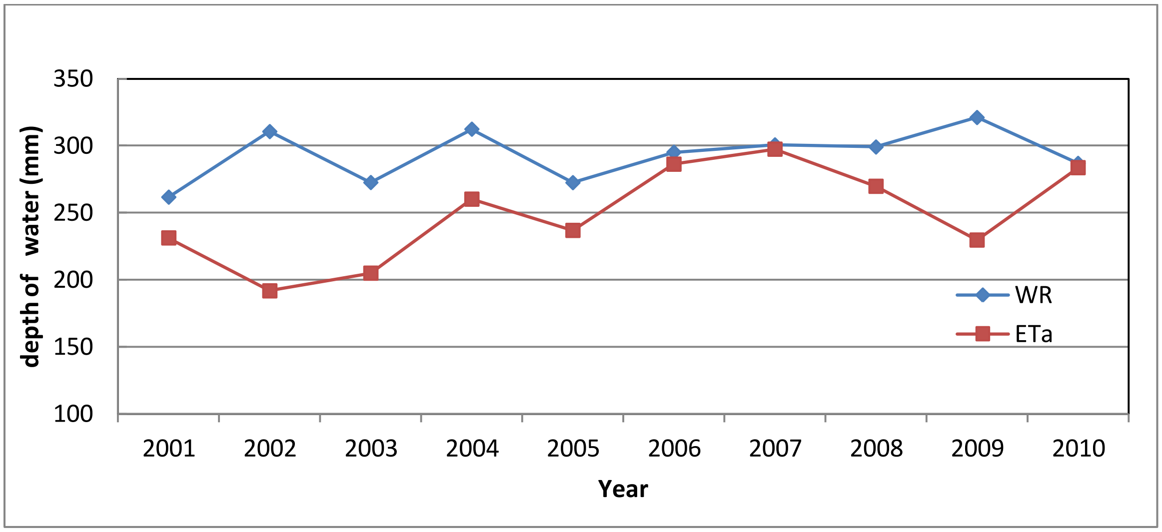


Fig.4.6 Temporal pattern of seasonal (June - September) WR and ETa

Whereas, the spatial distribution of WR and ETa revealed that higher WR and ETa in the ritf floor than the surrounding hightlands and this is presented in the ten years (2001-2010) mean seasonal water requirement (fig.4.7) and profile line drawn across the rift (fig 4.8) in order to have comparative visualization of rift floor and its surroundings WR. According to the result, higher WR was indicated in the rift floor than both edges of the escarpments.

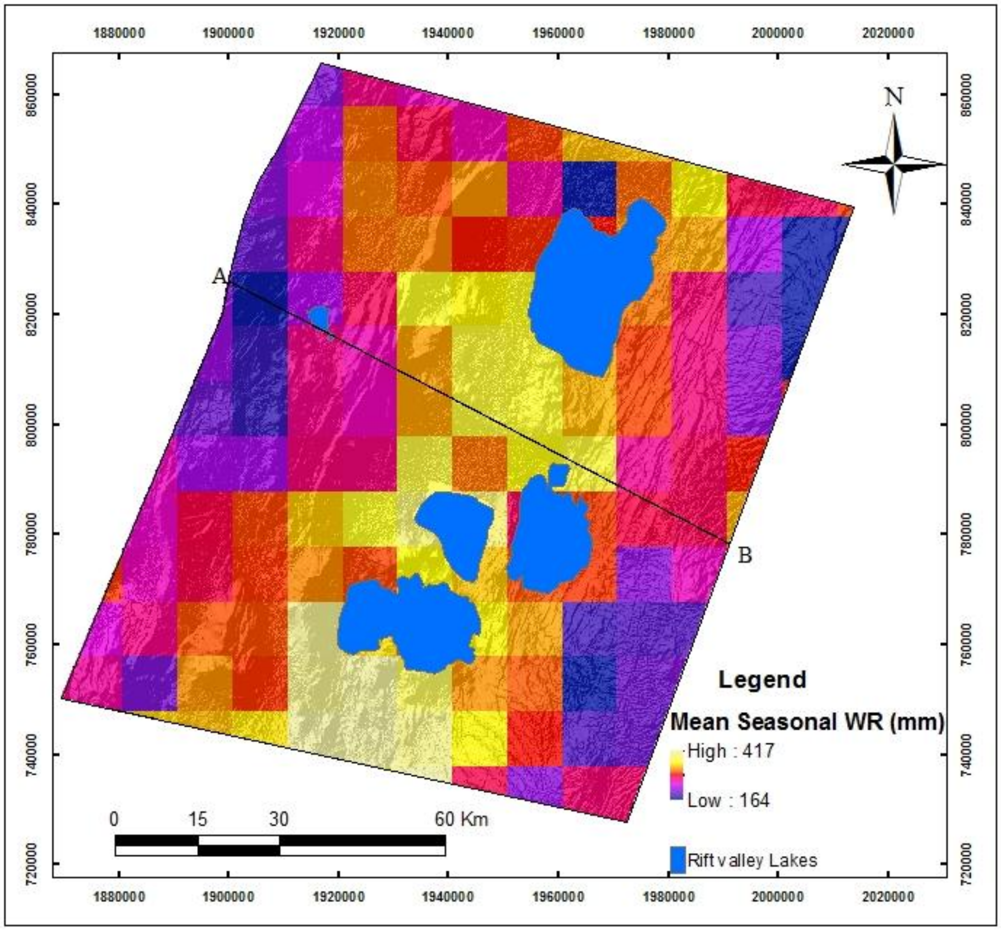


Fig 4.7 spatial pattern of mean seasonal water requirement map (2001-2010)

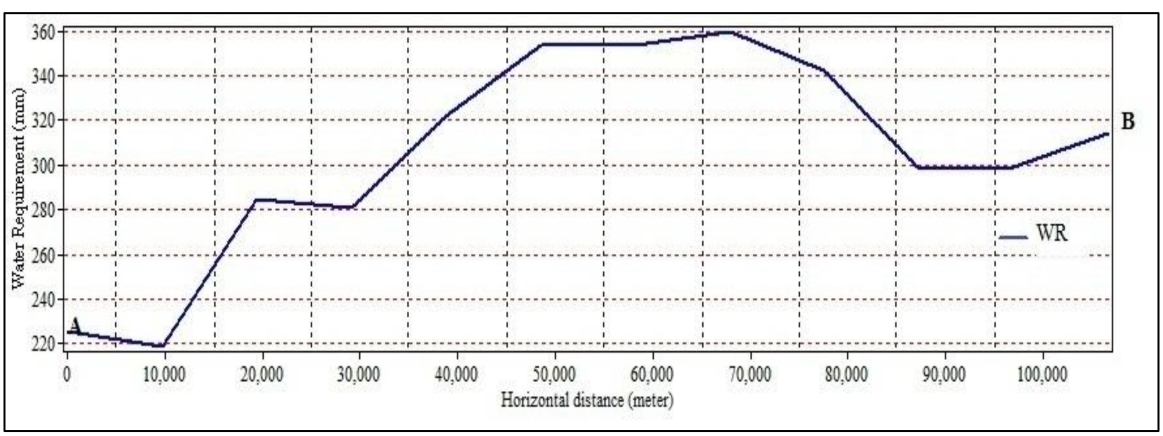


Fig 4.8 Water Requirement cross-section along line AB on fig 4.7

4.4. Crop performance evaluation

4.4.1. Characterization of yield reduction due to moisture deficit

From temporal crop WR and water use (fig.4.6), moisture deficit cropping seasons were identified as 2002, 2003, and 2009 and slight moisture deficit cropping seasons are 2001, 2004, and 2005. On the contrary, cropping seasons without water stress were 2006, 2007, 2008 and 2010. Rainfed agriculture always subjected to yield reduction due to moisture deficit and the result revealed that the highest yield reduction occurred during 2002 cropping season which is about 47% and then followed by 35%, 24%, 18%, and 18% in 2003, 2001, 2009 and 2005 cropping seasons respectively. However, the remaining years were subjected to 14% in 2004, and 5% to no yield reduction in the other years.

Regarding the spatial patterns of yield reduction are depicted in (fig 4.9) and (fig 4.10). During 2001 cropping season the area experienced moisture deficit that caused 0-20%, 20-40%, 40-60% yield reduction, having areal extent of 35%, 44%and 17% of total area respectively. The result of yield reduction during 2002 cropping season revealed that 0-20%, 20-40%, 40-60%, and 60-80% of yield reduction occupied an areal extent of 6%, 29%, 49%, and 16% of the total area respectively. Similarily, 0-20%, 20-40%, 40-60%, and 60-80% yield reduction occurred in 2003 cropping season covering 15%, 38%, 40%, and 6% of the total area respectively. In addition to these, during 2009 meher season the area was under moisture deficit, conseqeuntly, 0-20%, 20-40%, 40-60%, and 60-80% yield reduction occurred on an areal extent of 41%, 43%, 11%, and 5% of the total area respectively.The results revealed that there were significant yield reduction occurred during these seasons.

The results found in yield reduction estimation using water balance model are consistent with other reports. 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 the 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 resulted in substantial yield reduction (EWS, 2003).

However, for the purpose of comparison in 2008 cropping season, the large area about 96% was categorized in to 0 - 20% yield reduction and the remaining 4% area was belongs to 20-40% yield reduction. Besides this during cropping season of 2006, 2007 and 2010 the percent of yield reduction were estimated below 0 - 20%, 0 - 10% and 0 - 10% respectively. These imply that there were no significant yield reductions encountered due to moisture deficit during these seasons.

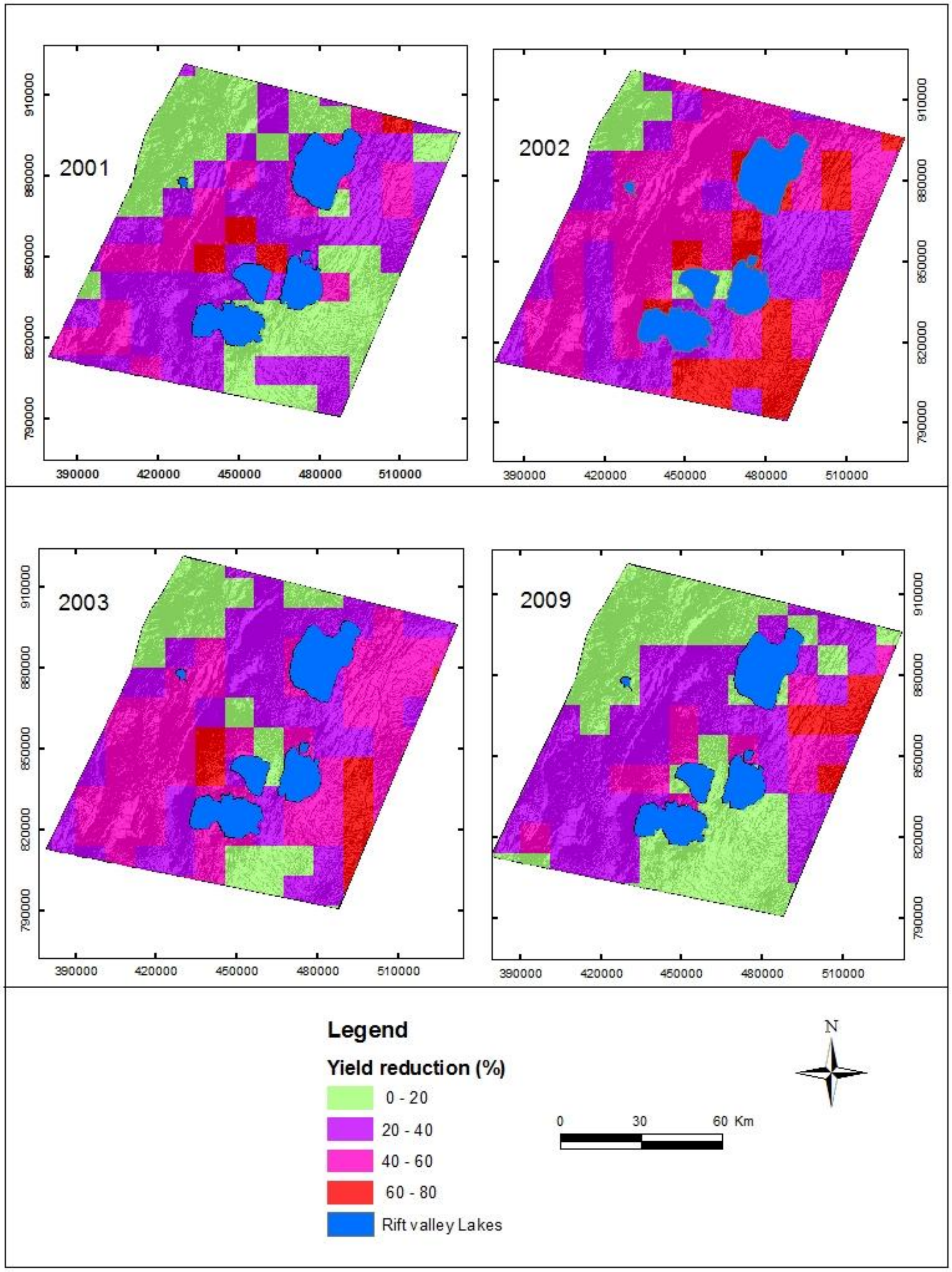


Fig.4.9 Spatial pattern of yield reduction during cropping seasons of years 2001, 2002, 2003, and 2009.

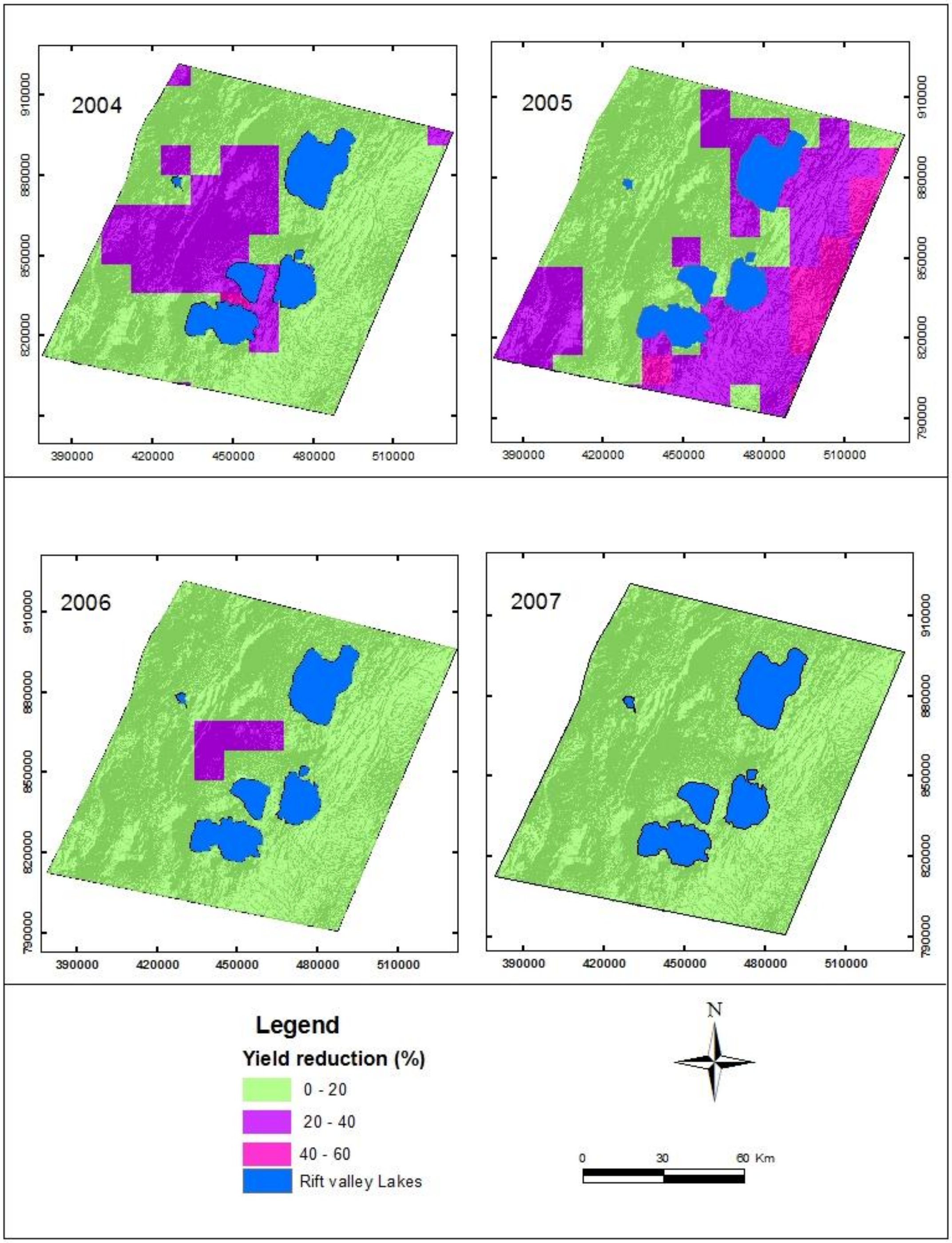


Fig.4.10 Spatial pattern of yield reduction during cropping seasons of years 2004, 2005, 2005, and 2007.

4.4.2. Determination of seasonal WRSI

The seasonal Water requirement satisfaction index (WRSI) of the area is estimated using eq.10. In order to perform a WRSI water balance model runs various input data including precipitation, evapotranspiration, Land surface Phenolgy, and crop coefficient data must be available. Technically, the Water Requirements Satisfaction Index (WRSI) is the ratio of seasonal actual crop evapotranspiration (ETa) to the seasonal crop water requirement, which is the same as the potential crop evapotranspiration (ETo). Originally developed by FAO, the WRSI has been adapted and extended by USGS in a geospatial application to support FEWS NET monitoring requirements (GEOWRSI, 2008).

Rainfall is one of the climatic variables that largely determine the occurrence of drought. The severity of drought is considered to be a function of rainfall. Areas under very severe agricultural drought class revealing that less than 50 percent of crop requirement was satisfied. According to smith (1992) cited in Gabriel Senay and Verdin (2002), seasonal WRSI value less than 50 is regarded as a complete crop failure condition due to moisture deficit. As a result, the index has revealed that high grain yield loss encountered in the area due to agricultural drought.

The results revealed that less WRSI values in large part of the study area were found during the cropping seasons of 2002, in which about 21% of the total area regarded as a complete crop failure and 32%, 32% of the area was prone to sever and moderate agricultural drought level respectively. Whereas, in 2003 and 2009 cropping seasons only about 4% and 6% of the total of the respective years were prone to complete crop failure. According to the result, spatially depicted in the (Figure 4.11, 4.12 and 4.13) in 2003 cropping season also 15% and 21% of the area was under sever and moderate agriculture drought levels respectively. However, the dominant percent 19% and 41% was under slight to no agricultural drought level respectively. Similarily, in 2009 cropping season sever and moderate agricultural drought levels covered 6%, 23% of areal extent respectively and the remaining, larger extents, 34% and 32% was categorized in slight to no agricultural drought level respectively.

Unlike the WRSI values during cropping seasons of 2002, 2003, and 2009, during 2006-2008 and 2010 cropping seasons the WRSI values in the area was nearly 100%. This finding implies that during 2002, 2003, and 2009 cropping seasons the area was under moisture deficit (drought seasons) and consequently crop yield reduction occurred in the area. On the contrary, 2006-2008, and 2010 cropping seasons were free of moisture deficit in general and no crop yield reported in the area. In addition to these, the drought severity of 2001, 2004, and 2005 cropping seasons were found in between moisture deficit and wet seasons. Their large areas are found in slight to no drought. Moreover, the percent and the agricultural drought levels are presented numerically in table 4.2.

Further more, Gizachew Legesse (2010) in his drought assessment in east Shewa zone, he identified 2000 and 2002 cropping seasons as drought-prone years. Large area coverage in north eastern, eastern and central part that accounts for 56 percent 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 percent of 18, 20 and 5, respectively. As crop growing on most of the area getting above 50 percent of their crop requirement, the level of agricultural drought was reduced during 2000 cropping season as compared to 2002 cropping season. The percentage of the area was 45, 30 and 25 for slight, moderate and severe agricultural drought severity level. WRSI is also successful in capturing the response of the crop during wet years. The result depicted that 2007 and 2008 cropping seasons were wet years and the dominant area was under slight to no drought level.

Table 4.2 Drought severity level percentage area coverage

Agricultural drought severity level	Area in (%)									
	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
Very sever drought	-	21	4	-	-	-	-	-	6	-
Sever drought	1	32	15	-	2	-	-	-	6	-
Moderate drought	7	32	21	5	2	-	-	-	23	-
Slight drought	20	9	19	27	17	2	-	1	34	-
No drought	72	6	41	68	78	98	100	99	32	100

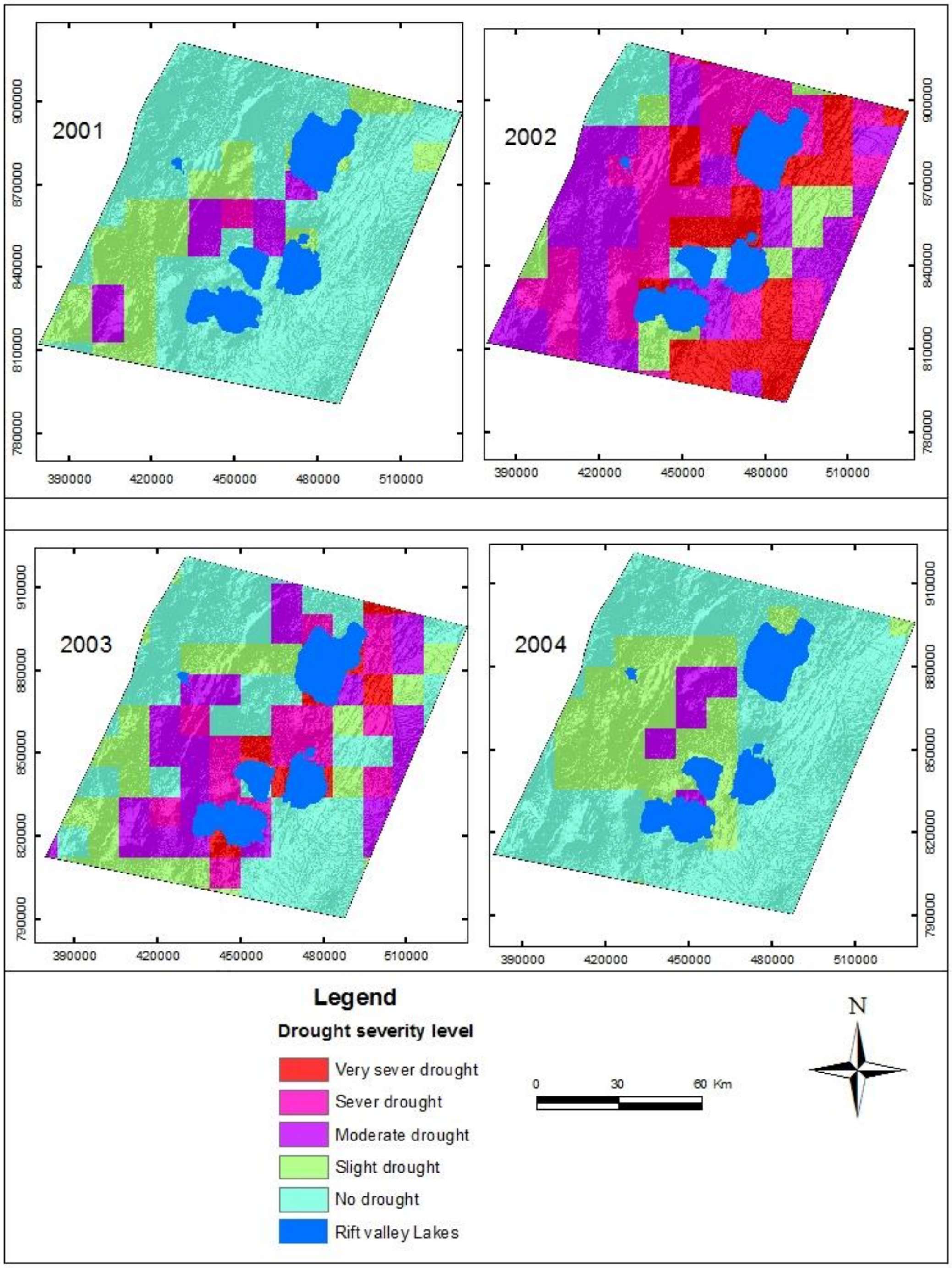


Fig.4.11 Spatial drought severity for cropping seasons of years 2001 to 2004 using WRSI

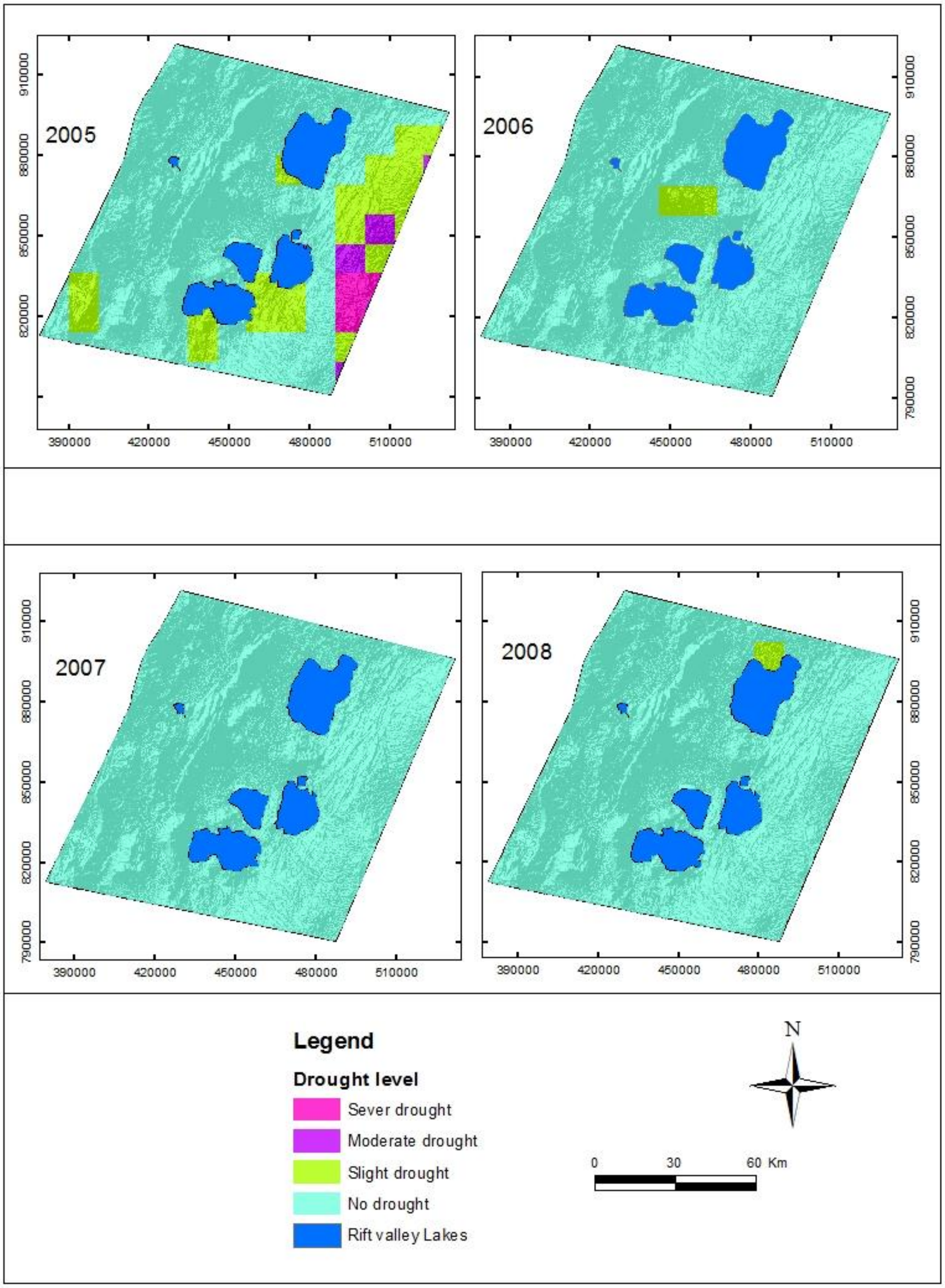


Fig. 4.12 Spatial drought severity for cropping seasons of years 2005 to 2008 using WRSI

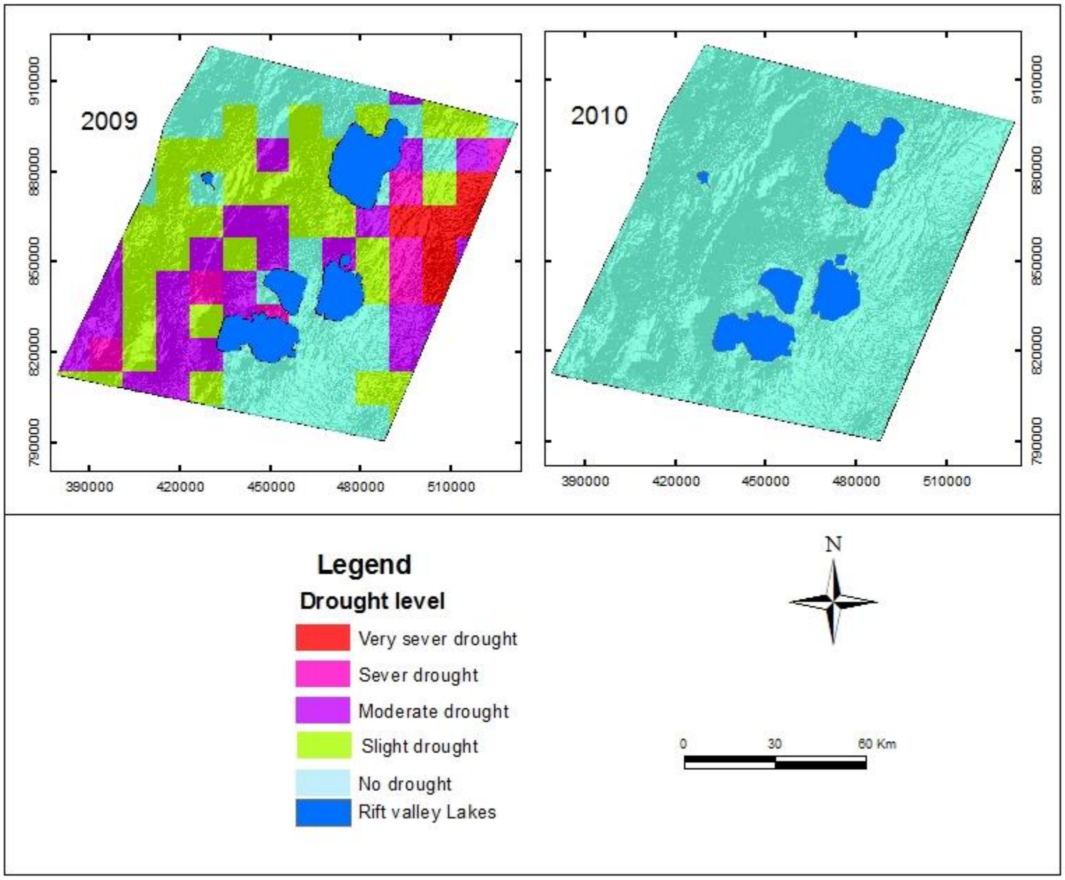


Fig.4.13 Spatial drought severity for cropping seasons of years 2009 and 2010 using WRSI

4.4.2.1. Water Requirement Satisfaction Index (WRSI) and grain yield

The relationship between satellite based WRSI and grain yield was analyzed using simple regression analysis for rift floor area. The grain yield data was collected from CSA on zonal level only except in case of special weredas. However, important grain yield data for 2002 and 2009 meher seasons are not available. The dominant crop types are teff, maize and wheat and the crop type specific correlation of WRSI is more siginificant in order to infer more drought resistant crop type. Hence, the correlation between WRSI values and teff, maize and wheat yield, as indicated in (fig.4.14, fig.4.15 and fig.4.16) have linear regression with coefficients of correlation (r =0.75, r =0.62 and r =0.38) respectively. Furthermore, the result indicates that Teff is the most sensitive crop to WRSI values and wheat is the least sensitive crop to WRSI values, in turn wheat is relatively more resistant to agricultural drought than Teff and maize crops.

Other researchers studied the correlation between WRSI and grain yield, among these (Gabriel Senay and Verdin, 2003) find the link between WRSI and crop yield in selected woredas in Ethiopia. As crop yield is affected by many factors besides availability of water, hence they identified water limited and water unlimited woredas. In water limited area, the correlation between WSRI and yield an encouraging (r=0.92) was obtained.

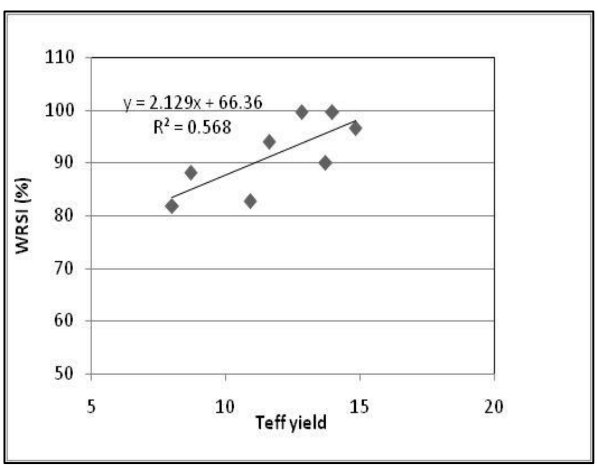


Fig 4.14 Relationship between WRSI and Teff yield

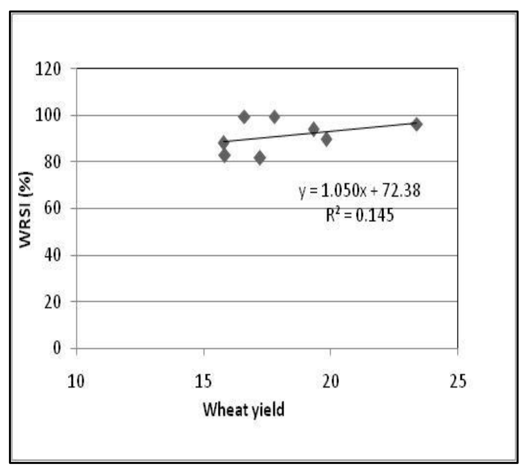


Fig 4.15 Relationship between WRSI and Wheat yield

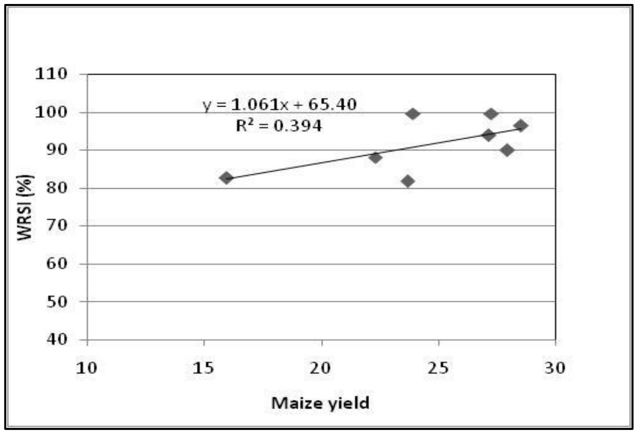


Fig 4.16 Relationship between WRSI and Maize yield

4.4.2.2. Relationship between yield reduction and WRSI

The relationship between WRSI and the corresponding crop yield reduction by water balance model mainly considering the rift floor is illustraeted in (fig.4.17). It indicated that they have strong negative linear regression with coefficient of correlation (r =0.92). It is found that lowest WRSI value (54%) corresponds to the highest yield reduction value (47%) encountered in 2002 cropping season. However, the highest WRSI values 100% corresponds to low crop yield reduction 0%, 3% in 2007 and 2010 respectively and this finding indicates that temporal variations of WRSI values and corresponding yield reduction values have good agreement.

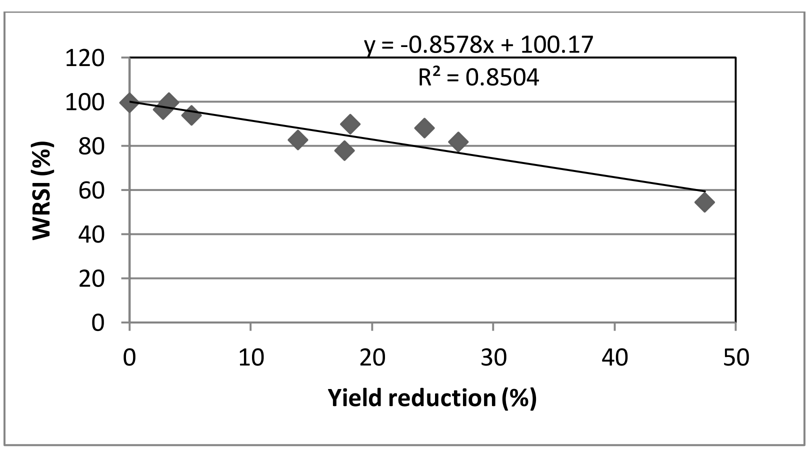


Fig.4.17 Relationship between WRSI and yield reduction

4.5. The Climate and its effects in the Main Ethiopian rift

Climate is one of among natural resources that the country depends on. Ethiopia has very variable climate classes, having 32 different agro-ecological zones (CAADP Ethiopia, 2009). In Main Ethiopian rift altitude or topographic setting controls climate variables like temperature, rainfall, potential evapotranspiration, and crop water use. In this study, the relationship between altitude and temperature established with randomly distributed 210 points and it is observed that they have negative linear correlation coefficient (r=0.88) with linear equation T = -0.004*A+26.47. Furthermore, according to (Tenalem Ayenew, 1998) meteorological records from 24 stations revealed that the temperature and altitude relation (correlation coeficient r =0.74) was given by:

$$T= -0.007*A+31.2$$

Where, T is ground temperature in ^{0}C, and A is altitude in meter.

4.5.1. The Effects of Temperature on potential evapotranspiration

The seasonal Potential Evapotranspiration (ETo) acquired from during 2001 to 2010 years calculated based on FAO Penman-Montheith Allen et al.,(1998) and plotted against the long term mean temperature as shown in Fig (4.18). The result of linear regression analysis from 210 randomly distributed sample points, showed that there is strong relationship between mean seasonal potential evapotranspiration and long term mean temperature (r = 0.93). This implies that 86% change in seasonal ETo can be described by the change in the amount of seasonal long term mean temperature. As temperature rises by 1^{o}C and the corresponding ETo will be increased by the amount 11 mm.

Jansen et al,. (2007) studied the effect of temperature on potential evapotraspiration in the Central Ethiopian rift. According to this research, over a period of 30 years the maximum daily temperature has increased with 1.5^{o}C. As a result the potential evapotranspiration will have increased in the order of 3-4%. This will have caused increased water stress to rainfed agriculture.

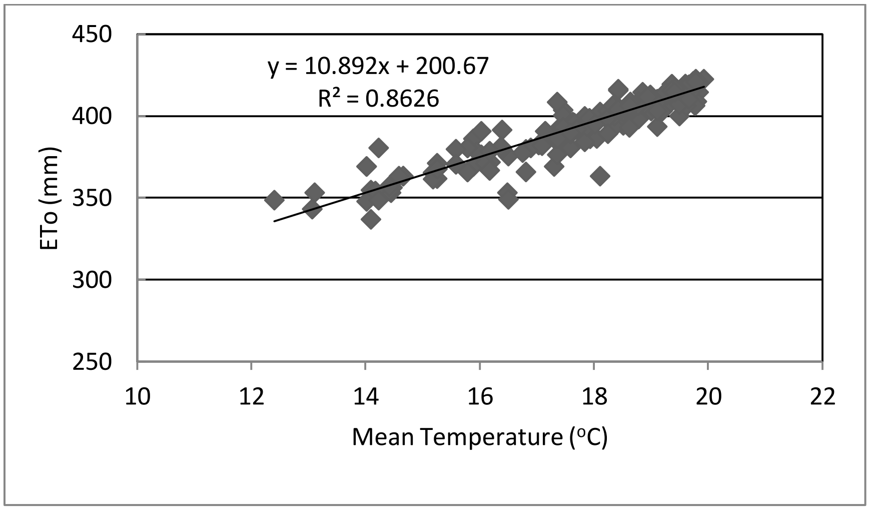


Fig. 4.18 Relationship between long-term mean temperature and ETo

4.5.2. Relationship between actual evapotranspiration and temperature

The plot of long-term seasonal mean temperature against actual seasonal evapotranspiration and the best-fit trend lines of linear models showed correlation coefficients (r) range from 0.3 to 0.60 for the study periods (2001 -2010). Unlike the relationship between potential evapotranspiration and temperature the result of regression analysis in these cases gave low coefficient of regression for the best-fit linear models. These imply that the relationship between long-term seasonal mean temperature and seasonal actual evapotranspiration is not straight forward and other factors such as the soil water stress coefficient and land surface phenology play a significant role

4.5.3. Aridity Index using ETo and rainfall

Based on the long term climate data (1950-2000) from IWMI, the study area is categorized under semi-arid, dry sub-humid and humid zones. As indicated in (fig.4.19) the larger part of rift floor is belongs to semi-arid region, having 3934 km^2 (32%) out of total area. Whereas, the dry sub-humid zone appeared in both sides of semi-arid zone and then followed by humid zone in eastern and western edges of the escarpments which occupy 5864km^2 (47%) and 2664km^2 (21%) of the total area respectively. The result revealed that high potential evapotranspiration in the rift floor than the both edges of the escarpments.Thus, higher ETo in the rift floor may be due to higher temperature in the ritf floor than edges of the escarpments.

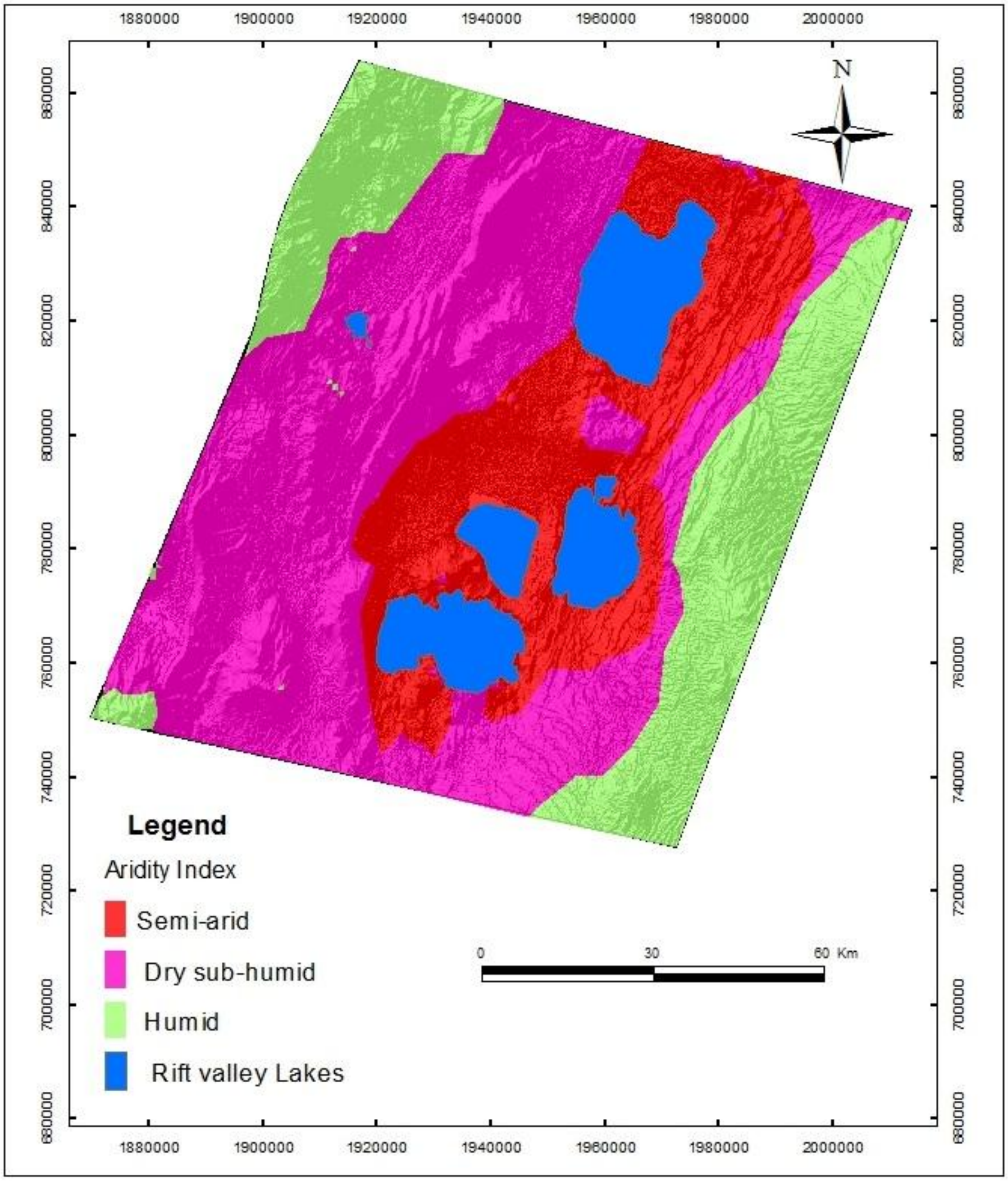


Fig. 4.19 Aridity Index Map

5. Conclusion and Recommendations

5.1. Conclusion

This study was conducted with the objectives of estimation of crop water use and its role in agriculture productivity using globally available data sets with the help of remote sensing and GIS techniques. In addition to assessing the technological capability of monitoring and evaluating crop performance per-harvest for policy makers, food security, and grain markets.

Agriculture remains by far the most vulnerable and sensitive sector that is seriously affected by the impacts of climate variability and climate change, which is usually manifested through rainfall variability and recurrent drought. The vulnerability agriculture sector in Main Ethiopian Rift, to climate variablity is because of its heavily relies on rainfall. Rainfall is one of the climatic variables that largely determine the crop yield and also influences the growth and development of crops which is directly reflected by crop water use. The Main Ethiopia Rift is experienced high climate sensitivity, which may be arised from its topographic setting, and it is inevitabily reflected on agriculture performance in the area.

The crop/vegetation water use/ was estimated by VegET model, which is principally based on water balance model using globally available dekadal RFE, ETo, and Land Surface Phenolgy (LSP) datasets since 2001 to 2010 years cropping seasons (June to September). The result confirmed the lowest seasonal /driest seasons/ water use estimated in 2002, which is 192mm and followed by 2003, 2009 and 2001cropping seasons with 205,230, and 231 mm respectively. On the contrary, moisture deficit free seasons' were found during 2006–2008 and 2010 years with water use values ranges from 270-297 mm in depth. As far as spatial patterns concerned, relatively higher crop water use is found in the rift floor than eastern and western edges of the escarpments. In the study area ETa and moisture availability (rainfall) have good positive linear relationship with coefficient of correlation (r=0.89).

Crop water requirement and use showed large devaition during 2002, 2003 and 2009 cropping seasons. This implies that these years were moisture deficit seasons in the area, while wet years were 2006-2008 and 2010 which is characterized by closer water use and water demand patterns. Similarly, as ETa did, the spatial patterns of the water requirement depicted that the higher water requirement in the rift floor than both egdes of the escarpments.This made the rift floor water deficit and more sensitive to climate variability area than both edges of the escarpments.

The Water balance yield reduction estimation model and Water Requirement Satisfaction Index (WRSI) are among the tools used for evaluation of crop performance in this study. The result revealed that the highest yield reduction occurred during 2002 cropping season which is about 47% and then followed by 35%, 24%, 18%, and 18% in 2003, 2001, 2009 and 2005 cropping seasons respectively. Similarly, the WRSI values indicated the drought severity level and the most droughttest was 2002 cropping season, and followed by 2003, 2009 and 2001 seasons in order of becoming less and less drought severity. This can be described by the amount of the rainfall and its variability. Hence, in 2002 the amount of seasonal rainfall was minimum, in turn resulted in a minimum ETa and the least water requirement was satisfied throughout study period. On the contrary, the remaining seasons were characterized by no to very low yield reduction and also no to slight drought severity level. The agreement between the two tools to evaluate crop performance, the water balance yield reduction estimation model and WRSI have good negative linear correlation determination coefficient (r=0.92).

Altitude or topographic settings controls many variables of climate of the area: temperature, rainfall, and potential evapotranspiration and vegetation water use. It is observed the linear regression analysis between long term mean temperature and potential evapotranspiration have positive correlation coefficient (r=0.93). Hence, from linear regression equation it is shown that 1^{0}C rises in temperature can cause 11mm rises in respective potential evapotranspiration.

Finally, the VegET modeling approach was demonstrated to have a promising application for drought monitoring/crop performance/ and early warning applications at various spatial and time scales for rainfed systems.

5.2. Recommendations

Based on the findings of the study, the following recommendations are suggested:

- ✓ Yield reduction estimates based on WRSI contribute to food security preparedness and planning. As a monitoring tool, the crop performance indicator can be assessed at the end of every 10-day period during the growing season. On the other hand, as forecasting (an early warning) tool, WRSI is projected to the end-of- season using using long-term average meteorological data.
- ✓ To achieve a more accurate estimation of actual evapotranspiration, field experiment or uses of directly measured methods are important for further use and the model calibration.
- ✓ The satellite rainfall estimate data, which is used to calculate soil water content, should be validated with ground based meteorological data.

5.3. Limitations of this research

- The satellite based rainfall estimate (RFE) under estimates the amount rainfall in the study area as compared to National Meteorological Agency (NMA) stations records. This may affect other important variables (soil moisture content, onset and offset time of rainfall).
- As globally available datasets are coarse in resolutions, hence site specific applications will have got problems.
- Absence of crop yield data in woreda level in order to validate the simulated results with observed data.

References

Allen, R.G., Periera, L.S., Raes, D., Smith, M.,(1998). Crop Evapotranspiration: Guidelines for Computing Crop Requirements, Irrigation and Drainage Paper No. 56. FAO, Rome, Italy, p. 300.

Allen, R.G., Tasumi, M., Trezza, R.(2007a).Satellite-Based Energy Balance for Mapping Evapotranspiration with Internalized Calibration (METRIC Model). Journal of Irrigation and Drainage Engineering, Vol. 133, No. 4, August 1, 2007

Aslam, M., Khan, I., M., Saleem, A. and Ali, Z. (2006). Assessment of water stress tolerance in different maize accessions at germination and early growth stage. Pakistan Journal of Botany, 38: 1571- 1579.

Bastiaanssen, W. G. M., Menenti, M., Feddes, R. A., and Holtslang, A. A.M. (1998a). A remote sensing surface energy balance algorithm for land (SEBAL) 1. Formulation, Journal of Hydrology 212(213), 198–212

Bastiaanssen, W. G. M., Pelgrum, H., Wang, J., Ma, Y., Moreno, J., Roerink, G. J., and van der Wal, T. (1998b). "The surface energy balance algorithm for land (SEBAL), Part 2: Validation." Journal of Hydrology 212(213), 213–229

CAADP(2009). Comprehensive African Agriculture Development Programme Ethiopia Study.

Ceccarelli, S. and Grando, S. (1996). Drought as a challenge for the plant breeder. Plant Growth Regulation, 20: 149-155.

CEEPA (2006).Climate Change and African Agriculture. Centre for Environmental Economics and Policy in Africa (CEEPA), University of Pretoria, discussion paper No.21

CSA (1997) Population Census, Addis Ababa.

CSA (2010) Population Census projection, Addis Ababa.

De Beurs, K.M. and Henebry, G.M. (2008). Northern Annular Mode Effects on the Land Surface Phenologies of Northern Eurasia American Meteorological Society, vol. 21, 4257-4279, DOI: 10.1175/2008JCLI2074.1

Doorenbos and Kassam, A.H. (1979). Yield Response to Water. Irrigation and Drainage Paper 33, FAO, Rome.

Doorenbos, J and Pruitt, W.O. (1975). Guidelines for Predicting Crop Water Requirements. FAO Irrigation and Drainage Paper 24, Rome.

Early Warning System. (2003).Food supply prospect. URL: www.dppc.gov.et.

FAO (2005).Special report on Crop and food supply assessment mission to Ethiopia. pp.44.

FAO (2006). Crop Evapotranspiration (guidelines for computing crop water requirements): Irrigation and Drainage Paper No. 56

FEWS NET, 2001 Ethiopia network on food security. Famine early warning system network (FEWS NET) monthly report 4/01. Available from: - http://fews.net Chemonics International, Washington, D.C.

Finance and Economic development Bureau of Oromia (2007). Socioeconomic profile of East Shewa zone. Addis Ababa.

Frere M, Popov G. 1986. Early agrometeorological crop yield assessment. FAO Plant Production and Protection Paper 73. Food and Agriculture Organization of the United Nations: Rome, Italy; 144 pp.

Gabriel Senay and Verdin, J. (2002). Evaluating the performance of a crop water balance model in estimating regional crop production. Retrived on Nov.20, 2011 from URL:http://earlywarning.usgs.gov/adds/pubs/Pecora15%20CropWaterBalance%20GSandJV.pdf

Gabriel Senay and Verdin, J., (2003) Characterization of yield reduction in Ethiopia using a GIS based crop water balance model.Canadian Journal of remote sensing, , vol. 29 No.6, pp 687-692,

Gabriel Senay.; Budde.M.E.;Verdin,J.P.,Melesse,A.M., (2007) A Coupled Remote Sensing and Simplified Surface Energy Balance Approach to Estimate Actual Evapotranspiration from Irrigated Fields: Sensors 2007, 7, 979-1000

Available on http://earlywarning.usgs.gov/fews/pubs/Sensors_7060979.pdf Accessed on Nov16, 2011

Gabriel Senay (2008). Modeling Landscape Evapotranspiration by Integrating Land Surface Phenology and a Water Balance Algorithm. Algorithms, 1, 52-68; DOI: 10.3390/a1020052. www.mdpi.com/journal/algorithms , accessed on Nov03, 2011

Gabriel Senay (2007). Landscape Evapotranspiration Estimation Using Remotely Sensed Data for Operational Applications in Agriculture and Hydrology. Presentation at the NIDIS Remote Sensing Workshop. February 6-7 2008, Boulder, Colorado.

Gao, Y.-C, Long, D., Li, Z.-L,.(2008) Estimation of daily actual evapotranspiration from remotely sensed data under complex terrain over the upper Chao river basin in North China. International Journal of Remote Sensing Vol. 29, No. 11, 3295–3315

Gert A.Schultz and Edwin T.Engman (2000), Remote Sensing in Hydrology and Water Management, NASA/Goddard Space Flight Center, Greenbelt, MD, USA

GEOWRSI, (2008) ftp://hollywood.geog.ucsb.edu/pub/geowrsi/GeoWRSI_v2Manual.pdf

Accessed on Nov.16, 2012.

Gieske, Ambro S.M. (2003). Operational Solutions of actual evapotranspiration. In: I.Simmers (Editor), Understanding water in a dry environment: hydrological processes in arid and semi arid zones, Rotterdam, pp.65-114.

Gizachew Legesse (2010). Agricutltural drought assessment using remote sensing and GIS techinques. Unpublished MSc thesis, Addis Ababa University, Ethiopa, 76p.

Hoefsloot, P. (2010). Livelihood early assessment (LEAP) version 2.4. For Ethiopia. Retrieved on Dec.20, 2011 from: http://www.hoefsloot.com/downloads/LEAP.pdf.

Jansen, H., Hengsdijk, H., Legesse, D., Ayenew, T., Hellegers, P., Spliethoff, P., 2007. Land and water resources assessment in the Ethiopian Central Rift Valley. Alterra report 1587

Liu Sanchao, Zhang Wanchang (2004), Distributed Hydrological Model and Integrated GIS and Remote Sensing Study, Advances In Marine Science, Vol.22 Sup.: 216-222.

Mecikalski, J. R., G. R. Diak, M. C. Anderson, and J. M. Norman, (1999). Estimating fluxes on continental scales using remotely-sensed data in an atmospheric-land exchange model. Journal of Applied Meteorology, 38, 1352-1369.

Menenti, M. and Choudhury, B.J., (1993). Parametrization of land surface evapotranspiration using a location-dependent potential evapotranspiration and surface temperature range. In: Exchange processes at the land surface for a range of space and time scales, Bolle, H.J. et al. (Eds.). IAHS Publ. no. 212: 561–568

National Meterological Service Agency (NMSA). (1996). Assessment of drought in Ethiopia. In: Meterological research report series No.2.Addis Ababa.

Neteler M., Grasso D. and Michelazz I. (2004). New image processing tools for GRASS. Proceedings of the FOSS/GRASS Users Conference 2004 - Bangkok, Thailand, 12-14 Sept. 2004.

Regional Land Management Unit (RELMA) (2005). Managing land a practical guidebook for development agents in Ethiopia, Technical handbook No.36. RELMA, Ministry of Agriculture and Rural Development, World Agroforestry Centre, Addia Ababa, Ethiopia. 282p. +xivp.

Rossi, G.:2000, Drought mitigation measures: a comprehensive framework.In Drought and Drought and Drought Mitigation in Europe. J. Voght and F.Somma (Eds), Kluwer Academic publishers, Dordrecht

Shaw E.M., (1988) Hydrology in practice. Second edition, Chapman and Hall, Newyork.

Smith, M. (1992) Expert consultation on revision of FAO methodologies for crop water requirements. Rome, Italy. FAO publication 73

Su, Z., 2002. The Surface Energy Balance System (SEBS) for estimation of turbulent heat fluxes. Hydrology and Earth System Sciences, 6(1), 85–99

Tasumi ,M., Allen,R.G., Kramber,W.J. (2000) Final Report Application of the SEBAL Methodology for Estimating Consumptive Use of Water and Stream flow Depletion in the Bear River Basin of Idaho through Remote Sensing**.** Idaho Department of Water Resources, December 15, 2000,

Tenalem Ayenew (2002a). Recent changes in the level of Lake Abiyata, central main Ethiopian Rift. Hydrological Sciences-Journal'des, 47(3) 493.

Tenalem Ayenew (2003) Evapotranspiration estimation using thematic mapper spectral satellite data in the Ethiopian rift and adjacent highlands, Journal of Hydrology 279 (2003) 83–93

Tesfaye Chernet (1982). Hydrogeology of the lakes region, Ethiopia (Lakes Ziway, Langano, Abiyata, Shalla and Awassa). Ministry of Mines and Energy, Ethiopian Institute of Geological Surverys. Addis Ababa, Ethiopia

UNEP (1993).World atlas of desertification: Edward Arnold, London

UNESCO (1997) Map of the world distribution of arid regions. Explanatory note. Man and Biosphere (MAB)

Verdin, J., and Klaver, R., (2002) Grid cell based crop water accounting for the famine early warning system. Hydrological processes, vol. 16, pp1617-1630

Victor, U. S., Srivatsava, N. N. and Ramana Rao, B.V. (1988). Quantification of crop yields under rainfed conditions using a simple soil water balance model. Theoretical and Applied Climatology, 39: 73-80.

Xie P, Arkin PA., (1997). A 17-year monthly analysis based on gauge observations, satellite estimates, and numerical model outputs. Bulletin of the American Meteorological Society 78(11): 2539–2558

Appendices

Appendix -1 Land uses land covers data

Coordinates		Land use/land cover types
X	Y	
514484	886544	Irrigated Farm
517400	888550	Intensively cultivated
516450	889700	Intensively cultivated
515640	890815	Intensively cultivated
515496	892279	Intensively cultivated
514122	891181	Intensively cultivated
512861	889800	Intensively cultivated
510900	887600	Intensively cultivated
508500	884600	Intensively cultivated
506400	881800	Mixed cultivated /with woods
505332	882003	Mixed cultivated /with woods
505268	885710	bush land
504309	887559	bush land
503807	888748	Mixed cultivated /with woods
503494	888537	bush land
502021	887772	river Keter Abura gaging station)
499300	890501	Intensively cultivated
498571	890796	dried lake (marsh land)
497177	893614	Mixed cultivated /with woods
496414	896768	Mixed cultivated /with woods
505557	884333	Mixed cultivated /with woods
467560	868476	Adami tulu town
466563	867045	Intensively cultivated
464503	863636	Intensively cultivated
462917	861128	Mixed cultivated /with woods
461184	858384	Intensively cultivated
461000	853329	Bulbula town
462834	848804	Intensively cultivated
464162	846389	Intensively cultivated
463934	846389	Intensively cultivated
463682	838944	Intensively cultivated
463373	834136	Intensively cultivated
464014	830401	Intensively cultivated
463952	819877	Mixed cultivated /with woods
462951	832003	Shalla -abijata Park

462228	831789	Mixed cultivated /with woods
461298	830775	Mixed cultivated /with woods
460030	828685	Bush land
467358	845351	Langao lounge
461271	858534	Mixed cultivated /with woods
468450	869142	Mixed cultivated /with woods
470195	868839	irrigated farm
468438	875015	irrigated farm
470523	874358	Riparian vegetation
470434	872178	irrigated farm
469010	880110	irrigated farm
469342	882931	Intensively cultivated
468653	877064	Zeway Town
462971	877252	bush land
461662	878140	bush land
459613	881091	bush land
459618	882075	bush land
458326	884045	Mixed cultivated /with woods
456563	884386	Intensively cultivated
448237	885784	Intensively cultivated
446867	886402	Mixed cultivated /with woods
442385	890754	Intensively cultivated
439565	892106	Mixed cultivated /with woods
432170	898684	Mixed cultivated /with woods
438762	903956	Mixed cultivated /with woods
444150	912237	Mixed cultivated /with woods
448834	917061	Mixed cultivated /with woods
458897	930284	Mixed cultivated /with woods
458550	936562	Mixed cultivated /with woods
524263	893007	Mixed cultivated /with woods
523895	891446	Intensively cultivated
517575	885965	large scale farm
544591	880249	Asela Town
518028	850250	Mixed cultivated /with woods
513280	872068	Mixed cultivated /with woods
513263	871880	Mixed cultivated /with woods
515633	865502	Mixed cultivated /with woods
515767	865288	Mixed cultivated /with woods
516884	859166	Mixed cultivated /with woods
516912	858907	Mixed cultivated /with woods
517322	855243	Intensively cultivated
516961	852244	Mixed cultivated /with woods

516967	852233	Intensively cultivated
518028	850250	Intensively cultivated
518453	849408	Intensively cultivated
519220	849422	Intensively cultivated
519436	846966	Intensively cultivated
520229	846461	Intensively cultivated
524972	840494	Intensively cultivated
526265	838126	Intensively cultivated
528046	833533	Intensively cultivated
514876	867175	Mixed cultivated /with woods
512189	865172	Intensively cultivated
507389	863314	Intensively cultivated
507393	863307	Intensively cultivated
505877	862585	Intensively cultivated
505869	862365	Intensively cultivated
504708	860659	Intensively cultivated
504991	859303	Intensively cultivated
504007	856387	Intensively cultivated
504003	856376	Intensively cultivated
503445	854538	Lole town, mixed cultivated
502221	851380	Intensively cultivated
502214	851360	Intensively cultivated
501296	848949	Intensively cultivated
498600	842071	Mixed cultivated/with woods ,Igo Town
497974	834166	Mixed cultivated /with woods
498062	833331	Mixed cultivated/woods, Kersa Town
495203	832434	Mixed cultivated /with woods
492572	832123	Mixed cultivated /with woods
491223	832697	Forest
490268	833107	Forest
489641	833893	Forest
489395	833609	Forest
488161	832076	Mixed cultivated /with woods
488140	830265	Forest
486834	829016	Forest
485160	825496	Forest
483972	823551	Mixed cultivated /with woods
482796	821215	Mixed cultivated /with woods
482796	820725	Mixed cultivated /with woods
476561	821235	Mixed cultivated /with woods
476550	821243	Mixed cultivated /with woods
474914	822258	Mixed cultivated /with woods

73758	823250	Mixed cultivated /with woods
473184	824930	Mixed cultivated /with woods
472411	826282	Mixed cultivated /with woods
471645	827648	Mixed cultivated /with woods
470992	827697	Mixed cultivated /with woods
470327	827663	Intensively cultivated , river
502019	887720	Keter river, Abura gaging station
488210	900704	Meki river , gaging station
502007	887731	Keter river
480339	900774	Meki river

Appendix-2 land uses / land cover types' pictures

D E C L A R A T I O N

I hereby declare that the thesis entitled “ESTIMATION OF ACTUAL EVAPOTRANSPIRATION AND ITS IMPACTS IN RAINFED AGRICULTURAL PRODUCTIVITY USING GEOSPATIAL TOOLS IN THE MAIN ETHIOPIAN RIFT” has been carried out by me under the supervision of Professor Tenalem Ayenew and Dr. Dagnachew Legesse, Department of Earth Sciences, Addis Ababa University, Addis Ababa during the year 2012 as a part of Master of Science program in Geoinformation science. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

Debele Aberra

Signature: ________________________________

Addis Ababa University

Addis Ababa

Date: June2012

C E R T I F I C A T E

This is certified that the thesis entitled “ESTIMATION OF ACTUAL EVAPOTRANSPIRATION AND ITS IMPACT IN RAINFED AGRICULTURAL PRODUCTIVITY USING GEOSPATIAL TOOLS IN THE MAIN ETHIOPIAN RIFT” is a bonafied work carried out by Debele Aberra under our guidance and supervision. This is the actual work done by Debele Abera for the partial fulfillment of the award of the Degree of Master of Science in Geoinformation Science from Addis Ababa University, Addis Ababa, Ethiopia.

Prof. Tenalem Ayenew
Signature: ________________________
Department of Earth Science
Addis Ababa University
Addis Ababa
Date: June, 2012

Dr. Dagnachew Legesse
Signature: ________________________
Department of Earth Science
Addis Ababa University
Addis Ababa
Date: June, 2012