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**Addis Ababa University**  
**School of Graduate Studies**  
**Department of Earth Sciences**

**Estimation of Actual Evapotranspiration for Rain-fed Agriculture Using  
VegET Model in the Meki – Wabe Catchment, Central - Ethiopia**

**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 Remote Sensing and Geographic Information System (GIS)**

**By: TESHOME LETA**

**June, 2013**

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## **List of Abbreviations**

AVHRR	Advanced Very High Resolution Radiometer
CSA	Central Statistics Agency
EROS	Center for Earth Resources Observation & Science
ET <sub>a</sub>	Actual Evapotranspiration
ET <sub>o</sub>	Potential evapotranspiration
FAO	Food and Agricultural Organization
FEWS-NET	Famine Early Warning System
GIS	Geographic Information System
K <sub>c</sub>	Crop coefficient
K <sub>cp</sub>	Phenology based Crop coefficient
LULC	Land use land cover
LSP	Land Surface Phenology
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
WHC	Water Holding Capacity
WR	Water Requirement
WRSI	Water Requirement Satisfaction Index
VegET	Vegetation Evapotranspiration

## Abstract

The major impact of climate change is manifested through increased temperature that results in increased evapotranspiration and therefore enhanced soil water deficits. Thus, the study was conducted with the aim of estimation of actual evapotranspiration for Rain fed Agriculture specifically to determine the effect of moisture deficit on crop production in Meki – Wabe Catchment, Central – Ethiopia. It was addressed by using VegET model that integrates commonly used water balance algorithms with remotely sensed Land Surface Phenology (LSP). A time series advanced very high resolution radiometer (AVHRR) NDVI, rainfall estimate (REF) satellite and potential evapotranspiration data for the years 2001-2010 were utilized as input data for the model while grain yield data was used in explaining the impact of moisture deficit on agricultural yield. The result conformed that the average seasonal water requirement of the area varies from 341 mm - 412mm whereas water use varies from 322mm-372mm. The correlation result of WRSI and major agricultural crops of the area indicated with the linear regression correlation coefficients of 0.82, 0.77 and 0.48 for Teff, Maize and Wheat respectively. The impact of moisture deficit on crop production was measured through estimation of yield reduction. Compared to other cropping seasons of the analysis period, 60% yield reduction occurred in 2002 has an area coverage 11.25 percent and 40% percent yield reduction occurred in 2002, 2004, 2008 and 2009 having area coverage of 15%, 26.25%, 16.25% and 13.75 of total area respectively. The relationship between the water balance model WRSI and yield reduction estimation have good negative linear correlation determination coefficient ( $r=0.74$ ). In the study area, seasonal water requirement vary spatially in the entire catchment. Therefore, the supply of agricultural technologies and type should be made to fit in to the seasonal water requirement of the area.

**Key words:** Meki-Wabe catchment, Moisture deficit, Remote Sensing, VegET Model, WRSI, WR, yield reduction estimation

# 1. INTRODUCTION

## 1.1. Background

Access to natural resources is essential for sustainable poverty reduction and especially access to water is important for poor people living in rural areas. The role of water in food and livelihood security is a major issue of concern in the situation of persistent poverty and spiral of environmental degradation (CAB, 2009). Therefore, access to water for crop production in general is important factors in striving towards poverty reduction, and it is therefore vital that this service is accessible to the rural poor. Thus, increasingly high demands are being located on water resources each year. With the increasing stress, water resource managers and users must continually expand methods to assist them in the quantification and allocation of water consumptive use.

The quantification of crop/vegetation water consumption needs knowledge of the evaporation of water from the surrounding soil and plant surfaces as well as how water is consumed by plants by way of transpiration. The combination of these two phenomena is known as evapotranspiration. Evapotranspiration (ET) is the amount of water that plants use in transpiration and building cell tissue plus water evaporated from an adjacent soil surface (Allen et al., 1998). It is an important component of the water and energy balance (Yan et al., 2012). Global ET consumes more than 50% of absorbed solar energy (Trenberth et al., 2009), and returns about 60% of annual land precipitation to the atmosphere (Oki and Kanae, 2006). The available estimated global evapotranspiration greatly facilitates studies of hydrologic cycles, carbon cycles, and climate change. In addition, quantifying the amount of ET occurring in an area provides water managers a valuable tool for quantifying crop/vegetation water consumption.

ET is difficult and expensive to measure on an operational basis. This is because ET influenced by dominant weather conditions through variables such as radiation, temperature, wind, and relative humidity. In addition to these weather variables, actual ET (ET<sub>a</sub>) is also affected by land cover type and condition and soil moisture. The reliance of ET<sub>a</sub> on these factors and 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, 2007). Traditionally water managers have used reference crop ET ( $E_{To}$ ) and reference crop ET based crop coefficients ( $K_c$ ) to assess how much of the available energy is utilized in ET.

To enhance the utility of  $E_{Ta}$  estimates, water planners must acquire data over large areas and over long periods. In addition, it is vital to have capability to estimate  $E_{Ta}$  from individual fields using tools like lysimeter experiments. On the other hand  $E_{Ta}$  can be estimated in various ways and at varying spatial and temporal time scales. Among the  $E_{Ta}$  estimation model, the hydrological modeling techniques used to estimate  $E_{Ta}$  is based on water balance approach (Allen et al., 1998; Verdin and Klaver 2002; Senay and Verdin 2003). The water balance model focuses on tracking the pathways and magnitude of rainfall in the soil-vegetation system, and use the concept of a reference crop ET to estimate the evaporative demand of the atmosphere under unlimited water conditions using an idealized reference crop with a standardized bulk and aerodynamic resistance factors for vapor transport. Considering the large spatial and temporal variation in the parameters controlling ET processes, it is not surprising that Remote Sensing (satellite) and GIS-based applications have become powerful tools in estimation of  $E_{Ta}$  in the study areas.

## **1.2. Problem Statement**

Although the estimation of  $E_{Ta}$  is the ultimate goal of many researchers for hydrological and agronomical applications, it is often difficult to quantify and most require extensive input data such as local meteorological parameters, hydrological parameters, surface properties and soil moisture availability (Gabriel Senay, 2007). 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. In addition, the methods are often expensive, demanding in terms of accuracy of measurement and can only be fully exploited by well-trained research personnel.

In many developing countries, the major impact of climate change is manifested through increased temperature that results in increased evapotranspiration and therefore enhanced soil

water deficits. The hazards associated with them are generally change in rain bearing weather systems that result into late onset and early cessations of rainy season, which cause a contraction in the growing season. The amount and distribution of rainfall in the growing season is also very erratic, indeed making crops vulnerable to moisture deficit.

Land degradation and erosion, landslides, siltation and sedimentation, changes of hydrological features, deterioration, and destruction of vegetation covers and deforestation are most of environmental factors, which contribute to reduction in agricultural productivity in the study area (PHE Ethiopia Consortium 2011; Meeraph Habtewold, 2006)

In addition of these problems in the study area, crop production is affected due to soil water deficit, erratic rainfall characteristics and variability in seasonal cropping calendar. In order to adjust the variability in cropping calendar and moisture deficit, knowing or estimation ETa is crucial. Spectral combinations of the visible and near infrared bands can be used to calculate vegetation indices that in turn can be coupled with methods for determining actual evapotranspiration from the study area using soil water balance to estimates of Seasonal ETa. This combination could provide a useful remote sensing based tool namely; VegET model is capable of estimating actual evapotranspiration (ETa) of rainfed crops and other vegetation types at the spatial resolution of the LSP between image dates and for entire growing seasons. Therefore, this study was addressed these important issues by driving the following objectives.

### **1.3. Objective of the Study**

#### General Objectives

- ✓ To estimate seasonal actual evapotranspiration in the main cropping season using VegET Model in the meki-wabe catchment

#### Specific objectives

- ✓ Estimating Spatial and Temporal water requirement of the area
- ✓ To evaluate the relation between water use and rainfed agricultural yield
- ✓ To estimate rainfed agricultural yield reduction due to moisture deficit

### **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 estimation of actual Evapotranspiration for rain-fed agriculture in the absences of observed ground climate data and Mapping seasonal water requirement. Moreover identifying moisture deficit of the area from this study useful for policy makers to prioritize their actions based on the risk level, in the same manner it is useful for researchers to generate agricultural technologies to enhance moisture deficit and boost production of smallholder farmers.

### **1.5. Limitation of the Study**

Lack of data on crop yield at Woreda level that helps to see inter-woreda water use and yield variability and using global available data sets for estimation good for regional level/large area but estimation for small area will get a problem.

## **2. LITERATURE REVIEW**

### **2.1. Importance of Rain-fed Agriculture**

The importance of rainfed agriculture varies regionally but produces most food for poor communities in developing countries (Wani, 2009). In sub-Saharan Africa, more than 95% of the farmed land is rainfed (FAOstat, 2005). Most countries in the world depend primarily on rainfed agriculture for their grain food. The Rainfed agriculture plays an important role in Ethiopia economy covering more than 96 per cent of the total net sown area. Uncertainty in production due to fluctuations in total rainfall and changes in its distribution, decrease in relative productivity in rainfed lands etc. affect the livelihoods of many poor and marginalized farmers.

Some studies (Gabriel Senay and Verdin, 2003) found in many parts of sub-Saharan Africa particularly in Ethiopia, substance agriculture is characterized by significant fluctuation in yield and production because of variation in moisture availability in staple crops. Extensive drought can lead to crop failure, with associated deterioration in food security in Ethiopia.

There is a need to focus attention on the growing problem of water scarcity in relation to food production. According to FAO (1996), the World Food Summit of November 1996 drew attention to the importance of water as a vital resource for future development (FAO 1996). A major part of the developed global water resources is used for food production. The estimated minimum water requirement per capita is 1,200 m<sup>3</sup> annually (50m<sup>3</sup> for domestic use and 1,150 m<sup>3</sup> for food production) (FAO 1996).

Sustainable food production depends on judicious use of water resources as fresh water for human consumption and agriculture become increasingly scarce. To meet future food demands and growing competition for clean water, a more effective use of water in both irrigated and rainfed agriculture will be essential (Smith, 2000). Options to increase water-use efficiency include harvesting rainfall, reducing irrigation water losses, and adopting cultural practices that increase production per unit of water.

### **2.1.1. Rain-fed agriculture and water stress**

According to Falkenmark (1986), there is a correlation between poverty, hunger and water stress. The UN Millennium Development Project has identified the ‘hot spot’ countries in the world suffering from the largest prevalence of malnourishment. These countries coincide closely with those located in the semi-arid and dry sub-humid hydroclimates in the world, where rainfed agriculture is the dominating source of food, and where water constitutes a key limiting factor to crop growth (SEI, 2005). Of the 850 million undernourished people in the world, essentially all live in poor, developing countries, which predominantly are located in tropical regions (UNSTAT, 2005).

### **2.1.2. Crop yields in rain-fed areas**

Agricultural land use has expanded by 20–25% (FAO, 2002) for the past 40 years that has contributed to approximately 30% of the overall grain production growth during the period (Ramankutty *et al.*, 2002). The rest yield outputs originated from intensification through yield increases per unit land area. Nevertheless, the regional variation is large, as is the difference between irrigated and rainfed agriculture. Rosegrant *et al.* (2002) shown in developing countries rainfed grain yields are on average 1.5 t/ha, compared with 3.1 t/ha for irrigated yields, and increase in production from rainfed agriculture has mainly originated from land expansion (CAB, 2009).

### **2.1.3. Constraints of rain-fed agriculture**

An insight into the inventories of natural resources in rainfed regions shows a grim picture of water scarcity, fragile environments, and drought and land degradation. These are due to soil erosion by wind and water, low rainwater use efficiency (35–45%), high population pressure, poverty, low investments in water use efficiency (WUE) measures, poor infrastructure and inappropriate policies (Wani *et al.*, 2003b; Rockström *et al.*, 2007). Among others, water scarcity

is one that affects productivity and requires attentions. It was lost through evapotranspiration and others.

## **2.2. Evapotranspiration**

A study of Chiew and McMahon (1991), evapotranspiration, the combination of free-water evaporation and plant transpiration, is usually the largest loss component in rainfall-runoff modelling. It has been estimated that 60% of the mean global precipitation falling on the continents is lost from the surface through evapotranspiration (Brutsaert, 1986). It is one of the main components of the water cycle and the importance of its accurate estimation is obvious, however, this is difficult to achieve in practice because actual evapotranspiration cannot be measured directly and varies considerably in time and space (Tsouni et al., 2008). To estimate evapotranspiration from different climatic and meteorological variables over the last 50 years, a large number of more or less empirical methods have been developed worldwide. Moreover, over the past decades there has been an effort to evaluate evapotranspiration (ET) over larger areas from primarily remotely sensed data (Trezza, 2005). By this method, the water consumed by the soil-water-vegetation system can be derived directly without the need for quantifying other complex hydrological processes. Evapotranspiration occurs from evaporation and transpiration, and it can be obtained from weather data and satellite images.

### **2.2.1. Evaporation**

Evaporation is the primary process of water transfer in the hydrological cycle. The water is transformed into vapour and transported into the sky. Evaporation will occur from any body of water (Todd, 1996), which is the portion of water that is lost from surface storage. The scope of evaporation from surface storage includes those amounts of water lost from small puddles, ponds, lakes, and flow channels, such as creeks and rivers, as well as from vegetated and bare soil surfaces. Evaporation can be classified into potential evaporation and actual evaporation. The potential evaporation is defined as the amount of evaporation that would occur if a sufficient water source were available. On the other hand, the actual evaporation is the amount of water

which is evaporated a normal day. The potential evaporation is the maximum value of the actual evaporation (Hongjie et al., 2002; Kalluri et al., 2003).

### **2.2.2. Transpiration**

It is the evaporation from within the leaves of a plant. Transpiration is included by the vaporization of liquid water contained in plant tissues and the vapor removal to the atmosphere (Hongjie et al., 2002; Kalluri et al., 2003). Losses through transpiration are conducted by vegetation into the atmosphere. Water is considered available for transpiration from the upper soil layer only (Todd, 1996).

### **2.2.3. Actual evapotranspiration**

Thornthwaite (1944) cited by Fetter (1994) defined ET<sub>a</sub> as the physical process whereby water flows from evaporating surface in to the atmosphere. According to Gabriel Senay (2008), it is influenced by weather variables such as radiation, temperature, wind, and relative humidity. Beside to these weather variables, actual ET (ET<sub>a</sub>) is also affected by land cover type and condition and soil moisture. ET<sub>a</sub>'s reliance on these factors, and its direct relationship with carbon dioxide assimilation in plants (Gabriel Senay, 2008), 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.

Precise estimation of actual evaporations are a prerequisite for optimal irrigation scheduling (Doorenbos and Pruitt, 1977; Doorenbos and kassam, 1979) they usually need various meteorological data, astronomical variables (Kastopoulos and Bamajimopoulos, 1997) and soil and crop data.

Many areas in south Ethiopia and especially the meki-wabe plain suffer from recurrent drought during the summer month when the inadequate water resources are in meki with the high crop water needs. Under such conditions water deficits develops in the root zone, which retards the crop growth and evapotranspiration. As crop yield is closely related to the magnitude of actual

evaporation it is consequently of great importance to estimate evapotranspiration under such conditions.

However, it is often difficult to quantify and requires expensive instrumentation for estimation of ET<sub>a</sub> but it is very important for hydrological and agronomical applications. Nevertheless, different hydrological modeling techniques are used to estimate ET<sub>a</sub>. These are mainly grouped into two broad modeling techniques namely surface energy balance (Bastiaanssen et al., 1998; Allen et al., 2005; Su et al., 2005; Gabriel Senay et al., 2007) and water balance principles (Allen et al., 1998; Verdin and Klaver 2002; Gabriel Senay and Verdin 2003). The main difference in the two approaches is in the calculation of a correction factor to take into account the impact of soil moisture to estimate ET<sub>a</sub> as a fraction of the reference ET (ET<sub>o</sub>) (Gabriel Senay, 2008). The water balance model uses a vegetation water balance approach to track soil moisture changes, while the energy balance model uses land surface temperature changes.

### **2.3. Vegetation ET (VegET)**

Many researchers (Gabriel Senay, 2008) reveal the choice of model depends on the availability of data and on the objective of the project. It is a water balance model. Similarly, to energy balance, VegET method requires reference ET, which can be generated using meteorological data. Besides, the availability of rainfall and land surface phenology (LSP) is important for the VegET water balance model. The presence of cloud cover adversely affects the SSEB model, but it does not affect the VegET model, which explicitly considers cloud information in the satellite-based rainfall estimation process. This feature guarantees a reliable daily ET<sub>a</sub> estimation anywhere in the world irrespective of cloud cover. This can be a significant advantage during the growing season in many parts of the world. Moreover, the VegET model only estimates “rain-fed” ET (Gabriel Senay and Verdin, 2003; Gabriel Senay, 2008). In nut shell, due to these VegET is explored to estimate actual evaporation in rain fed agriculture in mek-wabe catchment.

## 2.4. Energy Balance Approach

Several researchers (Bastiaanssen et al., 1998; Allen et al., 2005; Su et al., 2005) have been successfully used to estimate crop water use in irrigated areas and across the general landscape. Their approach requires solving the energy balance equation at the land surface where the latent heat flux, also referred to as ET<sub>a</sub>, is calculated as the residual of the difference between the net radiation to the surface and losses due to the sensible heat flux and ground heat flux, which is calculated as follows:

$$LE = R_n - G - H$$

The estimation of each of these terms from remotely sensed imagery requires quality, calibrated datasets. Allen et al. (2005) described the various steps required to estimate actual ET using a surface energy balance method that employs the *hot* and *cold* pixel approach of Bastiaanssen et al. (1998) in the SEBAL model. For net radiation, SEBAL requires meteorological data on incoming and outgoing radiation, and the associated surface albedo and emissivity fractions for shortwave and long wave bands are needed. The ground heat flux is estimated using surface temperature, albedo, and normalized difference vegetation index (NDVI). The sensible heat flux is estimated as a function of temperature gradient above the surface, surface roughness, and wind speed.

Though solving the full energy-balance approach has been shown to give good results in many parts of the world, the data and skill necessities to solve for the various terms in the equation are prohibitive for operational applications in large, data-sparse regions. As an option, a Simplified Surface Energy Balance (SSEB) approach was developed at USGS/Center for Earth Resources Observation and Science (EROS) for operational applications (Gabriel Senay et al., 2007). The SSEB approach produces actual Evapotranspiration estimates using a combination of ET fractions generated from thermal imagery and global reference ET over homogeneous areas with similar climate zones where differences in surface temperature are mainly caused by differences in vegetation water use rates.

## 2.5. Actual Crop Evapotranspiration

Doorenbos and Pruitt (1977) have been well-established procedures for estimating crop evapotranspiration by using a series of recommended crop coefficient values ( $K_c$ ) to determine  $ET_{crop}$  ( $ET_c$ ) from reference evapotranspiration ( $ET_o$ ). Accordingly,  $ET_c = K_c ET_o$ . This formula represents the single crop coefficient. Some researchers (FAO, 1998), defined Crop evapotranspiration ( $ET_c$ ) refers to evapotranspiration of a disease-free crop, grown in very large fields, not short of water and fertilizer.

## 2.6. $ET_o$ (reference ET)

Reference evapotranspiration is defined as the rate of evapotranspiration from a hypothetical reference crop with an assumed crop height of 0.12 m and a fixed surface resistance of  $70 \text{ sec m}^{-1}$  closely resembling the evapotranspiration from an extensive surface of green grass of uniform height, actively growing, well watered, and completely shading the ground. Because crop surfaces rarely remain wet for long periods, the potential ET has limited usefulness. In 1968, Jensen introduced the use of reference crop ET, which refers to the rate of ET occurring from a reference surface, which again is not limited by water supply. Typically, the reference ET is determined for a hypothetical clipped grass or alfalfa crop. The determination of reference crop ET identifies the evaporative power of the atmosphere at a given location, on a typical reference crop surface (Allen et al, 1998). The reference ET is calculated using weather data collected at or near the area of interest. This is then used as a reference to estimate specific crop evapotranspiration using crop coefficients (Boyd, 2007).

## 2.7. Crop water requirement

Studies Girma Mamo (2005) defined crop water requirement as the amount of water, which is essential to replenish the water lost through evapotranspiration (ET) processes. The cumulative seasonal values of the two terms namely evapotranspiration and crop water requirement are therefore identical except of opposite sign. That means, knowing the amount of ET per unit time

and space equals the amount of water that crop requires growing and developing successfully. According to Ritchie (1991) crop water requirement studies need the daily or seasonal water balance information that should take account of the soil water stored from the foregoing season at planting time, followed by sequences of rainfall throughout the season.

According to benefit from dry land farming one must understand the techniques of capturing and storage of soil water to cope with times of water deficit, which is universal in arid regions of the world (Smika, 1990). One popular misconception related to dry land farming involves the impossibility of making water available for farming under these conditions, as there is no control over the weather (Girma Mamo, 2005). The maximum yields in a water-limited environment could come from improving the water use efficiency.

## **2.8. Water Requirement Satisfaction Index (WRSI)**

It is one of the crop performance indexes, which is based on a water balance model that simulates the reduction of crop yield due to water deficit. This model is currently operational as yield monitoring and forecasting tools for region wide food security analyses in drought prone countries in Sub-Saharan Africa (Gabriel Senay and Verdin, 2002; Girmaamo, 2005).

WRSI is calculated using a water stress index calculation scheme that helps determining whether an agricultural season has performed well and a given crop has had sufficient water to achieve potential yield (Hoefsloot, 2004). It indicates the extent to which the water requirements of a given crop have been satisfied in a cumulative way at any growth stage (Mukhala, 2002). Studies Doorenbos and Pruitt (1977) have revealed that WRSI can be meaningfully related to crop production in semi-arid regions, using a linear-yield reduction function specific to a crop. Recently, Gabriel Senay *et al.* (2001) have reported a GIS-based WRSI in northwestern Ethiopia, whereas Verdin and Klaver (2001) have also demonstrated a regional implementation of WRSI in a grid-cell based modeling environment and found useful results.

Many inputs are required to calculate WRSI over the course of a growing season such as the start of the growing season (SOS), end of the growing season and length of the growing season (LGS)

(Girma Mamo, 2005). With the soil factors, water holding capacity and water balance are essential. Meteorological parameters include rainfall and potential evapotranspiration, while crop coefficients ( $K_c$ ) that define the water requirements of a specific crop at the different growth stages are also important. According to Mukhala, (2002) WRSI starts with a value of 100% at SOS, while water deficits and excesses above the soil water holding capacity have a negative impact on the crop performance and therefore decrease the value in proportion to the degree of water deficit or water excess.

### 3. OVERVIEW OF THE STUDY AREA AND METHODOLOGY

#### 3.1. Description of the Study Area

##### 3.1.1. Location of the study area

The study was conducted in Meki-Wabe catchment, central Ethiopia. It is found in SNNP region (Gurage Zone and partly Silite Zone) and Oromia region (Some part of East Showa and South West Showa zone). Geographically it is situated from 37°58' to 38°09'E and 07°08' to 08°06' N and has area coverage about 5555 square kilometers. The altitude of the study area ranges from 1015m to 3615 m above sea level. The lowest altitude was recorded in the Meki catchment whereas the highest in the Wabe catchment.

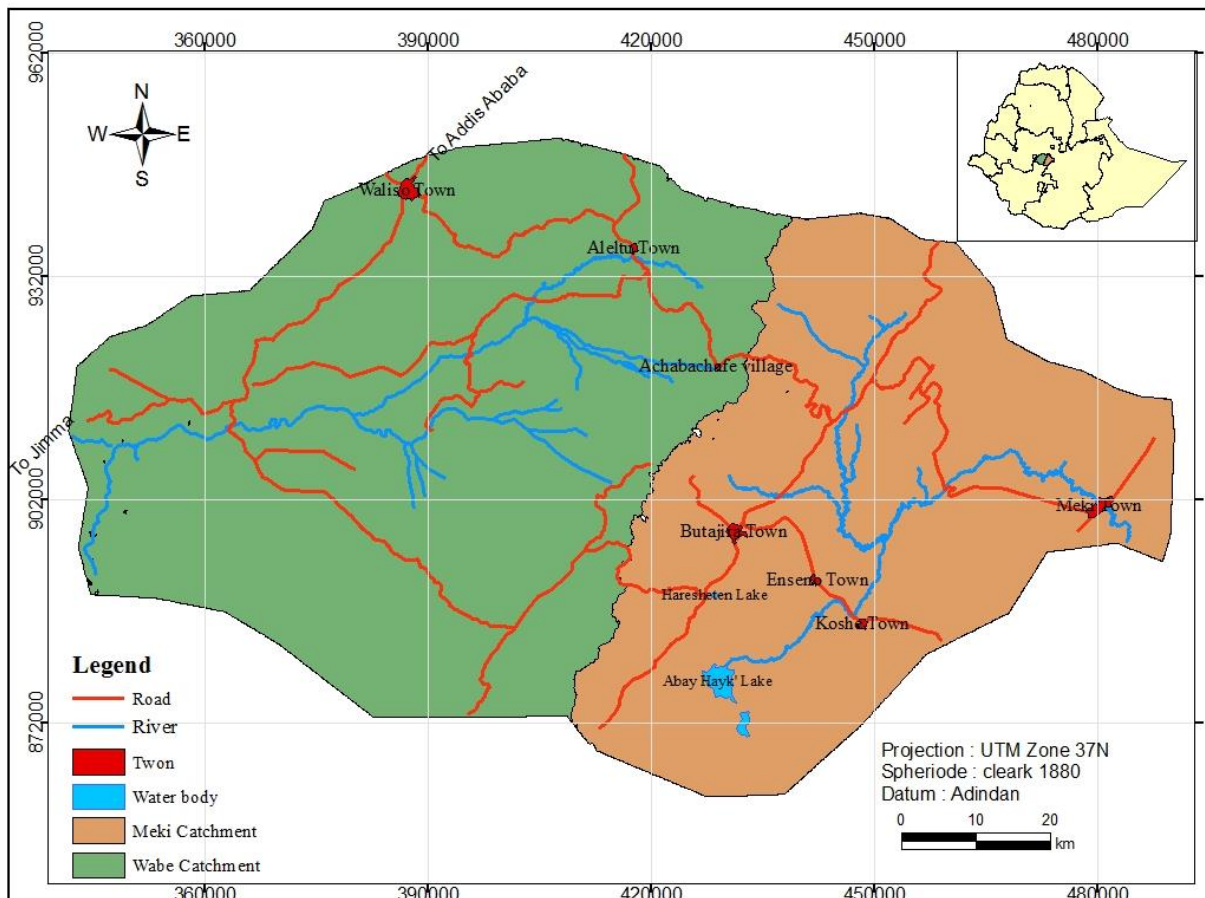


Figure 1 Location map of the study area.

### 3.1.2. Climate

The study area falls within the traditional Weyna-Dega agro-climatic zone, which can be classified as semi-arid climate. There were 15 metrological stations for recording climatic data in side and nearby the study area. These metrological stations were dissipated in figure 2 below.

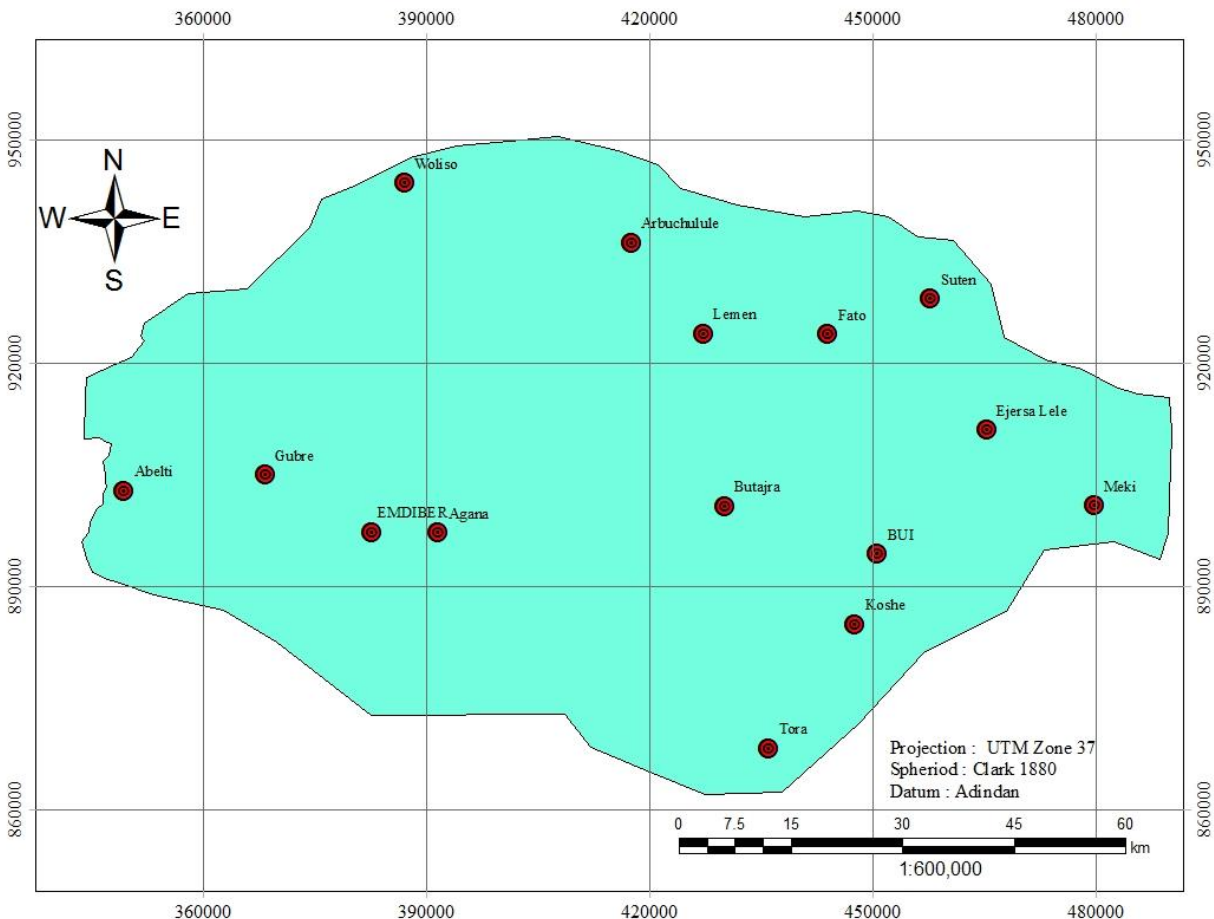
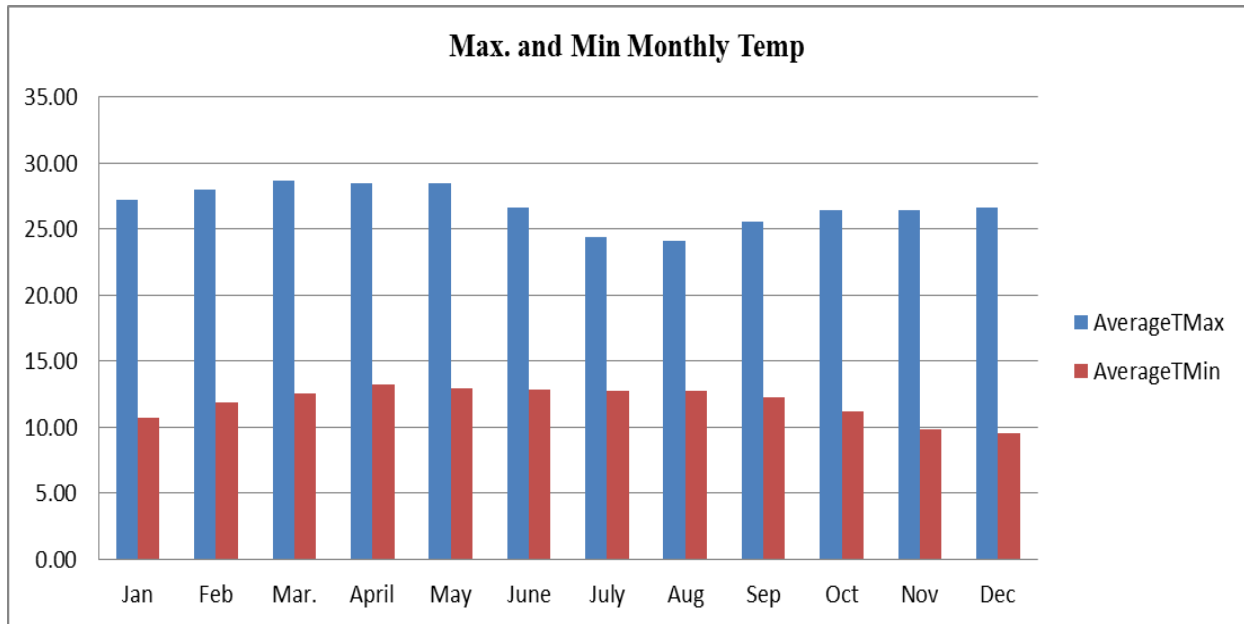


Figure 2 Distribution of metrological stations in the study area.

The average minimum temperature varied from 9.52 °C in Dec to 13.19 °C in April and the maximum temperature ranged from 24.04 °C in August to 28.44 °C in May figure 2. Air temperature regulated the growth and development of many plants by regulating the rate of biochemical processes. The growth of many crops ceased below a critical temperature of 5 °C or above 35 °C adversely affecting the yield.



**Figure 3** Mean Monthly Max and Min. Temperature in each station from 1991 to 2010 years.

### 3.1.3. Rainfall

The area has recorded total annual rainfall was 1200 mm with minimum of 22.09 mm in January and maximum of 228.83 mm in July. This pattern of rainfall indicated the possibilities of rain fed crop production from June to September. Figure 3 showed that the main cropping season was fall from June to September. Which the area receive higher amount of monthly rainfall among the years during 1991 to 2010

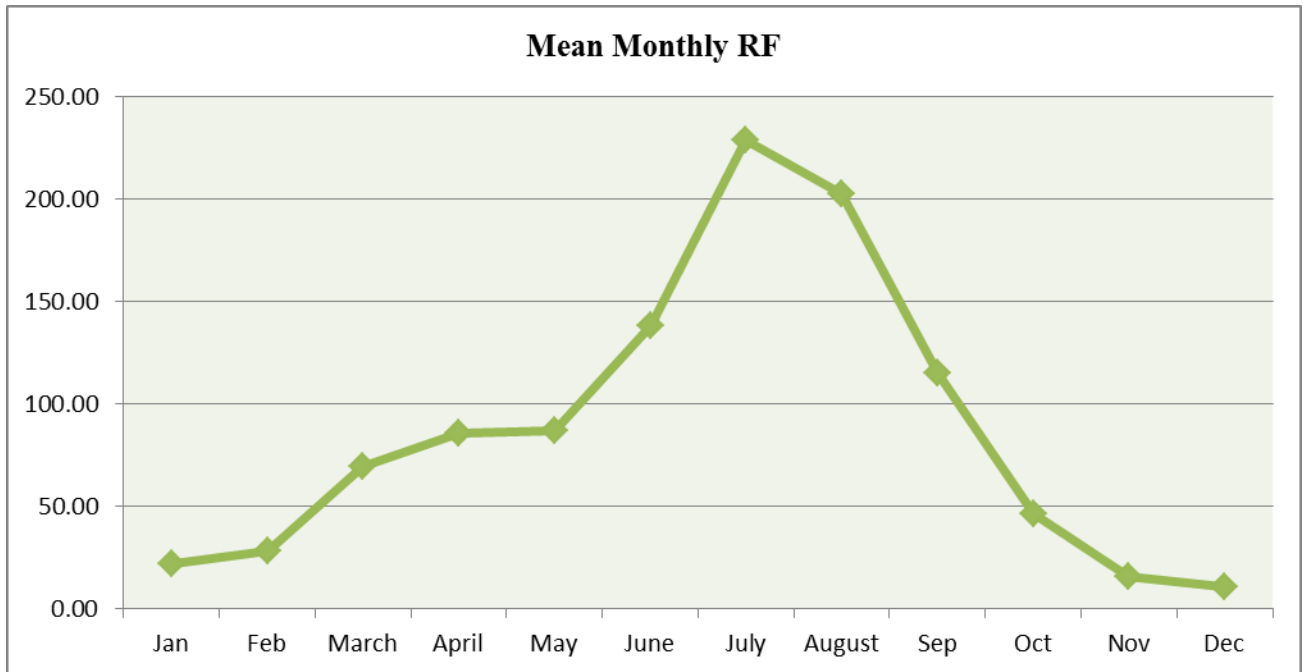


Figure 4 Mean Monthly rain fall in each station from 1991 to 2010 period in the study area

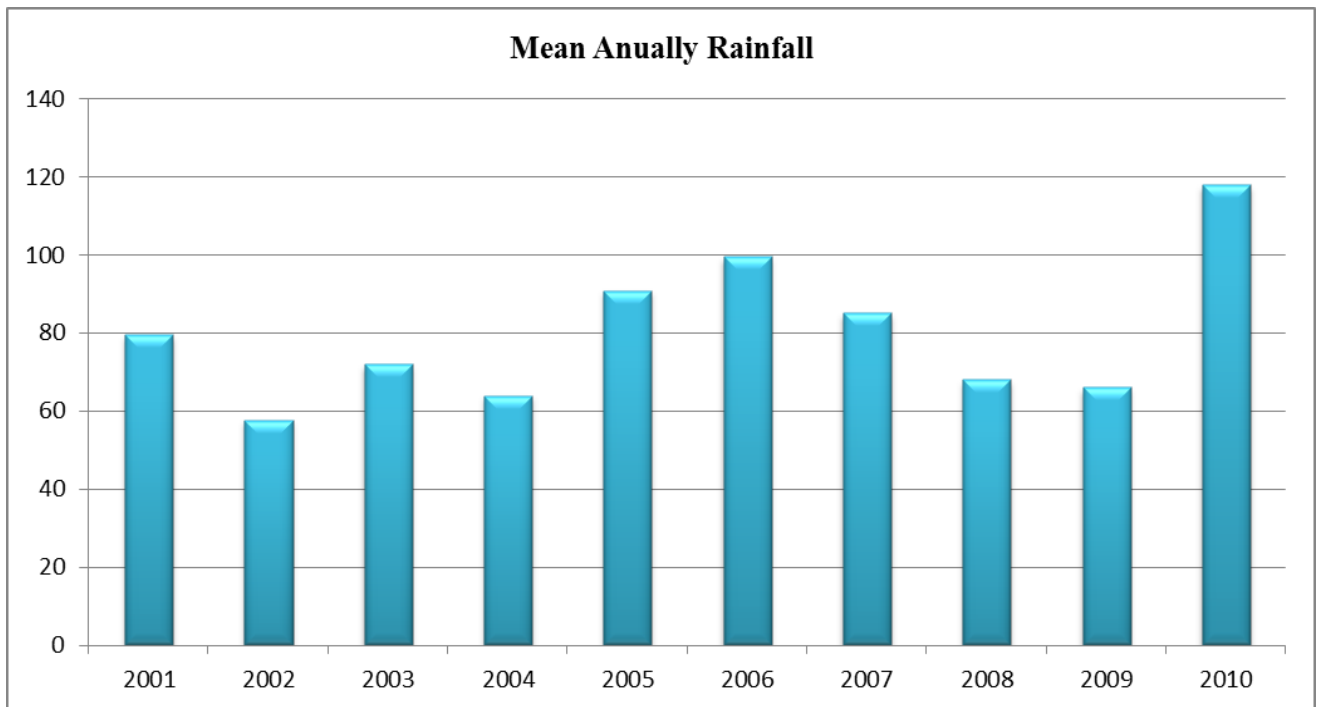


Figure 5 Distribution of annual rainfall all station of the study area for apriod 2001 to 2010

### 3.1.4. Soil

According to Food and Agricultural Organization (FAO) cited in Finance and Economic Development (2007), the different types of soils found in the study area dissipated in figure 6 below.

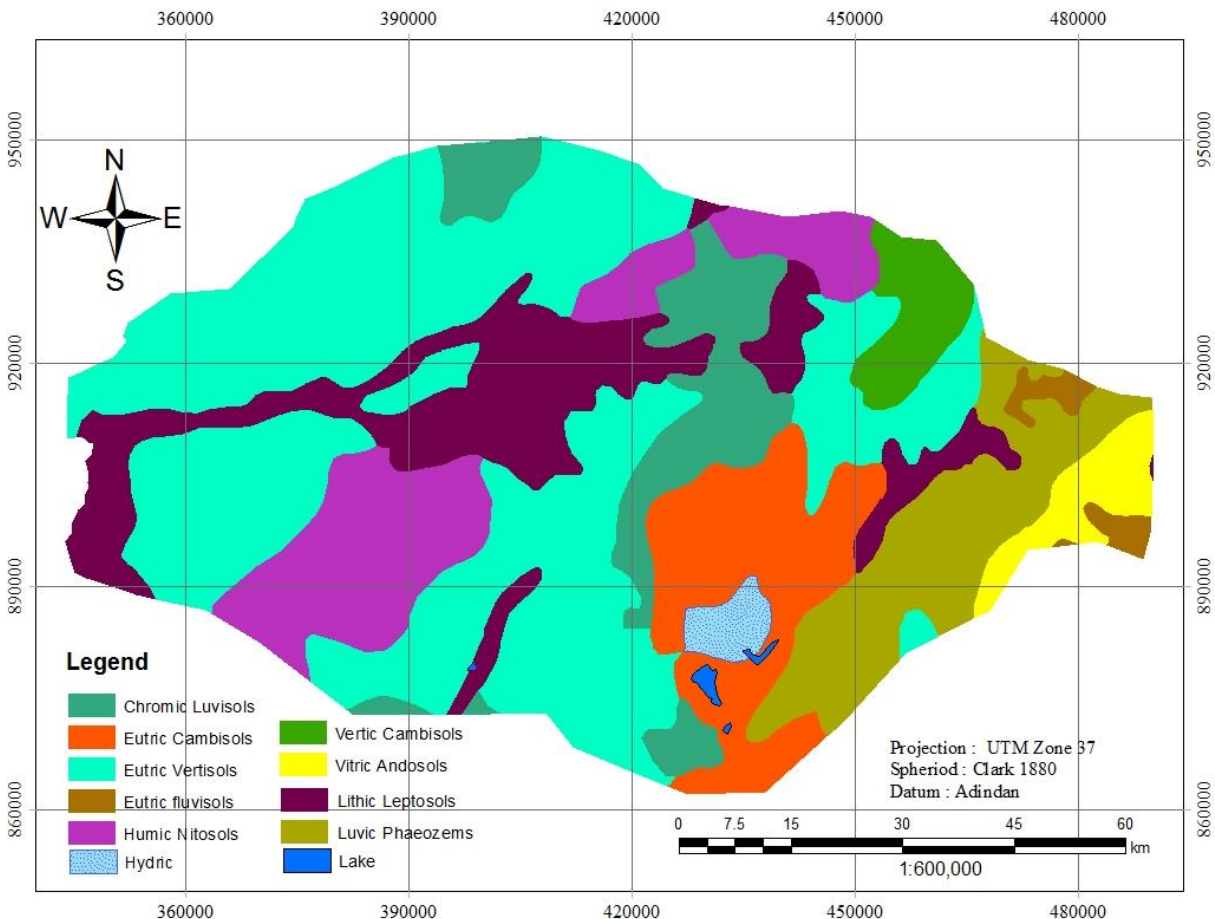


Figure 6 spatial distribution of soil classification in the study area.

### 3.1.5. Agro climatic 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 Mountains'). Day-time temperatures ranges from 2<sup>0</sup>C and 43<sup>0</sup>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.

Meki-wabe entire catchments are characterized by altitude ranges from 10015m to 3615m above sea level dissipated figure.7 blow and annual rainfall is 1615mm/year and the area falls in the Weyna-Dega and Dega agro-climatic zone

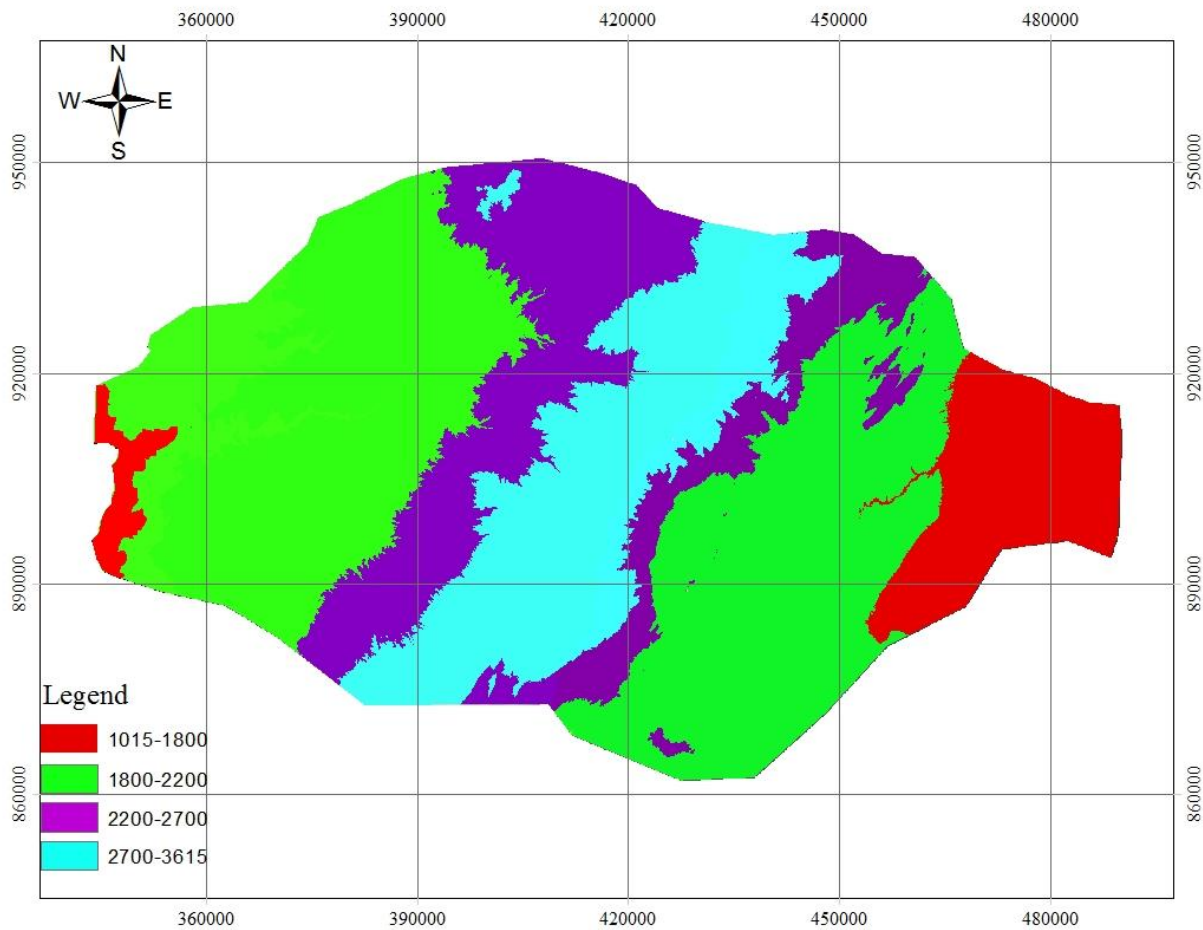


Figure 7 Classification of the study area based on their altitude.

### 3.1.6. Land use / Land cover

Meki-Webe catchment stretches over an area of 5555 sq. km. As it was observed, during field observation the study area was dominant by undulating and rolling features of land forms. The hilly and steep land accounts for large percentages and the flat lands are relatively small.

The land use and land cover map of the study area was derived using Landsat TM images of Jan. 2011 with paths and rows (p168, r054& p168, r055& p169, r054). The land use/ land cover pattern of the study area includes rainfed farm (intensively cultivated and mixed cultivated /with woods), bushes, shrubs, bare land /degraded land, water body, forest and settlements (Figure 8) and their percent of area coverage presented Table 1. The land use of the area is dominated by long period traditional rain-fed peasant farming system of individual holdings and Teff, maize and wheat are the major crops produced in the study area.

Table 1 land uses in the study area

Land uses	% of area coverage
Cultivated land	63
Bush, and shrubs	24.9
Forest	8
Bare land	2
Settlements	1.9
Lake	0.08
Swamps	0.12

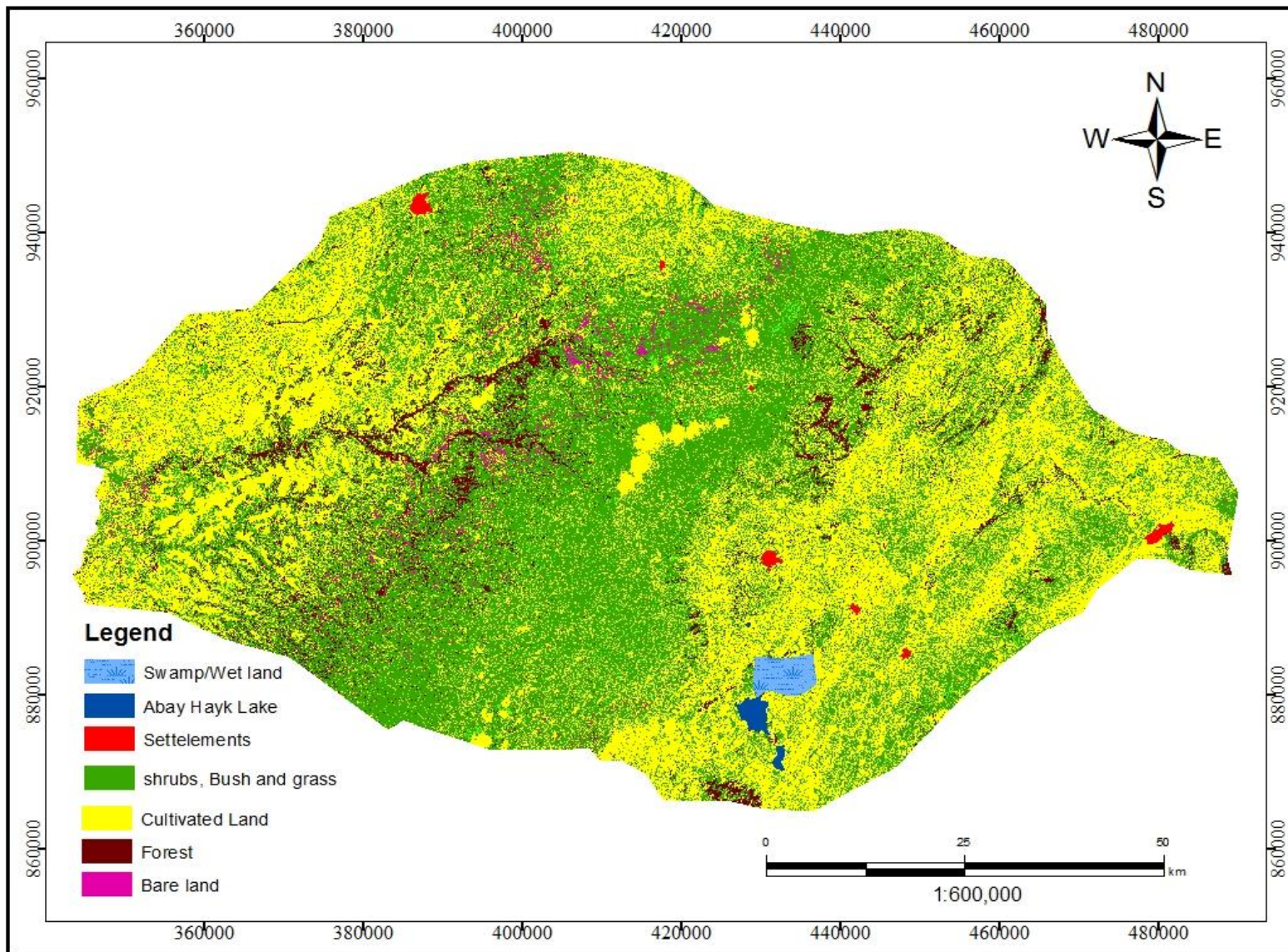


Figure 8 Land cover and land use of the study area

## 3.2. Methodology

For this specific study, different data acquisition methods were used to obtain qualitative and quantitative data from different sources such as FEWS-NET Data archive, USGS Data protocol, IWMI, CSA, published and unpublished materials. The data were acquired by using different software and GPS.

### 3.2.1. Data acquisition and software package

#### 3.2.1.1. Satellite images

A time series advanced very high-resolution radiometer (AVHRR) NDVI climatology, rainfall estimate (REF) and reference evapotranspiration (ET<sub>o</sub>) satellite data were used in this study Table 2. All these data have 8km, 10km and 10/100 km spatial resolution respectively and obtained in decadal (10 days) temporal resolution for the year 2001 to 2010 during the main rain season (June to September). These data were down loaded from the Famine Early Warning System (FEWS-NET) archive website: <http://earlywarning.cr.usgs.gov/adds/datatheme.php>

Table 2 Description of data used in this study

SN	Data types	Temporal resolution	Spatial resolution
1	Rainfall data (image)	dekadal (10 days)	10km
2	Reference ET (image)	“	10/100 km
3	Climatology NDVI	“	8 km
4	IWMI Reference ET	“	10 km
5	Meteorological data	Monthly	-
6	Landsat images	16 days	30m

#### 3.2.1.2. Grain Yield data

The average yield of the dominant crops in the study area was used to co-relate and see the effect actual evapotranspiration and crop performance indicator on yield. In order to find out the relationship of average zonal dominant crop yield data of the study area were collected from

Central Statistics Agency (CSA). The total grain yield data of crops grown in the study area is depicted in Table 3

Table 3 Avg. production Qun/hec of major crops of Maher season in the study area

SN	year	South West Showa			East Showa			Gurage			Silitie		
		Teff	Maize	wheat	Teff	Maize	wheat	Teff	Maize	wheat	Teff	Maize	wheat
1	2003	9.8	15.8	16.67	8.0	23.7	17.2	7.6	22.2	18.8	8.4	23.5	17.3
2	2004	11.7	14.9	17.07	10.9	16.0	15.8	9.8	21.7	20.8	7.1	11.9	13.2
3	2005	11.9	21.9	16.91	13.7	27.9	19.8	7.7	22.3	17.5	7.1	18.5	14.0
4	2006	11.8	22.6	17.58	14.8	28.5	23.4	9.1	25.2	19.1	7.8	22.3	17.0
5	2007	12.2	14.9	15.42	12.8	27.3	16.6	10.7	22.7	17.6	10.4	19.4	18.3
6	2008	11.7	17.6	15.01	11.6	27.1	19.3	9.8	20.5	21.5	10.5	18.3	20.4
7	2010	14.5	27.7	19.6	14.30	23.9	17.8	11.5	28.8	21.3	11.0	27.3	18.4

### 3.2.1.3. Software package

ArcGIS 10, ERDAS IMAGIN 9.2, GeospatialWRSI3.0 and Microsoft excel soft wares were used for data analyses.

### 3.2.2. Preprocessing of Data for this study

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 row images. Originally, the data is projected using ALBERS Conical Equal-Area Projection and with the datum Clarke 1866 spheroid. Then the data is re-projected to Adindan UTM\_Zone\_37N.

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 data was extracted and became ready for further analysis.

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 1). The resulting 10-km ETo grids will be used in this analysis. The downscaling method was developed and validated by the (Gabriel Senay et al., 2007) using similar IWMI data. Thus, the method was proven to be an effective technique to downscale the Global GDAS ETo.

$$X / Y * GDAS ETo \dots\dots\dots (1)$$

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

### 3.2.3. VegET model set up

The VegET model integrates commonly used water balance algorithms with remotely sensed Land Surface Phenology (LSP) to estimate actual vegetation ET (water use) in primarily non-irrigated crop and grassland environments for agro-hydrological applications, at the LSP’s spatial scale using readily available global weather data sets (Gabriel Senay, 2008). The model used Climatology NDVI, Rainfall estimate and reference ETo as input to calculate actual evapotranspiration for the main cropping seasonal of Meki-Wabe entire catchment for a period from 2001 - 2010 have been studied.

Estimated parameters are phenology-based crop coefficient (Kcp) and soil-water stress factor (Ks). Model outputs are ETa and runoff.

ETa is calculated as the product of ETo, soil stress coefficient (Ks), and Kcp

$$ETa = Kcp * Ks * ETo \dots\dots\dots (2)$$

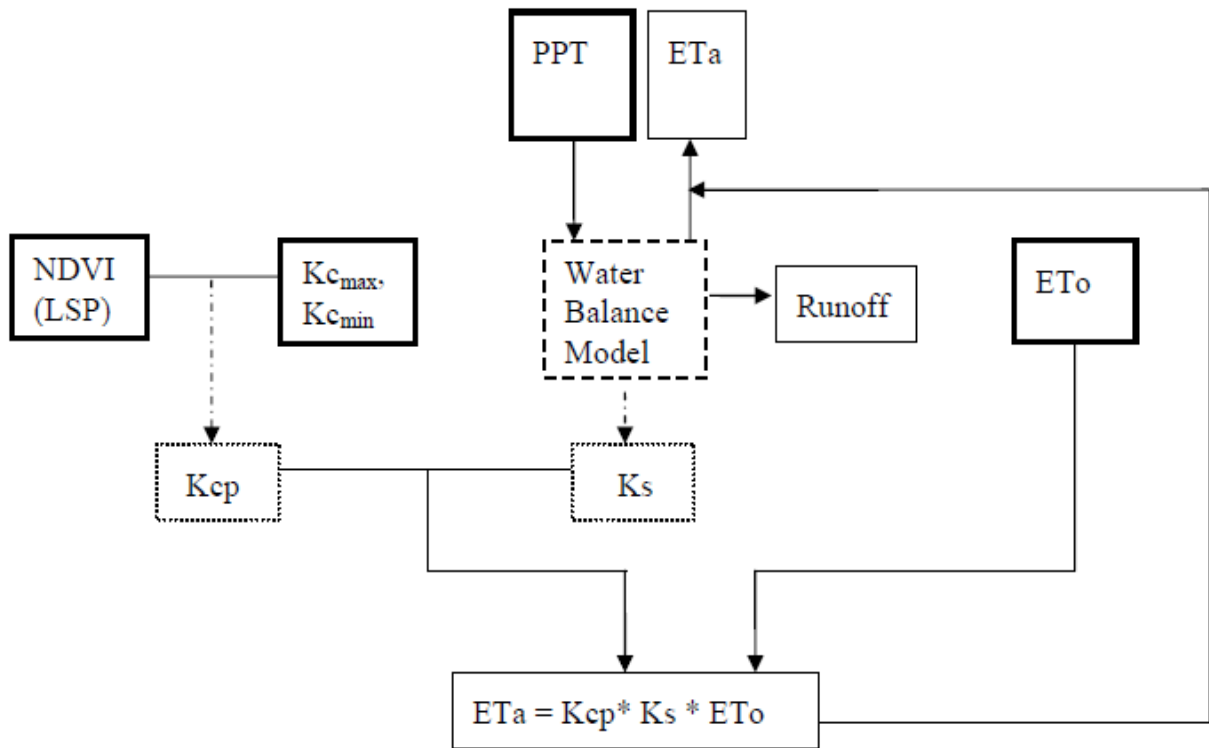


Figure 9 A simplified schematic representation of the VegET model

Source: Senay (2008)

### 3.2.3.1. NDVI climatology

Some of the studies (Gabriel Senay, 2008) defined the NDVI climatology is a “historical” average NDVI for a given time period. Moreover, it is historical defined as the average of at least 5 years of NDVI data. This type of data is available from AVHRR and MODIS for global applications. In this study, LSPs are simply represented by temporally smoothed (long term average) climatology decadal maximum composite at 8 km resolution NDVI data sets were used. A decadal is nominally composed of 10-day time periods in a month, except for the 3<sup>rd</sup> decadal of a month where it may assume values of either 8, 9, 10, or 11, depending on the month and year. Depending on the context of the discussion, the terms LSP and NDVI climatology are used interchangeably and the average spatial distribution of NDVI of the study area is dissipated in figure10 and its average value dissipated in table 4.

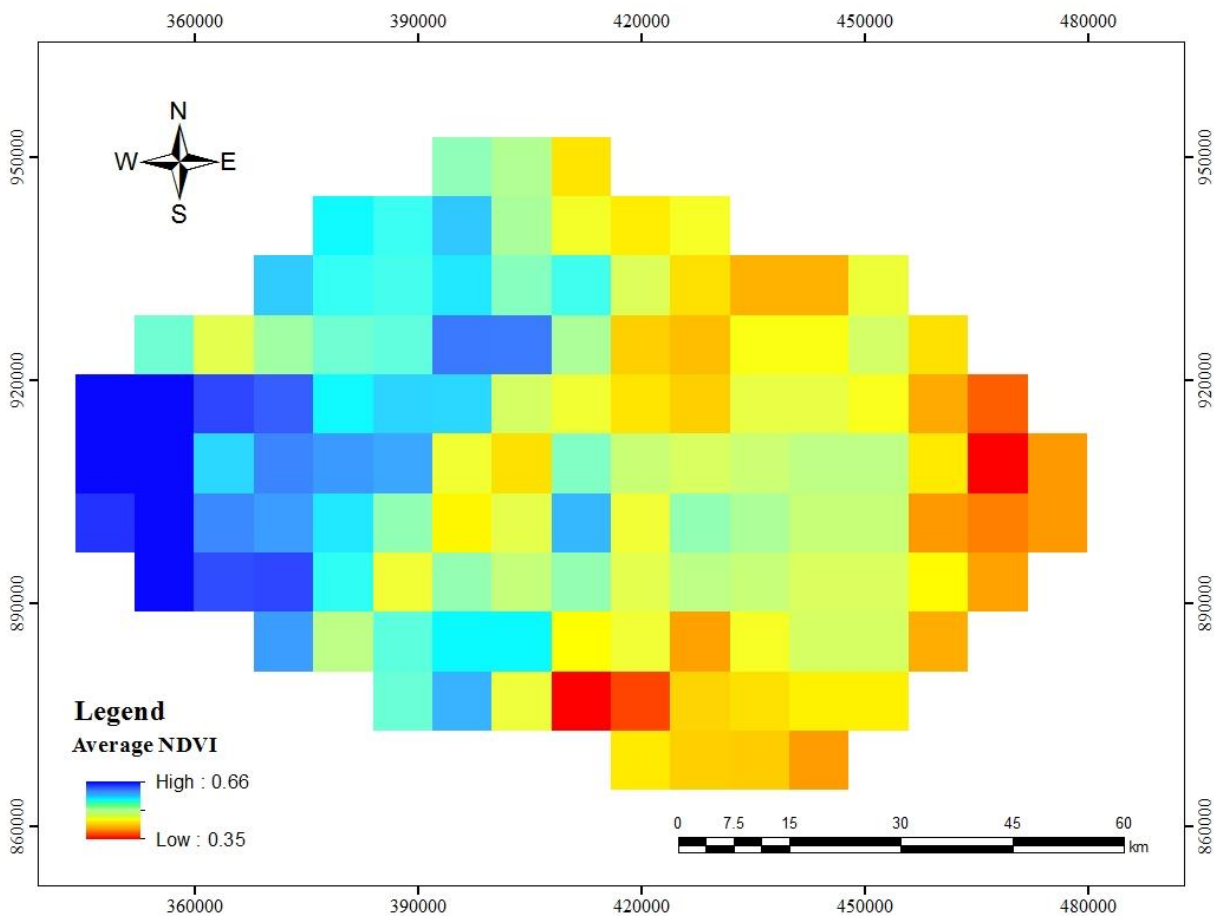


Figure 10 Spatial distribution of average NDVI of the study area

Table 4 Average value of NDVI of the study area

Months	Decadal(d)	MIN	MAX	RANGE	MEAN
June	NDVI_d16	0.26	0.58	0.32	0.42
June	NDVI_d17	0.27	0.54	0.28	0.42
June	NDVI_d18	0.28	0.57	0.29	0.41
July	NDVI_d19	0.25	0.63	0.38	0.43
July	NDVI_d20	0.30	0.66	0.35	0.44
July	NDVI_d21	0.31	0.68	0.37	0.46
Aug	NDVI_d22	0.31	0.72	0.41	0.48
Aug	NDVI_d23	0.33	0.73	0.40	0.51
Aug	NDVI_d24	0.36	0.74	0.38	0.54
Sep	NDVI_d25	0.44	0.73	0.29	0.58
Sep	NDVI_d26	0.45	0.72	0.26	0.59
Sep	NDVI_d27	0.46	0.71	0.25	0.60

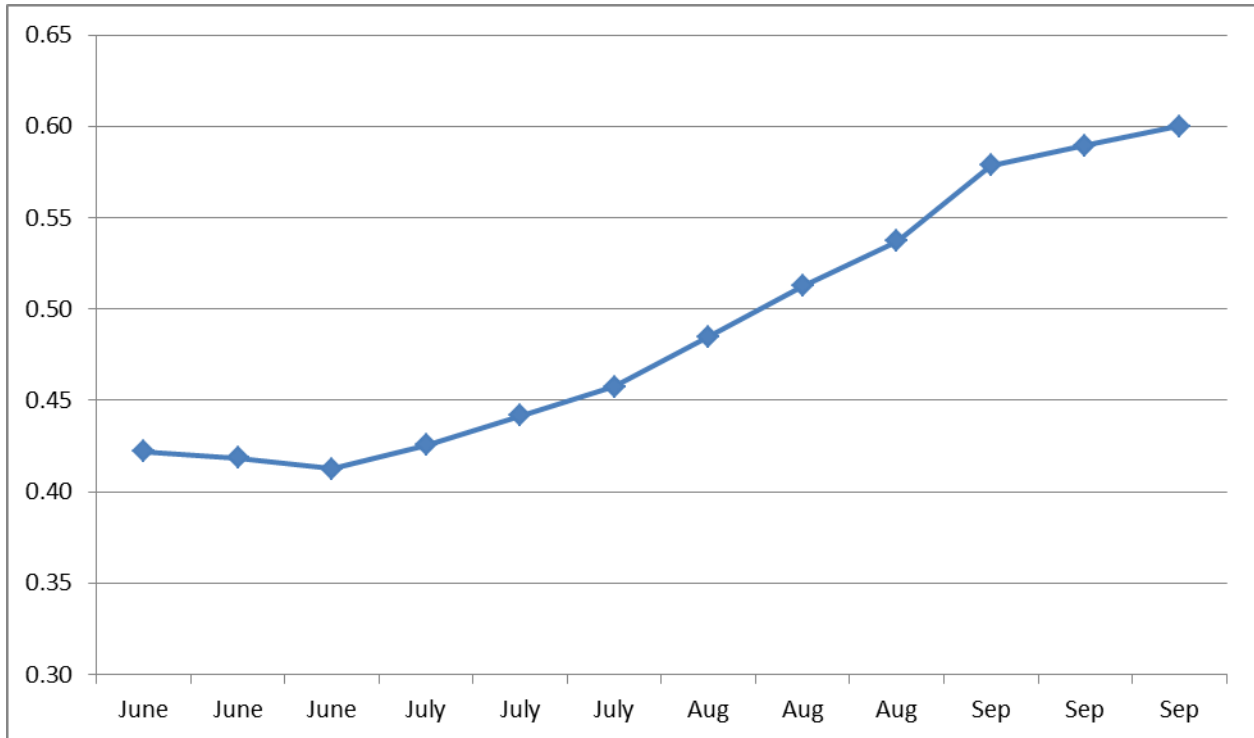


Figure 11 Graphical representation of NDVI of the study area (Jun – Sep)

### 3.2.3.2. Soil Moisture Stress coefficient (Ks)

It is determined from a soil water balance model for USGS/FEWS NET early warning applications using the following equations:

$$K_s = \frac{SW_i}{MAD} \rightarrow \underline{SW_i} < MAD; K_s = 1.0 \rightarrow \underline{SW_i} \geq MAD \dots\dots\dots (3)$$

Whereas: SW<sub>i</sub> is soil water of current time step in depth unit. MAD is the Maximum Allowable Depletion level of soil water in the root zone, below which the vegetation ET is less than “potential” and will be constrained by the availability of soil water. 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. Thus, MAD was estimated as 50% of the WHC derived from STATSGO.

More detailed information is available on the setup and initialization of the soil water balance model for operational crop monitoring (Gabriel Senay and Verdin, 2003). The Soil water index data was generated by using GeoSpatial tool

### 3.2.3.3. Kcp parameter function

According to Gabriel Senay (2008), Kcp parameter function is defined using NDVI climatology (LSP) and published crop coefficient minimum (Kcmin) and maximum (Kcmax) values, in which the Kc values provide the lower and maximum limits for the Kcp and the NDVI profile provides the temporal patterns of Kcp. The formulation of the Kcp parameter is used in Equation (2) to estimate landscape ET by using the following formula.

$$\underline{Kcp} = \frac{\underline{Kc_{max}} - \underline{Kc_{min}}}{\underline{NDVI_{max}} - \underline{NDVIo}} * (\underline{NDVIi} - \underline{NDVIo}) + \underline{Kc_{min}} \dots\dots\dots (4)$$

$$Kcp = Kc_{min} \longrightarrow Kcp < Kc_{min} \dots\dots\dots (5)$$

Where Kcmax is the maximum (mature) Kc value for a vegetation/crop type; Kcmin is the minimum (early stage) Kc value; NDVImax is the climatology maximum NDVI value in a year; NDVIi 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, 4 or 5.

NDVIo is calculated depending on the NDVI max for each pixel for the formulation of Kcp by the following.

Case I:  $\underline{NDVI_{max}} \geq 0.40$

$$\underline{NDVIo} = 0.3 \dots\dots\dots (6)$$

Case II:  $\underline{NDVI_{max}} < 0.40$

$$\underline{NDVIo} = 0.33 * (\underline{NDVI_{Max}} - \underline{NDVI_{Min}}) + \underline{NDVI_{Min}} \dots\dots\dots (7)$$

NDVimin is the climatology minimum NDVI value from the weekly maximum NDVI composite data set.

The Kcp function only uses these two parameters (NDVImax and NDVIo) to convert smoothed historical NDVI data sets from NDVI to Kcp according to Equation 4 or 5. For instance, a generic cereal crop has a published Kc of 0.3 (Kcmin) at the early stage and 1.15 (Kcmax) for the mature stage. Both NDVImax and NDVImin (NDVIo) are calculated from NDVIi data sets where “i” represents a “historical” NDVI time step. NDVIi data sets are available at weekly or longer time steps.

This model parameter was used the initialization threshold to an NDVI value of 0.30 when using NDVI derived from AVHRR data sets. This threshold is appropriate for a large area of the Earth where there is reasonable vegetation cover for parts of the year, the threshold is dynamically adjusted to handle landscapes in mainly arid and some semiarid regions with little or no vegetation cover.

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. Since Kcp is derived from LSPs that are unique to each modeling cell in the world, there is no need to redefine Kcp by region and climate as is the case for Kc. Kcp includes the vegetation calendar, i.e., start of season, length of growing period, and end of season from the LSP. 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 for each modeling grid cell using LSPs generated from NDVI climatology.

#### **3.2.3.4. Potential evapotranspiration (ETo)**

ETo data were calculated on global scale on a cell-by-cell basis according to the Penman–Monteith equation (Verdin and Klaver, 2002). These 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. These data was processed using Geospatial tool and down scaled from 1 degree into 0.1 degree by using the International Water Management Institute (IWMI) historical (1950-2000) potential evapotranspiration (PET) was used for this analysis.

### 3.2.3.5. 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).

### 3.2.4. Crop performance indicator

#### 3.2.4.1. Determination of water requirement satisfaction index (WRSI)

Water requirement satisfaction index (WRSI) is an indicator of crop performance based on the availability of water to the crop during a growing season. 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 (AET) to the seasonal crop water requirement (WR)

$$\text{WRSI} = (\text{AET} / \text{WR}) 100 \dots\dots\dots (8)$$

Where, WR is calculated from the Penman-Monteith reference crop evapotranspiration (ET<sub>o</sub>) using the LSP- based crop coefficient (K<sub>cp</sub>) to adjust for the growth stage of the crop.

$$\text{WR} = \text{ET}_o * \text{K}_{cp} \dots\dots\dots (9)$$

AET represents the actual amount of water withdrawn from the soil water reservoir where shortfall relative to potential evapotranspiration (PET) was calculated by function that takes into account the amount of soil water in the reservoir. Soil water content was estimated through simple mass balance equation where the total volume was defined by the water holding capacity (WHC) of the soil.

Table 5 WRSI based drought severity class

WRSI percent	Drought severity class
Less than 50	Very severe drought
50 – 60	Severe drought
60 – 70	Moderate drought
70 – 80	Slight drought
80 – 100	No drought

Source: Gezichew Legesse (2010)

WRSI was computed using Geospatial tool software and imported into GIS environment. Since the WRSI data are in a raster data format, the average value of the pixels located inside each zone of the study area was calculated to represent the entirely zone. Based on this average Water Requirement Satisfaction Index of the entirely zone administrative boundary was calculated during the main growing season (June – September) during 2001 - 2010.

#### 3.2.4.2. Computation of yield reduction due to moisture deficit

The impact of moisture deficit on crop production can be largely expressed by yield reduction. In view of this, yield reduction due to water deficiency was computed using Geospatial tool. Yield reduction was calculated from water balance output combined with an empirical formula developed by Doorenbosch and Kassam (Hoefsloot, 2008). The formula is:

$$100 - \left( \frac{1 - (1 - ET_a / WR) K_y}{1} \right) 100 \dots\dots\dots (10)$$

Where  $ET_a$  is the actual evapotranspiration,  $WR$  is the total water requirement without water stress.  $K_y$  is a crop dependent stress indicator determined by the authors. The major crops grown

in the study area, teff , maize, wheat, sorghum and their respective Ky is 1.1499 for teff, wheat and barley, 1.25, 0.8999 for maize and sorghum respectively, were considered in computation of aggregated yield reduction..

### **3.2.5. Regression analysis of grain yield, crop performance indicator and ETa**

Grain yield data and data derived from crop performance indicator were prepared for simple regression analysis. The average raster cell values of WRSI, ETa, rainfall and yield reduction were extracted using ArcGIS 10 zonal statistics. The relationship between WRSI with crop yield and yield reduction and ETa with rainfall were computed to validate the co-relation.

## 4. RESULT AND DISCUSSION

### 4.1. Estimation of Actual Evapotranspiration of the Main Cropping Season

In Meki-Wabe entire catchment during the main cropping season (June – September) from a period of 2001 to 2010 the spatial and temporal actual ET/crop/vegetation water was estimated. The analytical result has shown that the area experienced an average ETa/ crop/vegetation water uses maximum 372mm and minimum 322 mm which found in 2006 and 2002 years respectively. Table 6 summarizes average seasonal (June- September) actual evapotranspiration/ water uses of different land cover features (crop/vegetation) and its spatial distribution were dissipated in (fig.13, 14 and15). The spatial distribution of ETa results has shown that there is higher ETa/water use in the Meki catchment than Wabe Catchment and also large area of Meki catchment was lower in altitude than the Wabe catchment; due to the fact that lower land vegetation/crops grows faster when they got moisture/ rain and faster to dry when there is no moisture /rain stops while the high land vegetation slowly grows when moisture available and slowly dry when moisture deficits. Similar study By Debele Abera (2012) lower rift uses more water than adjacent highlands.

Table 6 Average, Maximum and Minimum ETa estimated of the entirely study area

Year	Min	Max	Range	Average
2001	279	353	73	324
2002	234	414	180	322
2003	255	429	173	332
2004	251	423	172	323
2005	268	441	173	332
2006	329	436	107	372
2007	360	472	113	371
2008	268	437	170	351
2009	337	454	117	363
2010	275	461	186	341

#### 4.1.1. Relationship between seasonal rainfall and ETa/water use

Rainfall is climatic variables that largely influence the growth and development of crops and yield which are directly reflected by crop water use. Seasonal rainfall and water use patterns of the study area for a period from 2001- 2010 have been correlated and the result has shown that there is good positive correlation ( $r=0.72$ ) between rainfall and ETa (Figure 12). This implies that from total 10 year's data 53% water use variability can be explained by variability of rainfall. It revealed that there is an increasing trend in both rainfall and ETa because when there was sufficient amounts of moisture/rainfall available the water use also increase. However, due to lag time response of vegetation/crop to the existing rainfall, the relationship between RFE and ETa variables may vary some places.

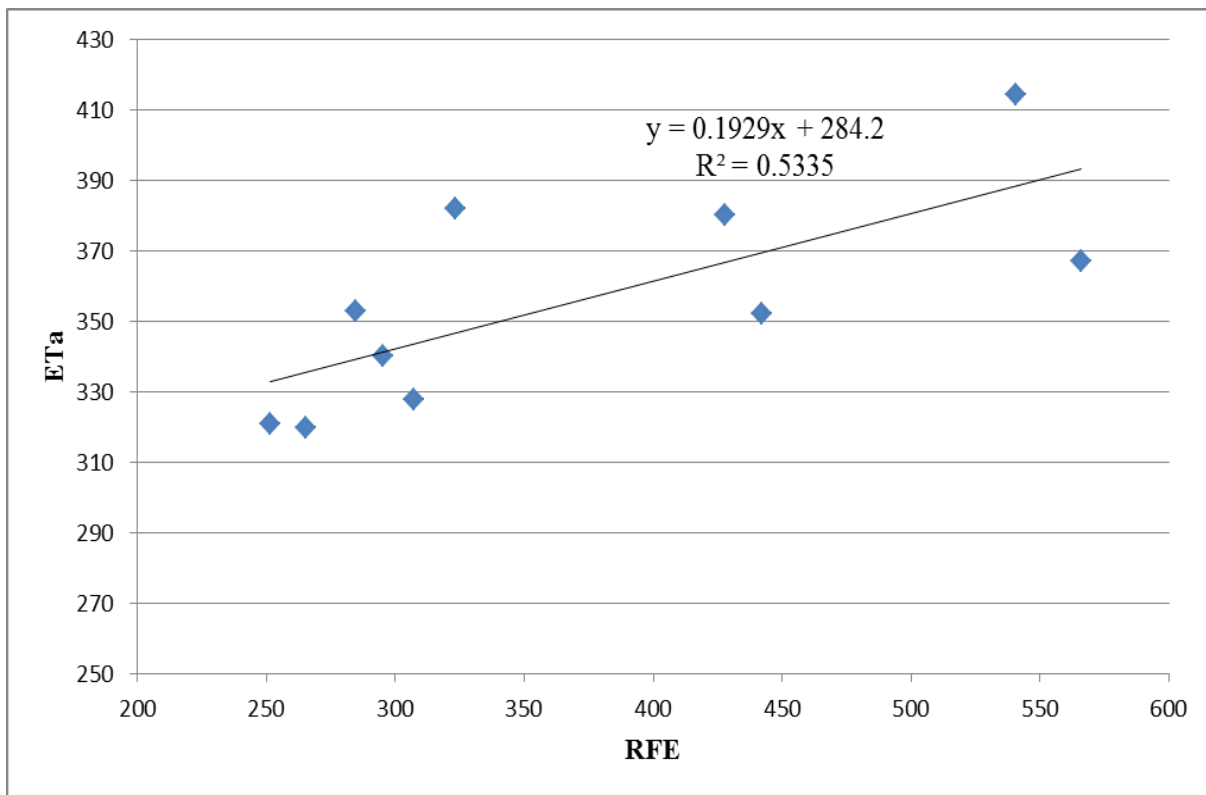


Figure 12 Seasonal (June-September) patterns of rainfall and ETa (2001 - 2010)

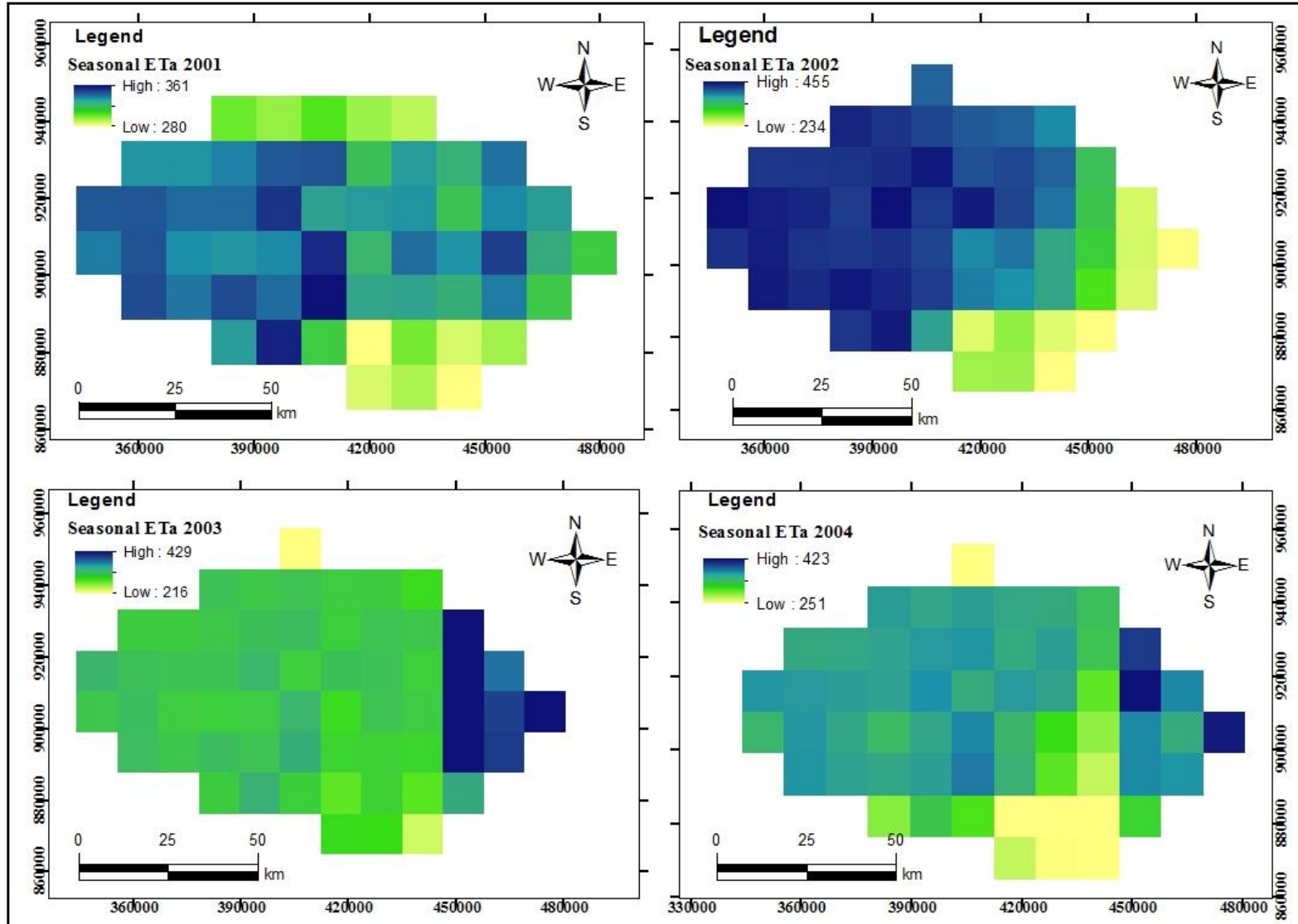


Figure 13 spatial patter of ETa (mm) estimated for the cropping Season (2001-2004)

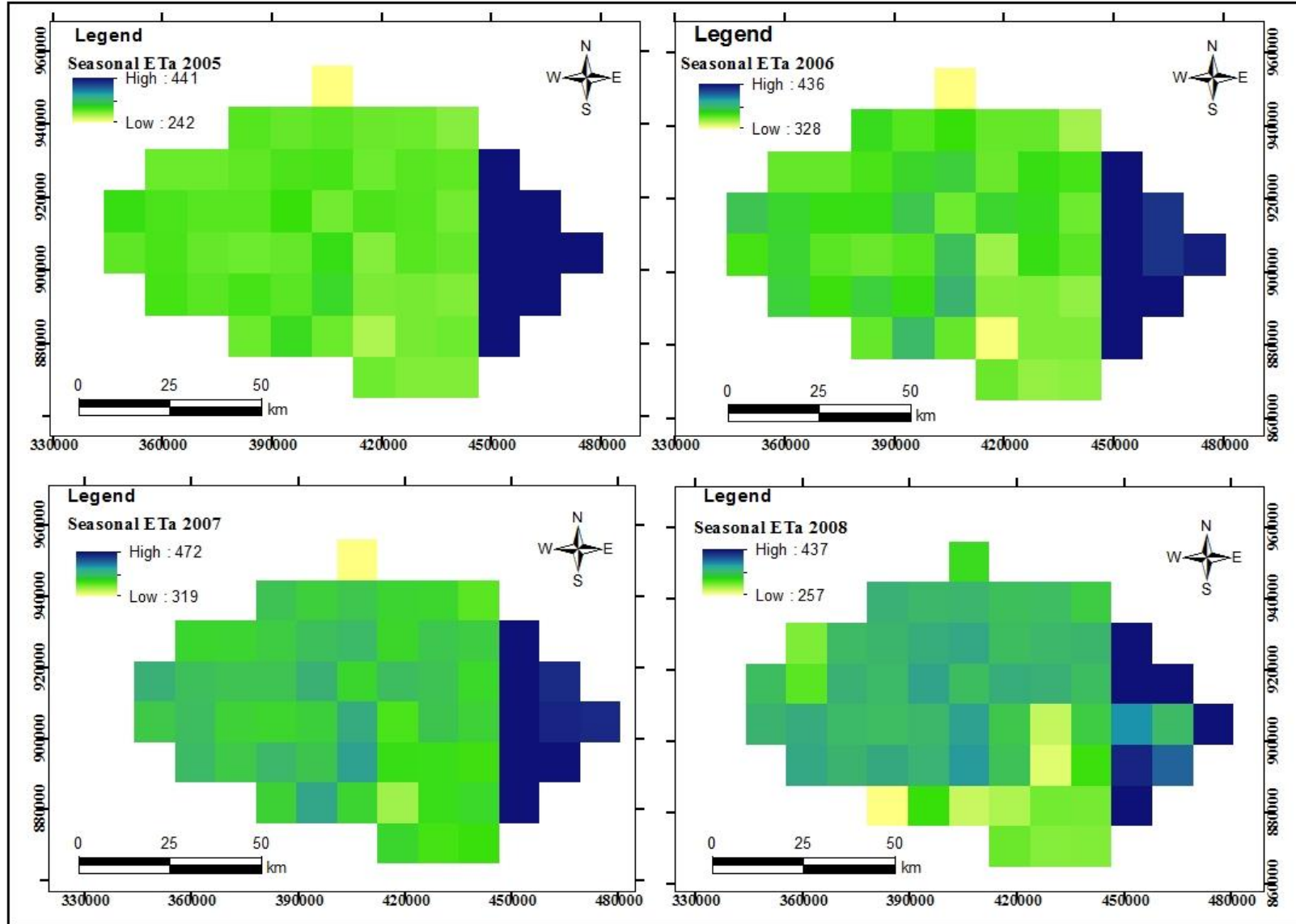


Figure14 Spatial pattern ETa (mm) estimated for the cropping Season (2005-2008)

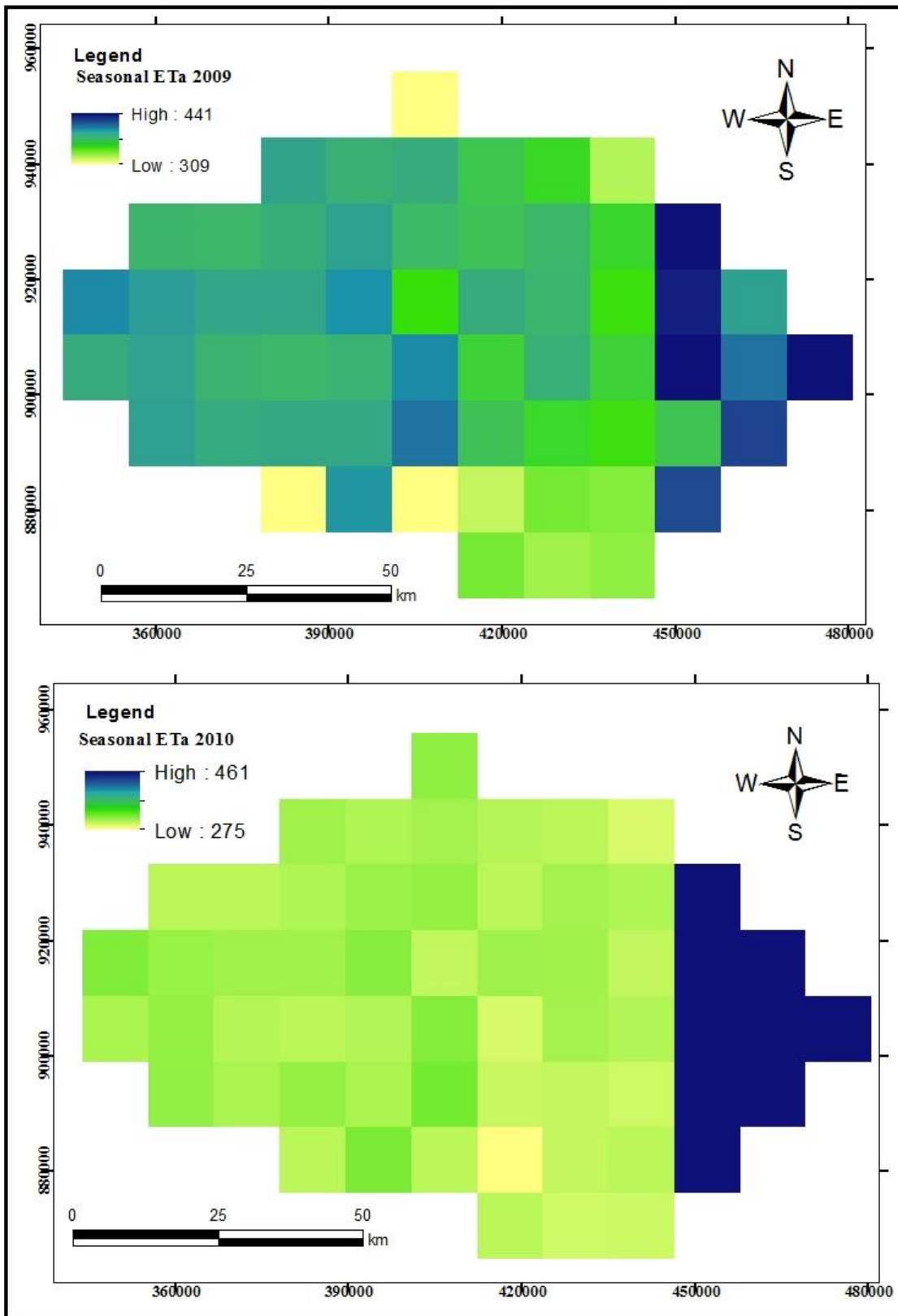


Figure 15 Spatial patterns ETa (mm) estimated for the cropping season (2009&2010)

## 4.2. Seasonal Spatial and Temporal Water Requirement

The spatial and temporal seasonal water requirement of the study area has been calculated. Basically the water requirement a function of potential evapotranspiration and Land surface phenology based crop coefficient as indicated in eq.9. The result revealed that the area experienced an average WR 412 mm Max and 341 mm Min seasonal water requirements which found, during the 2002 and 2005 respectively. The average water requirement of the study area during cropping season is in presented table 7 and its spatial distribution depicted in figure 16, 17, and 18. Regarding the spatial distribution of water requirement of the area shows similar trend that of water use, in areas higher water use shows higher WR with greater value of water requirement.

Table 7 Average Seasonal water requirement of the study area

Year	Min	Max	Range	Average
2001	306	357	51	342
2002	379	440	61	412
2003	275	431	156	347
2004	311	441	130	374
2005	259	443	184	341
2006	319	440	122	378
2007	320	442	122	380
2008	302	445	143	369
2009	343	477	134	409
2010	266	464	198	353

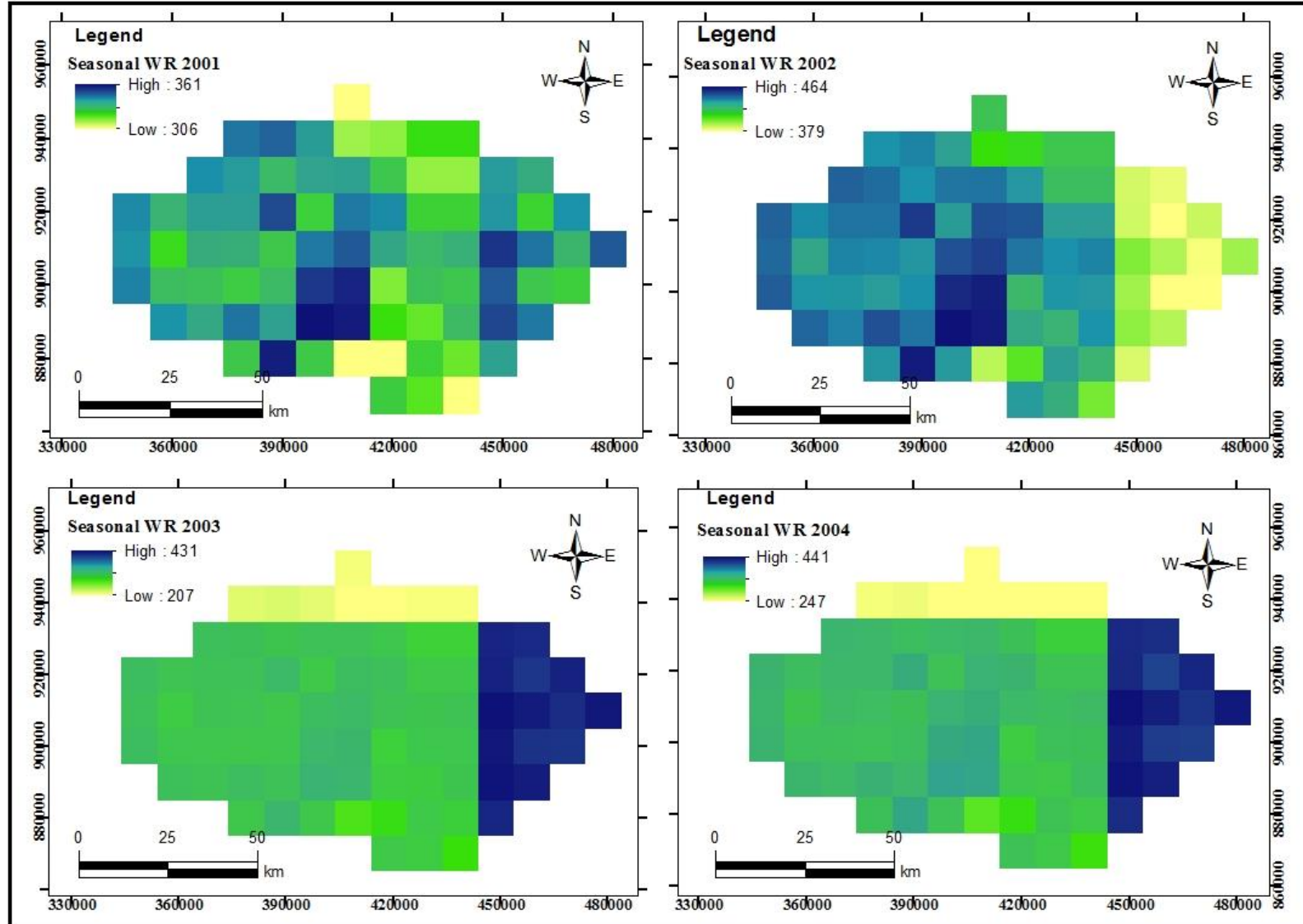


Figure 16 Spatial patterns WR (mm) estimated for the main cropping season (2001-2004)

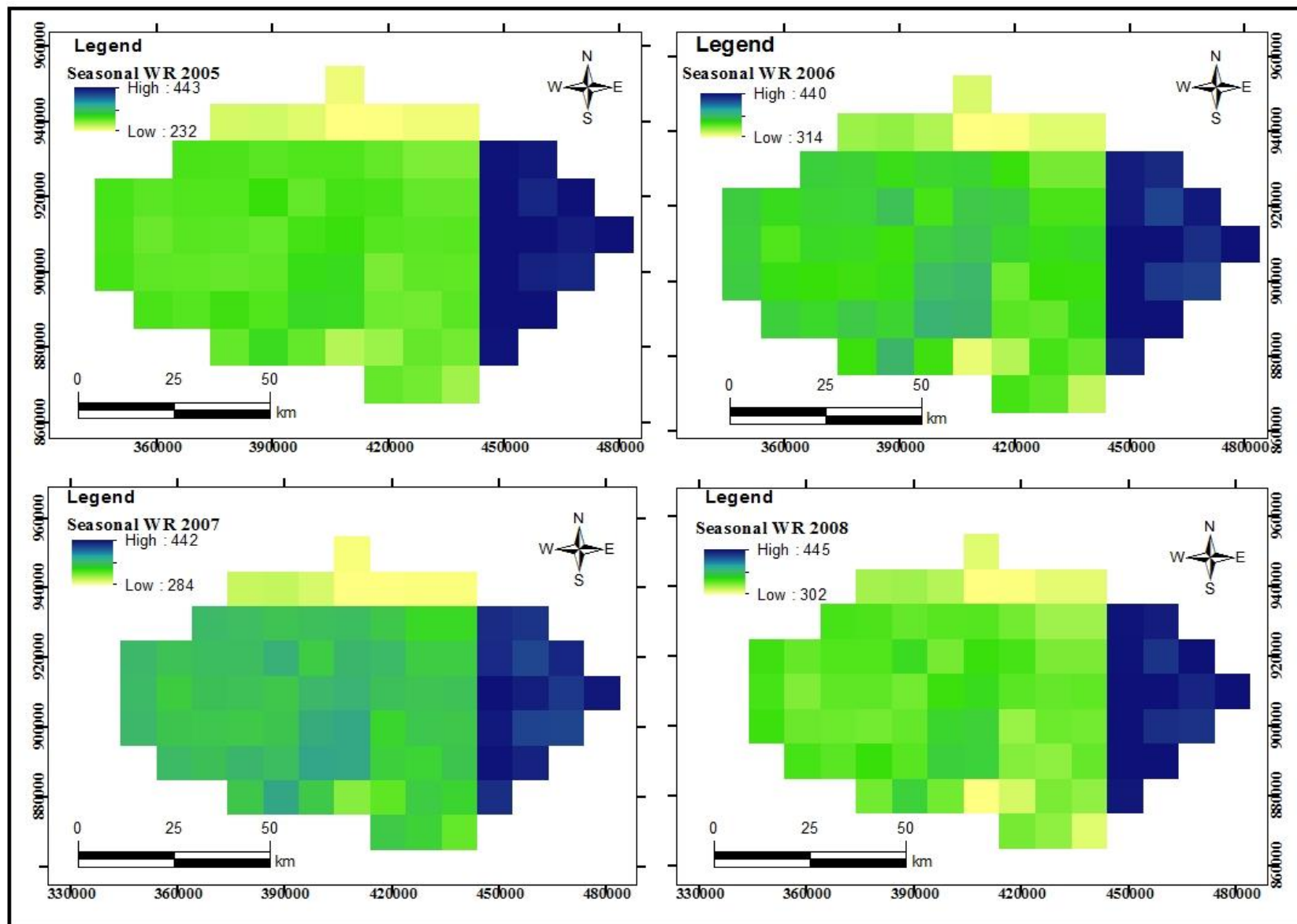


Figure 17 Spatial patterns WR (mm) estimated for the main cropping season of 2005 -2008

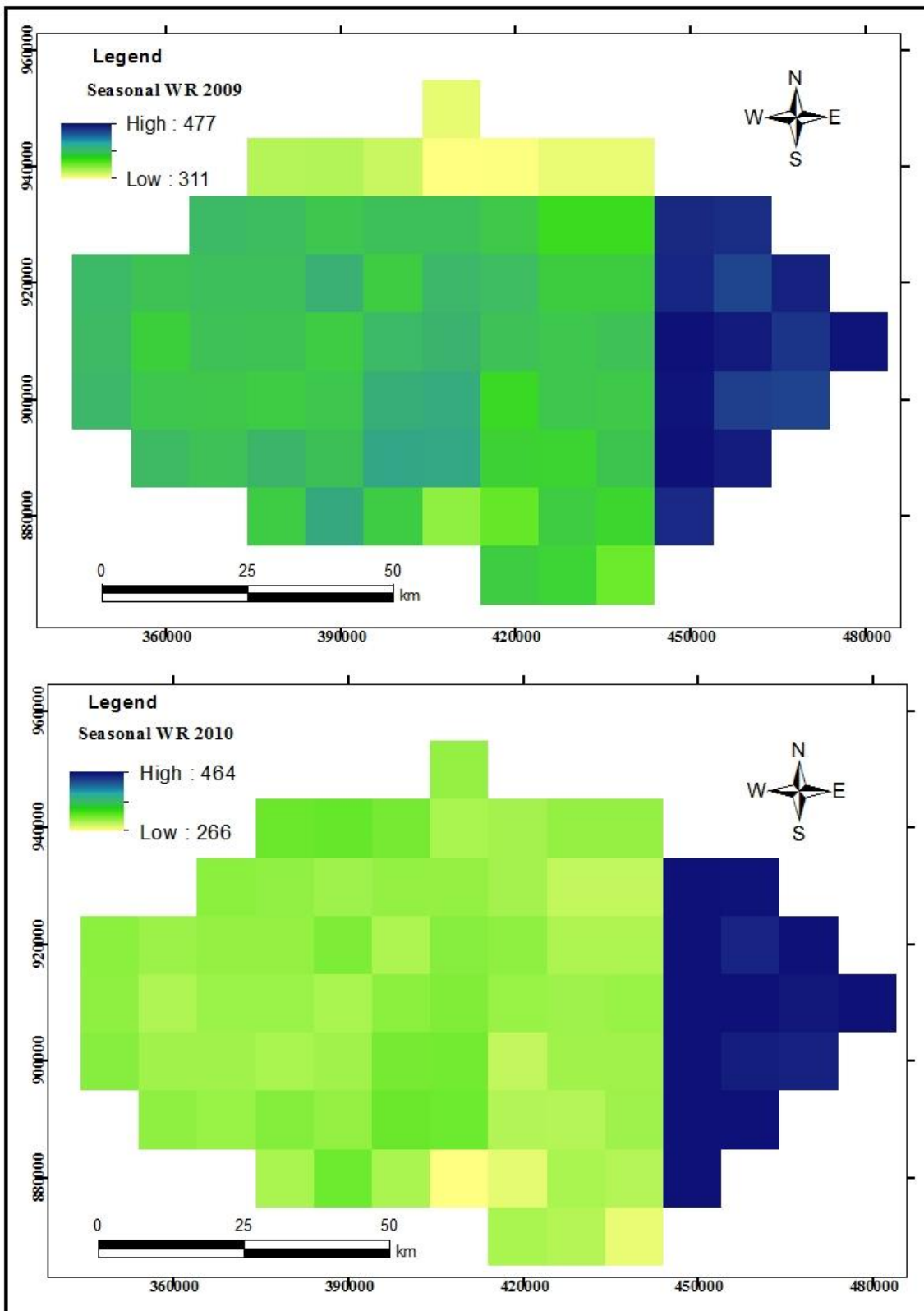


Figure 18 Spatial patterns WR (mm) estimated for the main cropping season of 2009 -2010

### 4.3. Seasonal Actual Evapotranspiration and Water Requirement

Seasonal water use and water requirement of the study area was estimated separately. Compared the analysis these two results (WR and Water use) were identified moisture deficit and wet season during the period study conducted figure 19.

The graphical representation has shown that the cropping season of 2002, 2004, 2008 and 2009, water requirements and water use graph apart each other which mean there was water deficit during these years because during these years the area utilize water less than the area water requirement. While ETa/water use and WR of cropping seasons 2005, 2006, 2007 and 2010 close each other or almost in the same line, this implies that there is no moisture deficit during these years. The remaining years 2001 and 2003 were found in between the moisture deficit and wet cropping seasons.

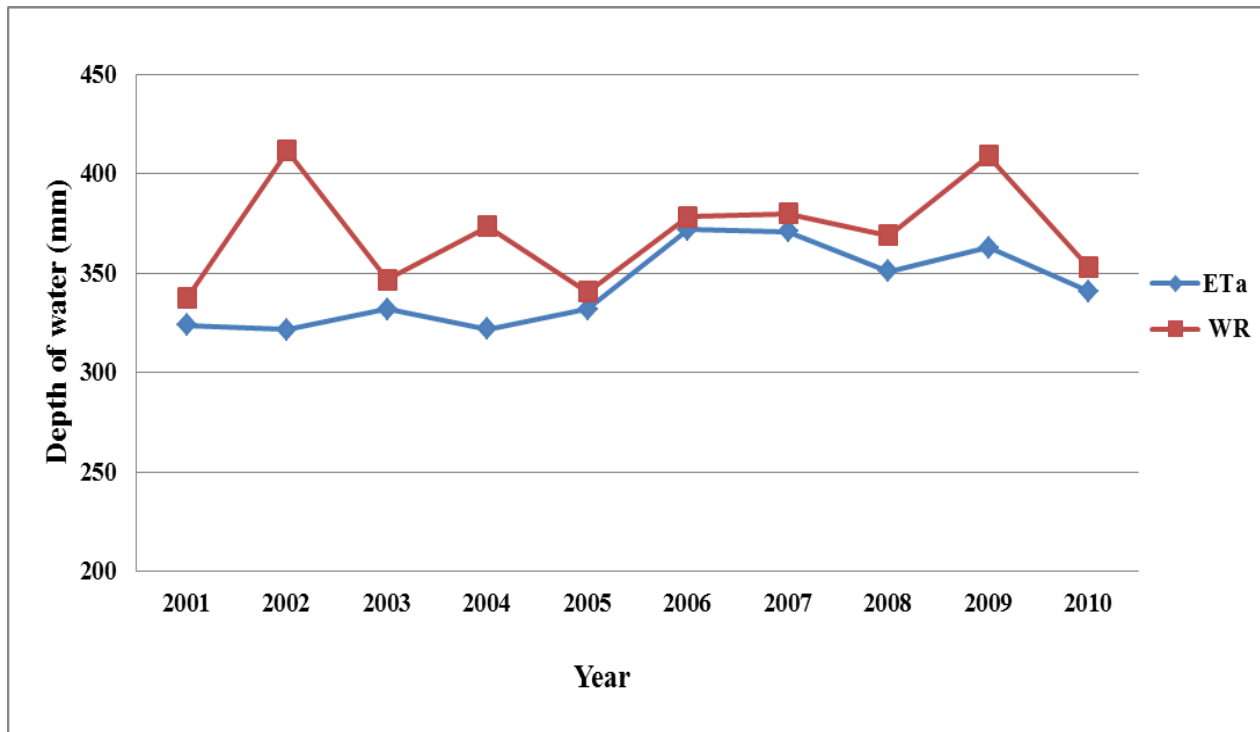


Figure 19 comparison of seasonal WR and Water use of cropping season of 2001 – 2010

## **4.4.Crop Performance Indicator**

### **4.4.1. Water requirement satisfaction index (WRSI)**

Seasonal WRSI in the study area has been estimated for the analysis period. Technically it was calculated using eq. (8) it is, the ratio of seasonal actual evapotranspiration (ETa) to the seasonal water requirement (WR).

Moisture is one of climatic variables that determine the production of crops and shows the occurrence of drought. Accordingly, the performance crops during the growing period were analyzed by using WRSI index. The result revealed that less WRSI values in the study area showing moisture deficit during the years 2002 in which 2.5 % of the total area under severe drought and 13.75 % and 10 % was under moderate and slight drought respectively followed by 2004 in which 6.25% under moderate drought and 16.25% was under slight drought. Whereas during the seasons 2008 and 2009 were 2.5 % and 3.75 % under moderate drought and 8.75% and 7.5% under slight drought respectively. Its spatial distribution dissipated in figure 20, 21 and 22.

During 2005, 2006, 2007 and 2010 cropping season unlike the moisture deficit season (2002, 2004, 2008 and 2009) WRSI is greater than 80. This implies that during 2002, 2004, 2008 and 2009 cropping seasons the area was under moisture deficit (drought seasons) and consequently crop yield reduction occurred in the area. On the other hand, 2005, 2006, 2007 and 2010 cropping seasons were free of moisture deficit and there were no crop yield reduction reported in the area like during moisture deficit years. In addition to these, the drought severity of 2001, and 2003 cropping seasons were found in between moisture deficit and wet seasons. Their large areas are found in no drought.

In general as similarly study indicated by 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. Therefore in the study area there was no very severe agricultural drought class revealing that less than 50 percent of crop requirement was not satisfied.

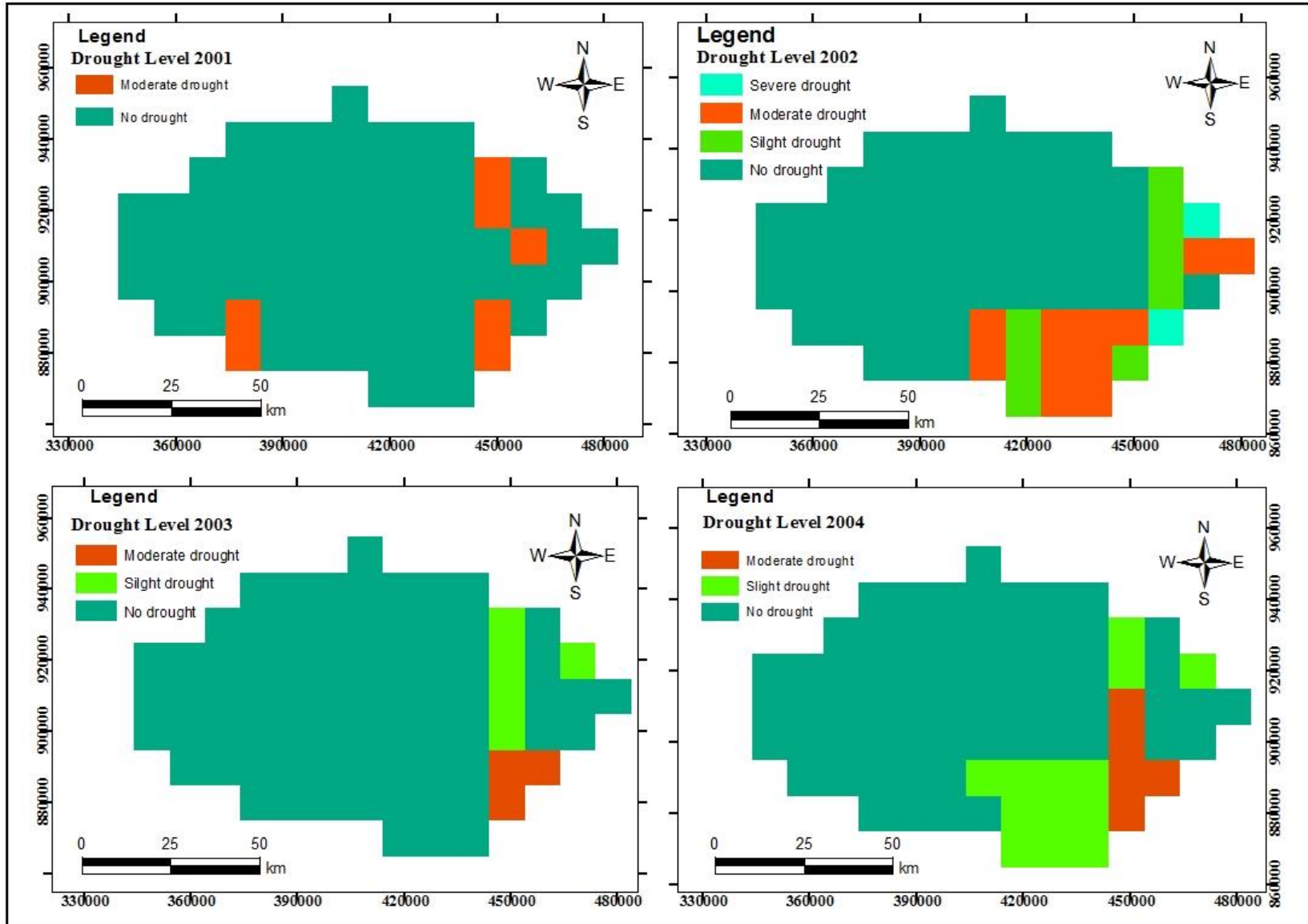


Figure 20 Spatial pattern of agricultural drought severity for the cropping season (2001-2004)

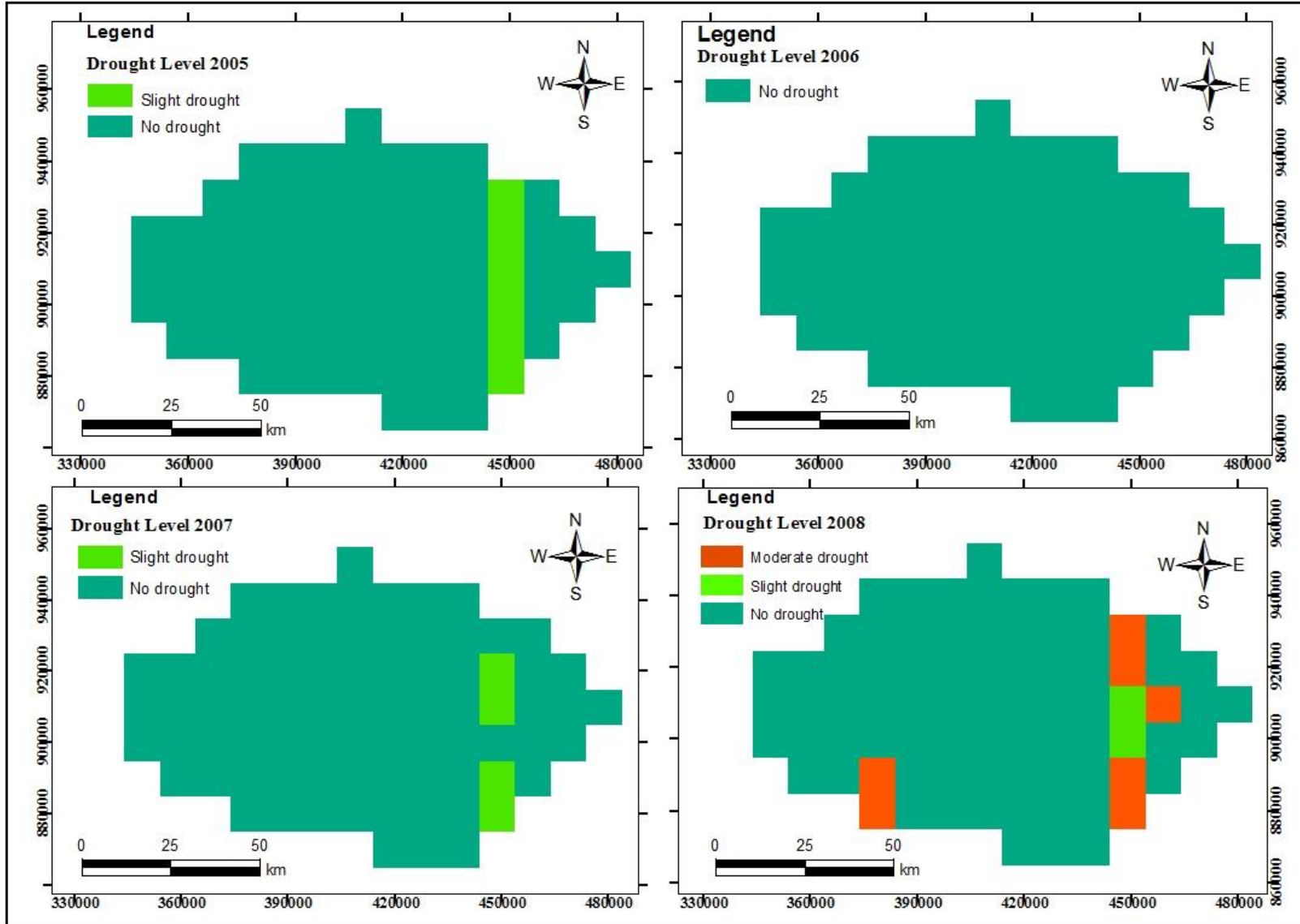


Figure 21 Spatial pattern of agricultural drought severity for the cropping season (2005-2008)

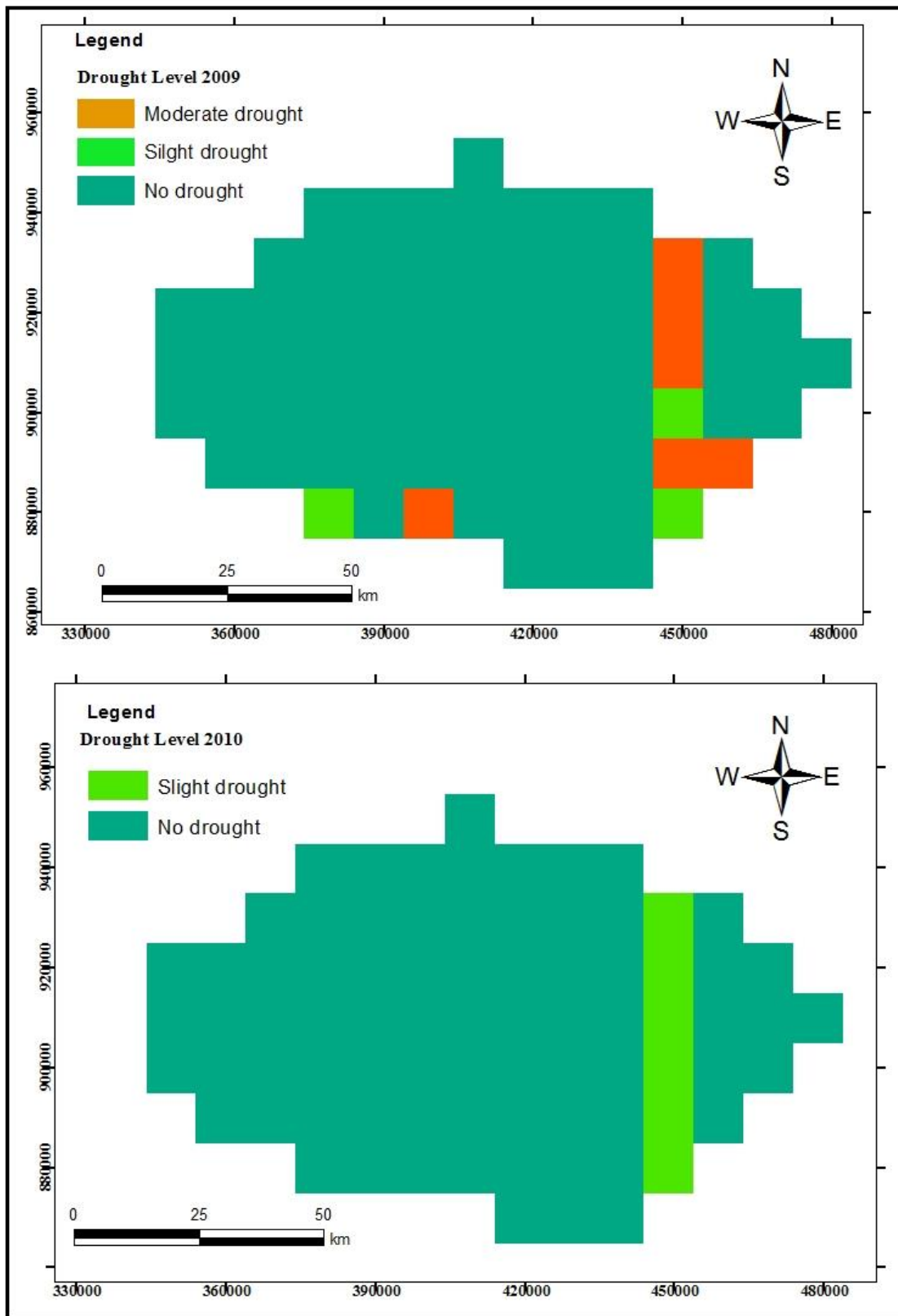


Figure 22 Spatial pattern of agricultural drought severity for the cropping season (2009-2010)

#### 4.4.2. Water requirement satisfaction index and crop yield

The average satellite based WRSI and grain yield collected from central statistics for the period of ten years (2001–2010) except unavailable of grain data for the years of 2001, 2002 and 2009 was collected to see their correlation based on a simple regression analysis. The grain yield collected based on average quintals per hectare for the respective zones and WRSI was averaged based on zonal administrative boundary to represent the entirely zone and their result were correlated with the dominant crops of the study area such as: Teff, maize and wheat and their correlation result indicated in figure 23.

The correlation result indicates that the linear regression coefficients for Teff, Maize and Wheat are 0.82, 0.77 and 0.48 respectively. From this correlation coefficient, teef yield highly correlated with WRSI and wheat less correlated, this implies teef yield is the most sensitive and wheat the least sensitive to moisture deficit crop among the three major crops.

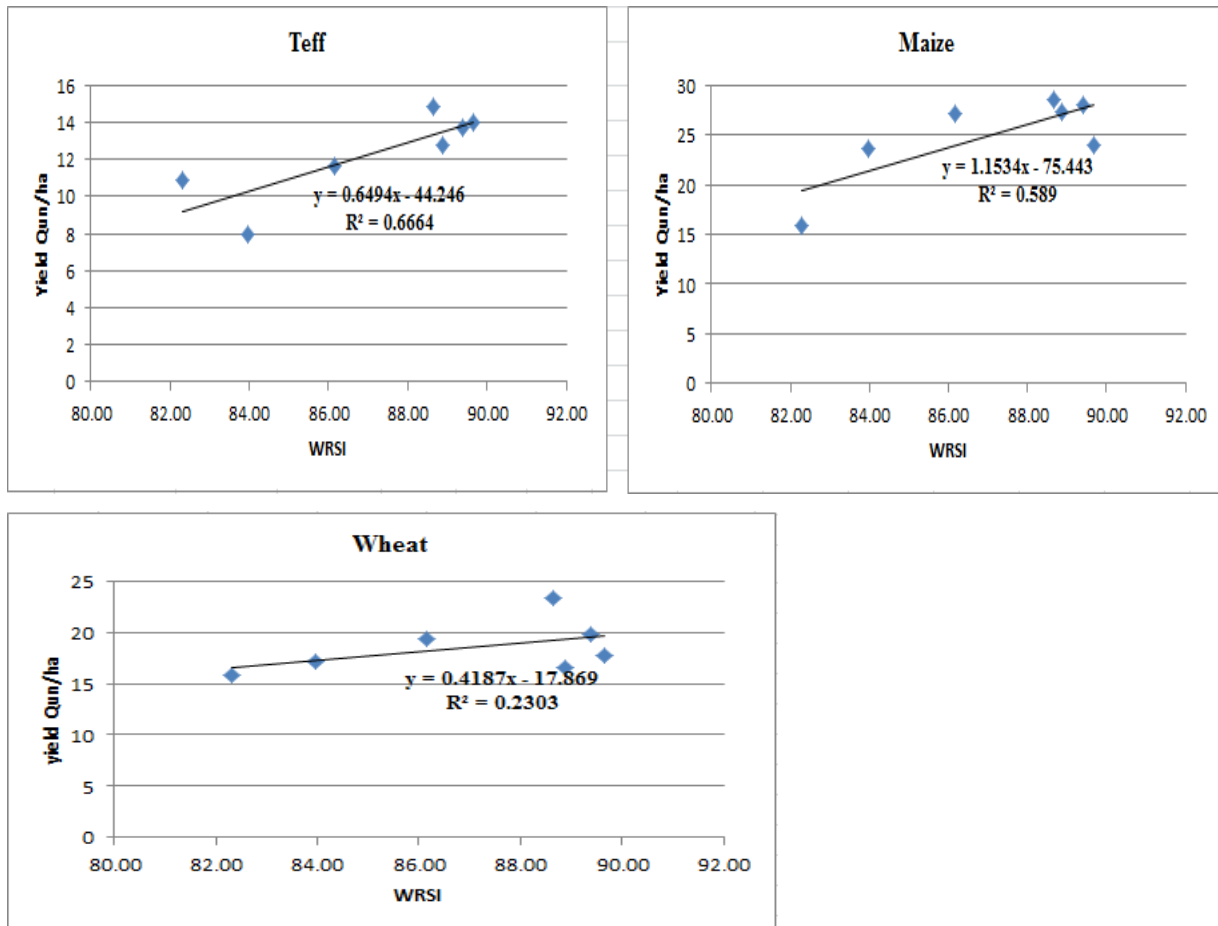


Figure 23 Relationship of WRSI and grain yield

#### **4.4.3. Yield reduction due to moisture deficit**

Rain-fed agricultural crops subjected to yield reduction due to moisture deficit. Thus, moisture deficit significantly influence the growth and development of crops through the reduction of various yield components of a crop and ultimately yields. From water requirement and water use analysis those cropping season has moisture deficit and those wet season was identified.

Among the years of study conducted, 60 % yield reduction occurred in 2002 has area coverage 11.25% and 40% percent yield reduction occurred in 2002, 2004, 2008 and 2009 having area coverage of 15 %, 26.25 %, 16.25% and 13.75% of total area respectively. Even though, yield reduction varies in area coverage and severity among seasons but the year 2002 was the highest yield reduction among the seasons/years study conducted in which 60% yield reduction occurred followed by 2004, 2008 and 2009. This implies that season 2002 moisture deficit year. The result spatially depicted in the Figure 24, 25 and 26 below.

Large area yield reduction occurred in the study area 0 -10 percent have an area coverage around 70 % of total area coverage during wet and medium moisture deficit years and also have around 50% area coverage of the total area during moisture deficit years. Therefore in the area except in the year of 2002 (60% yield reduction occurred) there was no severe yield reduction.

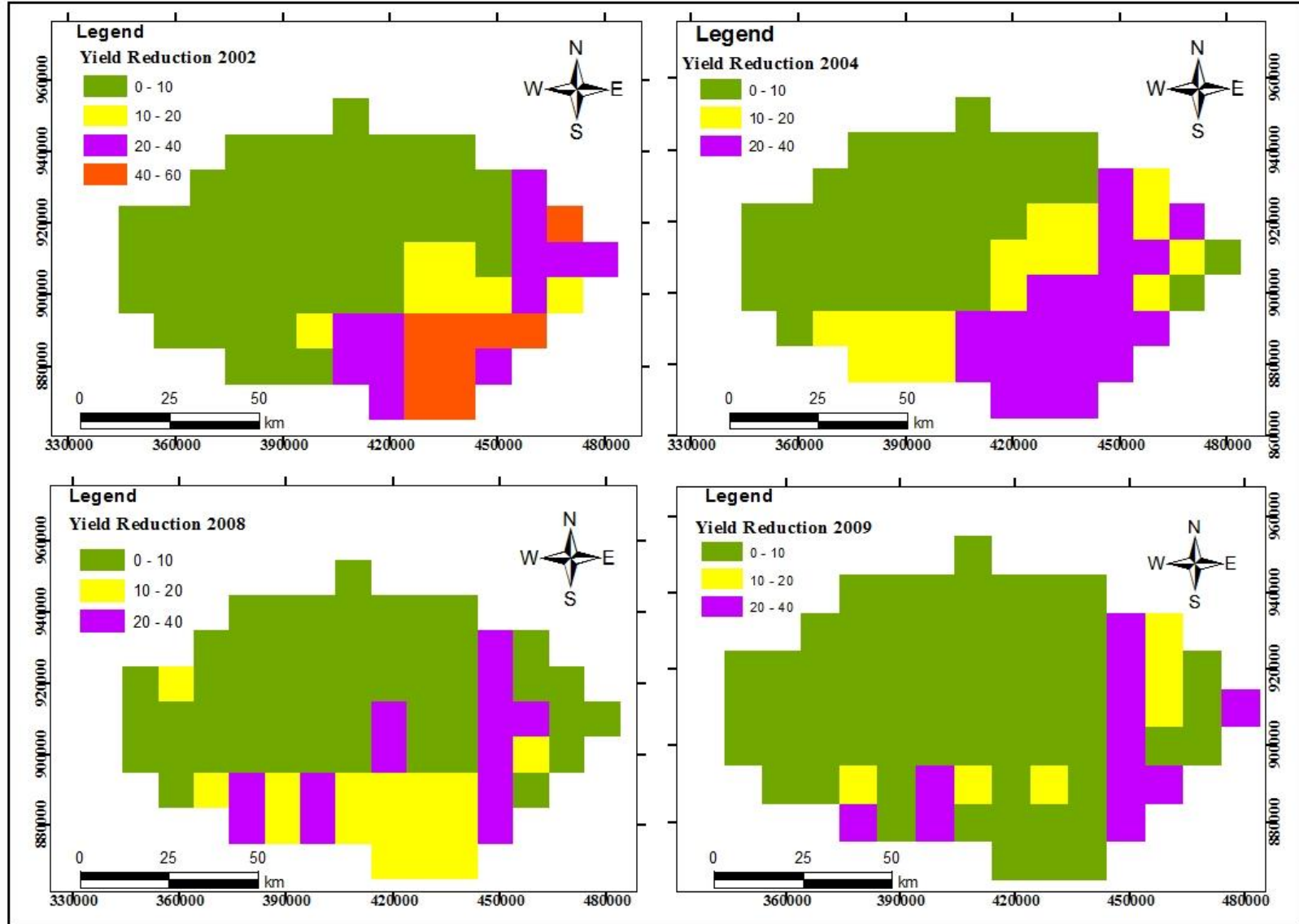


Figure 24 spatial pattern of yield reduction during cropping season 2002, 2004, 2008 and 2009

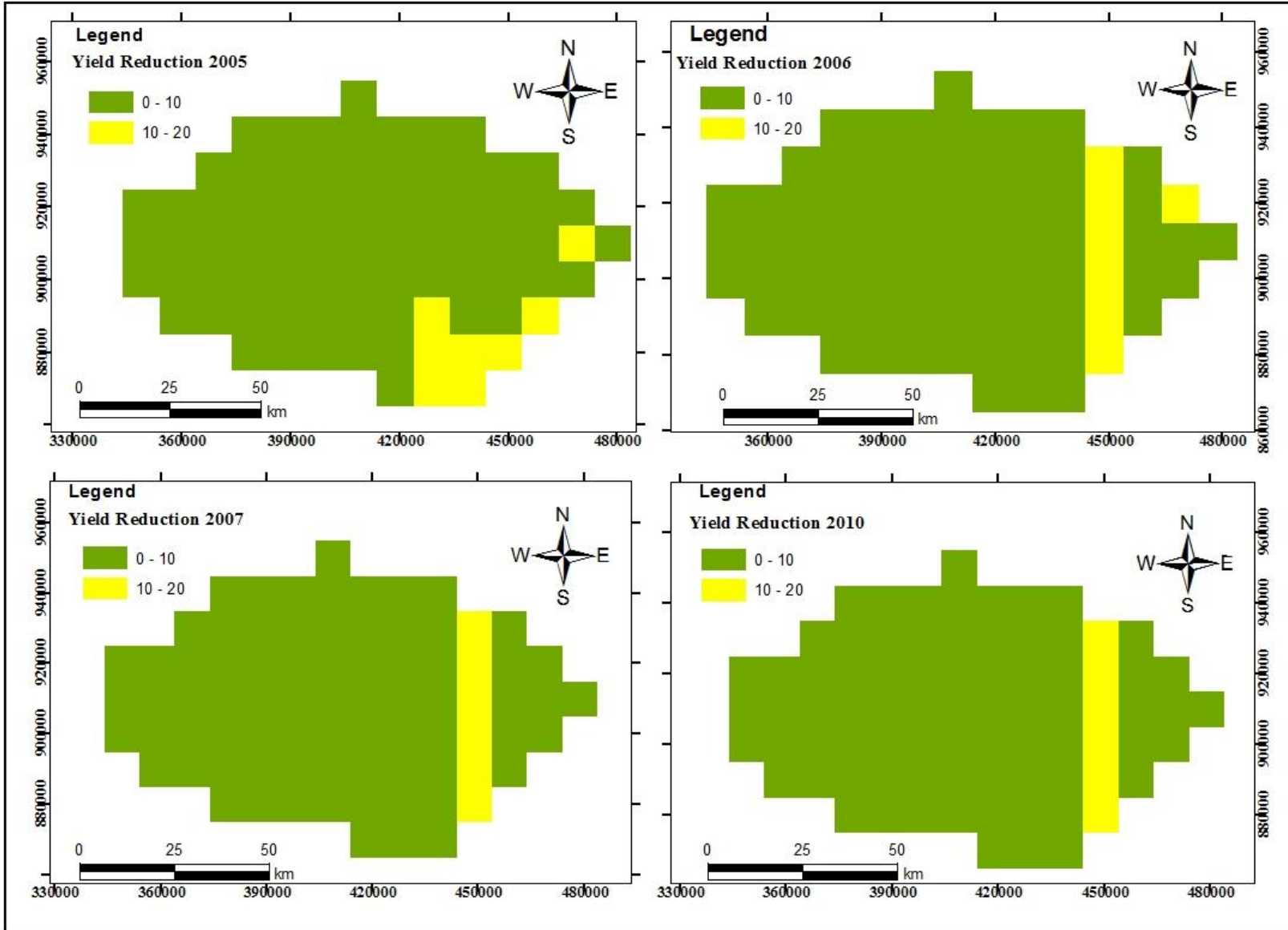


Figure 25 spatial pattern of yield reduction during cropping season 2005, 2006, 2007 and 2010

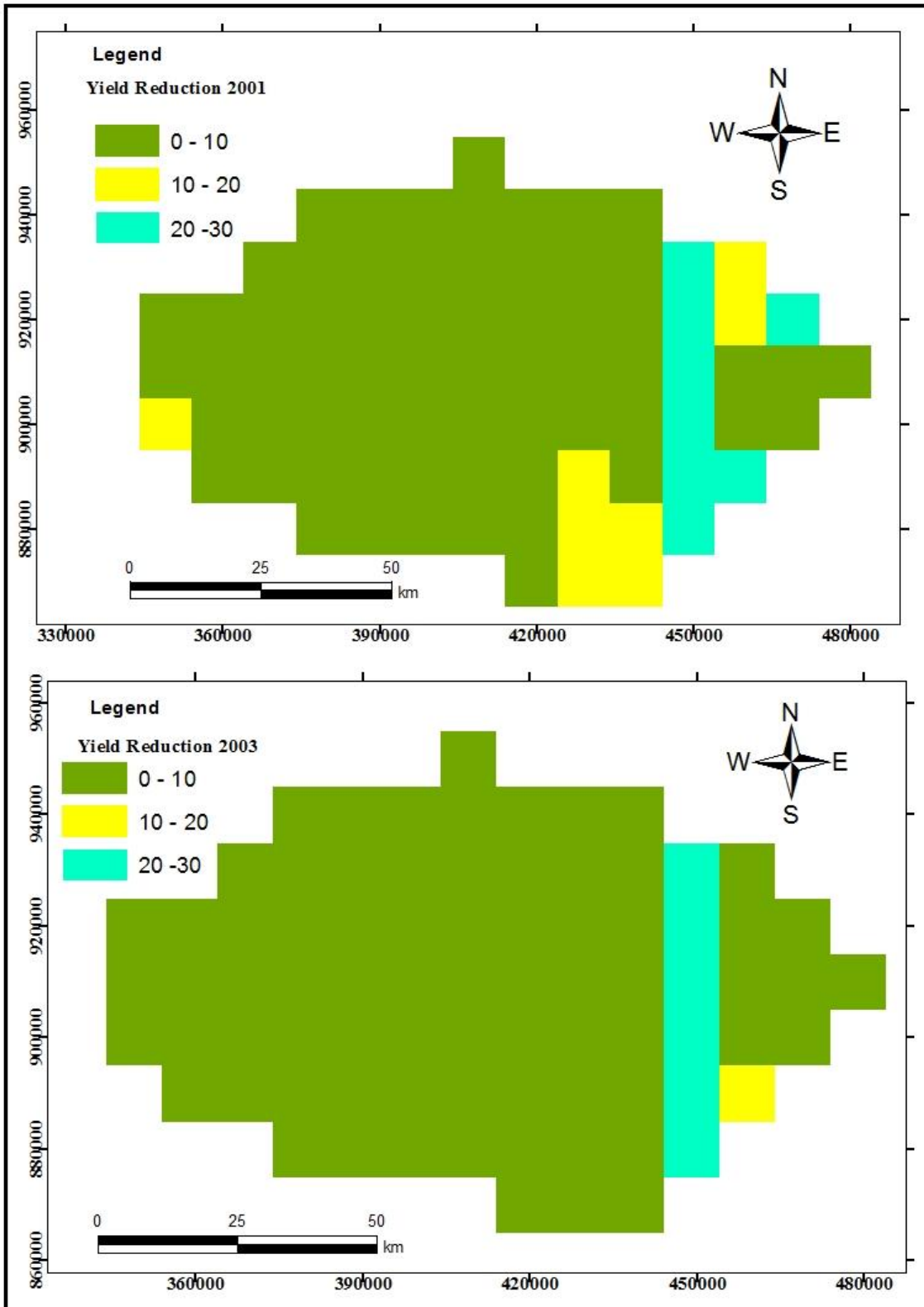


Figure 26 spatial pattern of yield reduction during cropping season 2001 and 2003

#### **4.4.4. Relation between WRSI and yield reduction**

In a rain-fed based cropping system, seasonal water use variability is inevitably reflected in variable agricultural production and /or yield. WRSI and yield reduction of the study area were analyzed during the main cropping season separately and the relation between them is depicted in Figure 27. From the figure 27 shows that the WRSI values and the corresponding yield reduction of crops have followed an inverse relation. Compared to other cropping seasons of the analysis period of 2001 - 2010, the highest yield reduction occurred during 2002, 40 % and the corresponding WRSI was 65.44 %. The statistical correlation, an encouraging R- squared value (0.74) was obtained.

The average WRSI and yield reduction has shown that the change in yield is to be more sensitive than the change in WRSI values Figure 27. For instance, the WRSI change from 2001 to 2002 is about 12 % reduction; however, the corresponding reduction in yield was 24 %. A similar study on sorghum yield indicated by Girma Mamo (2005) keeping the other inputs at the best level and changing only WRSI from 100% to 75%, resulted in 49.7 % in the case of Miesso, 40.8% for Melkassa and 24.3% in the case of Arsi Negele. While changing WRSI are further down to 50%, resulted in total crop failure at Miesso and Melkassa, while it resulted in 52.8% yield reduction at Arsi Negele.

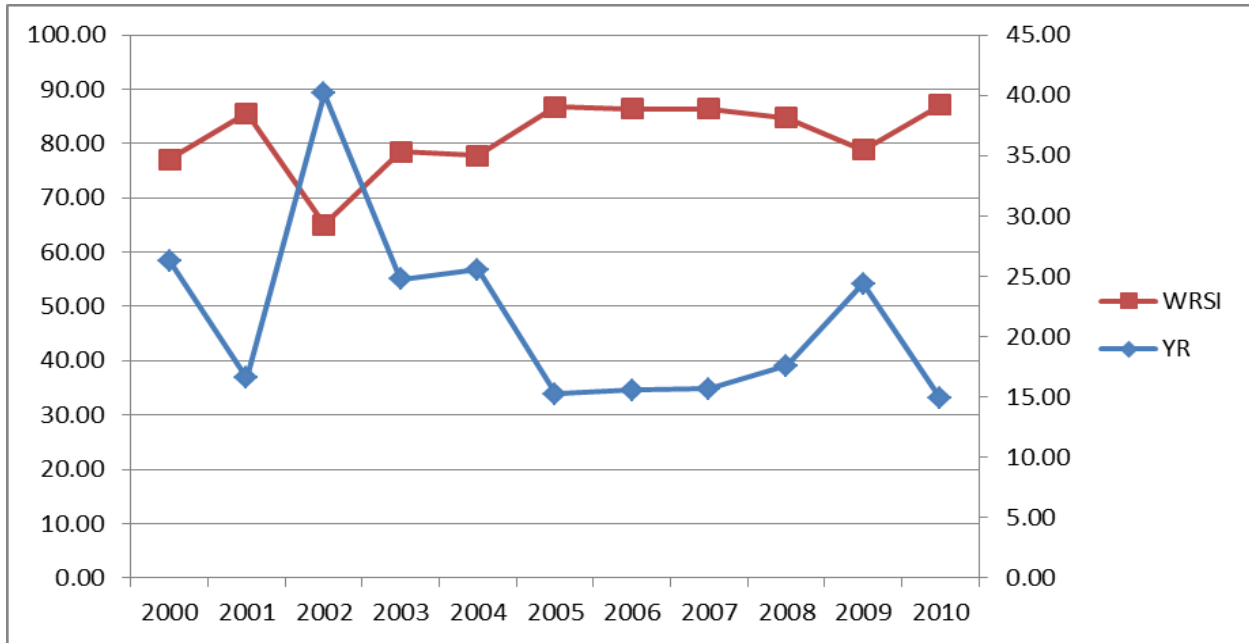


Figure 27 Temporal trends of seasonal WRSI and yield reduction (2001-2010).

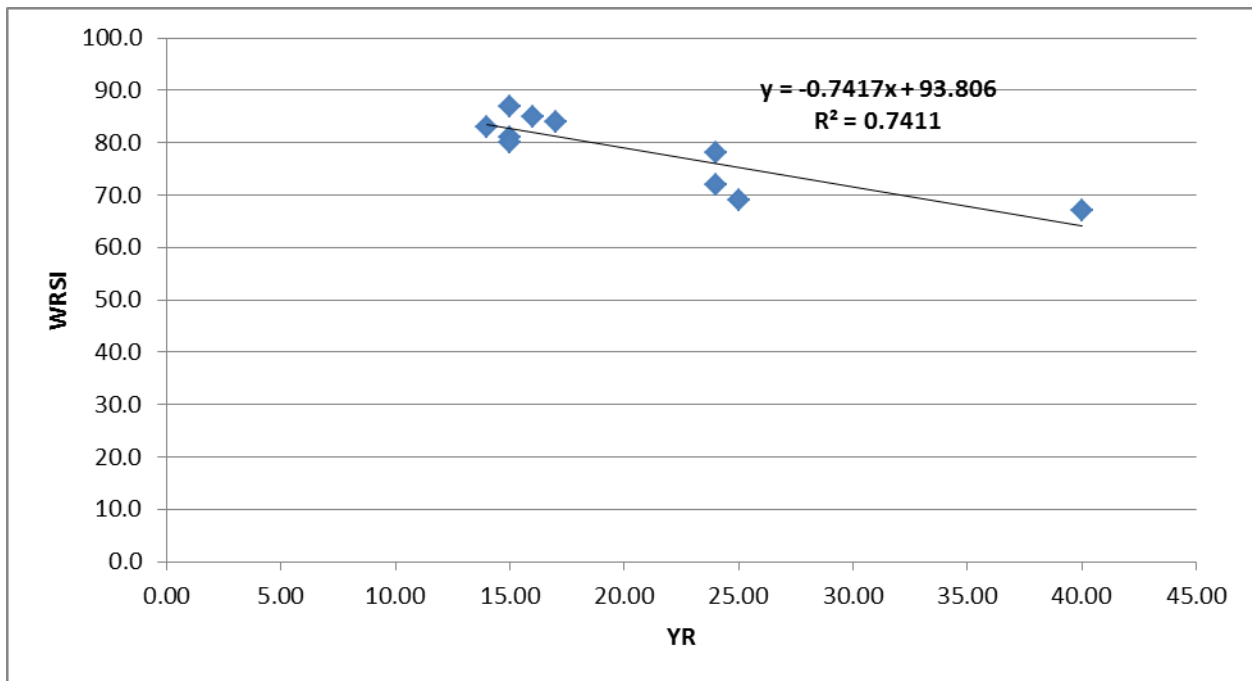


Figure 28 Correlation between yield reduction and WRSI

## 5. CONCLUSION AND RECOMMENDATION

### 5.1. Conclusion

Crop production is affected by drought due to moisture deficit and erratic rainfall characteristics as well as seasonal variability in cropping calendar, which is directly reflected by crop water use. In order to adjust the variability in cropping calendar and moisture deficit, knowing or estimation of ETa seasonal will be crucial. The study was conducted with the objective of estimation of Seasonal actual evaporation using VegET model for rainfed agriculture; and to assess yield reduction due to moisture deficit in the meki-wabe catchment. In addition, the objective of the study is to estimate water requirement the area using GIS and Remote Sensing.

Seasonal actual evapotranspiration/crop/vegetation water use was estimated by using VegET model which based water balance algorithm, used global available decadal ETo, crop based phenology and RFE for period of 2001 to 2010 during main cropping season (June to September). The results revealed that highest and lowest estimated seasonal water use in the area was 372mm and 322mm which found during of 2006 and 2002 respectively. Concerned the spatial distribution of crop/vegetation water use partly meki catchment shows relatively higher water use than the adjacent area.

The study area were experienced an average highest and lowest estimated seasonal water requirement was 412mm and 341 mm which are found during the year of 2002 and 2005 respectively. Seasons of 2002, 2004, 2008 and 2009 were deviated apart each other on the temporal pattern representation of water requirement and use graph, which implies these years are moisture deficit years. Because the area utilized less water than it required and seasons of 2005, 2006, 2007 and 2010 are moisture deficit free/wet seasons because their temporal pattern of representation of water use and requirement are close each other.

The result of WRSI revealed that less WRSI values in the study area showing during the moisture deficit years 2002 in which 2.5 % of the total area under severe drought and 13.75 % and 10 % was porn to moderate and slight drought respectively and followed by 2004 in which

6.25% under moderate drought and 16.25% was under slight drought. Whereas during the season 2008 and 2009 were 2.5 % and 3.75 % under moderate drought, 8.75% and 7.5% under slight drought respectively. And also the study confirmed that seasonal water requirement satisfaction index (WRSI) and grain yield (Qun/hect) patterns of the entire study area have good correlation ( $r=0.82$  for Teff and  $r=0.48$  for wheat) and 67 Teff and 23 of wheat percent of yield variability can be explained by seasonal WRSI.

Rain-fed agricultural crops subjected to yield reduction due to moisture deficit and 60 % yield reduction occurred in 2002 has area coverage 11.25 percent and 40% percent yield reduction occurred in 2002, 2004, 2008 and 2009 having area coverage of 15%, 26.25%, 16.25% and 13.75 of total area respectively. Large area of yield reduction occurred in the study area 0 -10 percent has an area coverage around 70 % in wet and medium moisture deficit years of total area coverage and also during moisture deficit years (2002, 2004, 2008 and 2009) have an area coverage around 50 % of the total area. Therefore, in the area except small area during 2002 there was no severe yield reduction. The WRSI and yield reduction of the study area shows a negative correlation coefficient of  $r=0.74$

In general VegET model is capable of estimating actual ET from a pixel up to regional level with certain accuracy and ability to identify moisture deficit years in respective to yield reduction and also estimating seasonal water requirement of the area.

## **5.2. Recommendation**

Based on the study conducted, the following recommendation are forwarded

- In the entire catchment there was yield reduction due to moisture deficit but it is difficult to quantify the amount of yield reduction due to water factor even if WRSI is good indicator for yield reduction due to moisture deficit. Therefore, there should be further research in the area to be conducted to identify non-water factors.
- Since seasonal Water requirement varies spatially in the entire catchment and among zones in the study area, selection of agricultural technologies and information (moisture deficit tolerance crops, the type of crop variety and soil moisture conservation practices) should be made to fit in to the seasonal water requirement of the area.
- To get more accurate of ETa estimation there should be ground measurement of these global available data sets for their validation of the model.

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## APPENDICES

### Appendix 1 Partial View of the Study Area



## Appendix 2 Land Use Land Cover Control Ponto

Land_Use	X_Coord	Y_Coord
Cultivated Land	345604	892759
Cultivated Land	345621	894908
Cultivated Land	346040	895091
Cultivated Land	347944	895087
Cultivated Land	348189	893161
Bare Land	352233	905953
Bare Land	352331	907646
Cultivated Land	361685	917003
Cultivated Land	363010	914107
Cultivated Land	363810	916941
Cultivated Land	364803	914893
Cultivated Land	365976	925294
Cultivated Land	366424	913658
Cultivated Land	366431	916472
Forest	367082	911001
Cultivated Land	370643	919320
Cultivated Land	373459	915438
Bare Land	374875	894980
Bare Land	376096	894945
Forest	378103	913860
Cultivated Land	379879	940825
Cultivated Land	381876	942707
Cultivated Land	382000	940888
Shrubs_ Bush_Grass	383967	931358
Shrubs_ Bush_Grass	384388	882400
Shrubs_ Bush_Grass	384388	880089
Shrubs_ Bush_Grass	387749	877357
Settlement	387990	943767

Shrubs_ Bush_Grass	390691	941654
Forest	392564	920971
Shrubs_ Bush_Grass	393002	940813
Forest	395617	948306
Forest	395759	920377
Forest	397248	920412
Bare Land	397479	911360
Forest	397481	921996
Bare Land	397972	907887
Forest	398060	946694
Forest	398060	946694
Forest	398060	946694
Forest	398060	946694
Shrubs_ Bush_Grass	398466	883451
Shrubs_ Bush_Grass	398923	905518
Forest	402535	928505
Forest	402794	926043
Forest	403155	927541
Forest	403345	925922
Shrubs_ Bush_Grass	404690	901525
Shrubs_ Bush_Grass	404769	888914
Forest	405153	925828
Bare Land	406698	922949
Bare Land	407538	926320
Cultivated Land	409760	945244
Shrubs_ Bush_Grass	409821	894224
Cultivated Land	409856	943799
Shrubs_ Bush_Grass	411493	911817
Cultivated Land	412490	944871
Cultivated Land	414501	875574
Cultivated Land	416641	872182

Shrubs_ Bush_Grass	417166	886182
Settlement	417959	935273
Cultivated Land	418180	939909
Cultivated Land	418903	873337
Cultivated Land	419012	876571
Cultivated Land	419890	938819
Shrubs_ Bush_Grass	420318	908035
Cultivated Land	423361	940264
Cultivated Land	423526	937654
Shrubs_ Bush_Grass	424100	906774
Forest	424537	866920
Forest	425563	868197
Cultivated Land	426959	896105
Cultivated Land	427978	879739
Forest	428055	866019
Cultivated Land	428509	900133
Shrubs_ Bush_Grass	428723	914128
Forest	428844	867296
Cultivated Land	430051	889014
Cultivated Land	430357	879271
Bare Land	431040	933797
Cultivated Land	431230	889699
Settlement	432052	897865
Shrubs_ Bush_Grass	432085	929677
Cultivated Land	432105	888922
Cultivated Land	432209	899762
Bare Land	432324	935565
Bare Land	432905	933675
Cultivated Land	433466	900178
Cultivated Land	434175	896282
Forest	435008	928075

Forest	435387	927627
Forest	435516	926301
Cultivated Land	436888	879388
Shrubs_ Bush_Grass	439018	934089
Settlement	441989	890528
Forest	443277	895998
Cultivated Land	445672	892331
Cultivated Land	446497	884024
Settlement	448847	885142
Cultivated Land	453893	888943
Cultivated Land	454830	902010
Cultivated Land	456480	901822
Cultivated Land	456816	890766
Cultivated Land	458261	883216
Shrubs_ Bush_Grass	458349	897739
Forest	462178	906423
Cultivated Land	462812	914067
Cultivated Land	464451	916735
Forest	465854	923585
Forest	465927	924394
Forest	466002	894912
Cultivated Land	467035	910466
Forest	467471	909319
Forest	470566	905352
Cultivated Land	470613	912643
Shrubs_ Bush_Grass	473478	899630
Forest	475507	906881
Settlement	479813	901293
Cultivated Land	482507	903773
Cultivated Land	483593	902004
Cultivated Land	485158	901810

## **DECLARATION**

I hereby declare that the thesis entitled “Estimation of Actual Evapotranspiration for Rain-fed Agriculture Using VegET Model in the Meki-Wabe Catchment, Central – Ethiopia” has been carried out by me under the supervision of Prof. Tenalem Ayenew, Department of Earth Sciences, Addis Ababa University, Addis Ababa during the year 2013 as a part of Master of Science program in GIS and Remote Sensing. I further declare that this work has not been submitted to any other University or Institution for the award of any degree or diploma.

**Teshome Leta**

Signature: \_\_\_\_\_

Addis Ababa University

Addis Ababa

Date: June, 2013