GIS Based Multicreatrea Analysis for Identification of Suitable Irrigable Land in Gilgel Abay River, Lake Tana Sub Basin, Amhara Region

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Adama

DECLARATION

I hereby declare that this MSc Thesis is my original work and has not been presented for a degree in any other university, and all sources of material used for this thesis have been duly acknowledged.

Name:____

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This MSc Thesis has been submitted for examination with my approval as thesis advisor.

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APPROVAL OF BOARD OF EXAMINERS

We, the undersigned, members of the Board of Examiners of the final open defense by Fentahun Bezie Erkie have read and evaluated his thesis entitled “GIS Based Multicreatrea Analysis for Identification of Suitable Irrigable Land in Gilgel Abay River, Lake Tana Sub Basin, Amhara Region” and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirement of the Degree of Masters of Science in Geodesy and Geomatics Engineering.

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LIST OF ACRONYMS

AHP	Analytical Hierarchical Process
ANRS	Amhara National Regional State
CSA	Central Statistics Agency
CWR	Crop water requirement
DEM	Digital Elevation Model
FAO	Food and Agriculture Organization
GIS	Geographic Information System
HVA	Handels Vereeniging Amsterdam
IFPRI	International food policy research institute
IWS	Irrigation Water Scheduling
MCDM	Multi criteria Decision Making
MCE	Multi Criteria Evaluation
MoWE	Ministry of water and Energy
NASA	National Aeronautics and Space Administration
OLI	Operational Land Imager
NMSA	National Metrological Service Agency
PWC	Pair Wise Comparison
UNCED	United Nation Conference on Environment and Development
USGS	United states Geological Survey
WLC	weighted Linear Combination
WLC	Weighted Linear Combination
WSDP	Water Sector Development Programme

LIST OF ABBREVIATIONS

mm	Millimeter
Km	Kilometer
Ha	Hectare
Cm	Centimeter
m3	Meter cube
Mha	Million hectare
mm/dec	Millimeter per decade
mm/day	Millimeter per day
ET	Evapotranspiration
ETo	Reference crop evapotranspiration
ETc	crop evapotranspiration under standard conditions
ETc adj	crop evapotranspiration under non-standard conditions

ABSTRACT

The study aimed at GIS based Multicritrea analysis of land for suitable irrigation in Gilgel Abay, Tana sub basin, Ethiopia which used to identify suitable irrigable land and to estimate crop water requirement and Schedule of Maize and Tomato in Bahir Dar and Dangila. The analysis of land considers land use, soil type, slope, drainage density, soil depth, proximity (distance), rainfall and temperature as factors to identify and prioritize its suitability for irrigation.

Lack of detailed study that showed the potential of irrigable land in Gilgel Abay did not trigger private investors in the area of irrigation, poor know how of irrigation significance by the communities, reduces the initiation local administrators for irrigation and in general reduced management and practice of tradition irrigation(Dillip, R. Khairnar, M, etal 2015).

The main factors considered to identify potentially suitable irrigable land were the soil type, land use, slope, drainage density, soil depth, proximity (distance), rainfall and temperature with their weight 41%, 25%, 14%, 9%, 5%, 3%, 2%, & 1 % respectively. The map of parameters was prepared and reclassified using ArcGIS 10.3 and ERDAS IMAGINE 2014 software.

Weighted overly used to produce Suitable Irrigable Map using spatial analyst of ArcGIS software Very High, High, Moderate, Low and Very Low suitability orders with 14%, 38%, 36%, 10 %, and 2% area coverage of the study area accordingly. The large parts of the study area have a potential of cultivation for irrigation purpose with 52 % of Very High and High classes of suitability.

CWR and Schedule in highly suitable irrigable land for Maize, and Tomato was analyzed using cropwat8 window tool in Bahir Dar & Dangila for vertisol soil types. CWR of Maize in Bahir Dar estimated 482.2 millimeter of water per decade and 176.9 millimeter of water per decade in Dangila. This variation is due to higher temperature, wind speed and solar radiation, dry humidity and low rainfall in Bahir Dar. Similarly, CWR of Tomato in Bahir Dar (180.7 mm/dec) is higher than Dangila (176.9 mm/dec). The result indicates that Maize requires higher amount of water than tomato due to crop characteristics, Kc and growth period variations.

The water discharge (flow) varies in different for Maize and Tomato in Bahir Dar as well as in Dangila. 8.5 l/s/ha water as flow required for Maize in Bahir Dar which is larger in Dangila with 7.14 l/s/ha. Similarly, Tomato needs 4.24 l/s ha and 3.91 l/s ha in Bahir Dar and Dangila respectively. This variation comes as the result of climatic variation in Bahir Dar and Dangila, difference in Kc and characteristics of Maize and Tomato.

Key Words: Irrigation, GIS & MCDM, CWR, Schedule, cropwat 8

CHAPTER 1: INTRODUCTION

1.1 Background of the Study

Irrigation is a vital component of agricultural production in many developing countries. In 1997-99, irrigated land provided two-fifths of crop production in developing countries, and accounted for about one-fifth of the cultivated area. Developing countries are particularly dependent on irrigation: in 1997-99, 59 percent of cereal production in developing countries was irrigated. Food production in developing countries is increasing in response to the demands of an expanding population and rising prosperity. Some of this demand will be met by increased productivity of rain fed agriculture, some by increased imports, but irrigated agriculture will be a major contributor (FAO, 2013).

Irrigation is one means by which agricultural production can be increased to meet the growing food demands in Ethiopia. Increasing food demand can be met in one or a combination of three ways: increasing agricultural yield, increasing the area of arable land, and increasing cropping intensity (number of crops per year) (FAO, 2015).

The solution for food security will be provided by a combination of these factors, enhancing water availability for production and expansion of irrigation that can lead to security by reducing variation in harvest, as well as intensification of cropping by producing more than one crop per year. This should be combined with improved partitioning, storage and soil water-retention capacity to increase plant water availability, and use of rainwater to overcome erratic rainfall especially in the relatively higher rainfall areas of highland Ethiopia. There are also important other ways to reduce risk for farmers (social, economic, spatial diversity) and for the government (trade, buffer, pricing) (Devereux, 2000).

Global estimates indicate that irrigated agriculture produces nearly 40 % of food and agriculture commodities on 17% of agricultural land. At present in Africa, about 12.2 million hectares benefit from irrigation, which is equal to only about 8.5% of the cultivated land. FAO also stated that in sub-Saharan Africa, only about 10% of the agricultural production comes from irrigated land. Trends in irrigated land expansion over the last 30 years show that, on average, irrigation in Africa increased at a rate of 1.2% per year (FAO, 2003).

Reports of World Bank (1973) show the irrigation potential at a lowest of 1.0 and 1.5 million hectares, and a highest of 4.3 million hectares. Awulachew (2007) report that the traditional irrigation schemes alone cover 138,339 ha, and that 48,074 ha are under modern small-scale irrigation, 61,057 ha under modern large- and medium- scale schemes, with the aggregated sum of irrigated agriculture at 247,470. From the latter, it can be seen that small-scale irrigation contributes 75 percent of the irrigation 56 percent from traditional and 19 percent from modern small-scale irrigation. Given the current household level irrigation expansion through traditional schemes and water harvesting, it is assumed that the total sum of actual irrigation development could be over 250,000 ha.

According to Water Sector Development Programme (WSDP) report in 2002, a review of master-plan studies and related river basin surveys shows that the aggregate annual runoff from the 9 river basins amounts to 122 billion m^3. The 3 largest river basins (Abbay, Baro-Akobo, and Omo-Gibe) contribute 76 per cent of the total runoff from a catchment area comprising only 32 per cent of the total area of the country. Abay river basin have a potential of 199 812 Km^2 catchment area and has 52.6 Billion M^3 annual runoff (WSDP, 2002).

Pressure on water resources in the Blue Nile Basin is likely to increase dramatically in the near future as a result of high population growth in all the riparian states, and increasing development-related water needs in Ethiopia and Sudan (Conway, 1997).

GIS is used as a decision making tool for the site suitability analysis and for development activities. Land use suitability mapping and its analysis is one of the most useful applications of GIS. Integration of GIS with Multi criteria evaluation methods reveals its extreme applicability in site

GIS technology is used to formulate different criteria maps which are used to construct the site suitability model (Muema, 2016). Multi criteria analysis is concerned with the allocation of land to suit a specific objective on the basis of a variety of attributes that the selected areas should possess (Carver, 1991).

CROPWAT 8.0 used for the calculation of crop water requirements and irrigation requirements based on soil, climate and crop data. In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns (FAO, 1998).

1.2 Statement of the Problem

Ethiopia endowed with ample Land and water resource; it cannot meet its large food deficit through rain fed production. Growing population pressure in the highland areas of rain fed agriculture on a rapidly declining natural resource base has secured irrigated agriculture a prominent position on the country's development agenda (WSDP, 2002).

The practice of traditional agricultural in the country in general and also in the study area particularly did not increase the production of agricultural raw materials for industries and export by increase yield and crop intensity, develop capacities for planning, implementing, and operating irrigation projects, exploit land and water resources to enhance sustainability of agriculture and rural livelihoods and reduce dependence on rain-fed water sources for agriculture and vulnerability to erratic rainfall patterns (Mintesinot, 2004).

These problems couples with Low capacity of farmers, lack of know-how in, and access to, the opportunities of irrigation technology; weak economic base of most farmers and the relatively high development costs involved in developing irrigation schemes are also the other key constraints (Mekuria,2003). In many parts of the country; the farmers are practicing irrigation without essential know-how on crop water need, water application method and irrigation interval (Berhanu, 2006 and Mekuria, 2003).This is due to lack of good water and management system, which intern leads to less Productivity of the area, increase wastage of water due to lack modern water management (like CWR), poor practice in intensity of cultivation and Rain fed agriculture dependency.

Modern irrigation was started in the early 1950's by the bilateral agreement between the government of Ethiopia and the Dutch company jointly known as HVA-Ethiopia for sugar cane plantation (Gebremedhin and Asfaw, 2015). The literatures showed that large potentials of irrigation from both land and water resource have been estimated in the Basin of Abay(Awulachew, 2007, WSDP, 2002, MoWE, 2014). One of the major tributary for the basin was from Gilgel Abay in which its potential irrigable land were not estimated.

Lack of detailed study that showed the potential of irrigable land in Gilgel Abay did not trigger private investors in the area of irrigation, poor know how of irrigation significance by the communities, reduces the initiation local administrators for irrigation and in general reduced management and practice of tradition irrigation(Dillip, R. Khairnar, M, etal (2015)).

To increate this utilization analyzing of resources using GIS and remote sensing is not practiced. Gilgel Abay River is not still used for irrigation purpose except small traditional irrigation were practiced by farmers near the river and tradition way of water management was practiced.

Multicreatrea decision making using GIS, CWR and Schedule methods used starting from selection of Suitable irrigable land potential, estimation of water quality and availability, types of most productive crops, utilization of water resources, Management of irrigation up to performance evaluation of agricultural irrigation sites.

1.3 Objective of the Study

1.3.1- General objective of the Study

The major objective of study is to analyze and classify suitable irrigable land by using GIS Based Multicreatrea techniques in Gilgel Abay River, Lake Tana Sub Basin, Amhara Region.

1.3.2- Specific objective of the Study

To achieve the major objective, the following specific objective were designed

- To identify Suitable Irrigable land size for irrigation
- To identify the factors that contributes for identification of suitable irrigable land.
- To identify CWR for Maize and Tomato in Bahir Dar and Dangila
- To identify Crop Irrigation schedule for Maize and Tomato in Bahir Dar and Dangila.

1.4 Significance of the Study

GIS Based Multicreatrea Analysis for Identification of Potentially Suitable Irrigable Land is the most important resource to be done for every place in order to make the area more productive, to reduces wastage of water using CWR, increase intensity of cultivation and reduces rain fed agriculture dependency. About 85 % of the Ethiopian people are highly dependent on rain fed agriculture with small amount of land. As a result, production of crops does not much with the growth of population of the country. So potentiality of the land should be studied in order to make the fragmented land more profitable.

The CWR of productive crop analysis used to support sustainable agriculture by identifying the water requirement of crops in different location based on their soil suitability and available climatic condition. This reduces the risks with seasonal and variable rainfall distribution in Ethiopia. Irrigation is used on full season agricultural crops to provide a reliable yield every year. It is also used on crops where water stress affects the quality of the yield.

1.5 Scope and limitation of the Study

This study conducted in Tana sub Basin particularly, in Gilgel Abay River due to time and financial constraints. The thesis will not asses the chemical properties of soil and water quality as they require further testing that needs cost time and multidisciplinary knowledge for collection and testing. The thesis used also FAO crop and soil characteristics which may not be recommended for irrigation water management using CWR and scheduling.

CHAPTER 2: LITERATURE REVIEW

2.1 Benefits of Irrigation

2.1.1- Contribution of Irrigation to Agricultural Productivity

Increased supplies of irrigation water have been instrumental in feeding the populations of developing countries in the last 50 years. Irrigation water has increased food security and improved living standards in many parts of the world. With a rapidly growing world population and a limited food supply, fifty years ago it was common to hear concerns of food shortages and mass starvation. This was particularly true for the populations of developing countries. While malnutrition is still a concern in many countries, the reason is not a lack of a sufficient global food supply. In fact, in the early 1990s, nearly 80% of malnourished children lived in countries that produced food surpluses, evidence that the problem is not one of insufficient supply (FAO,1999). The last 50 years has seen a larger increase in food production than expected, more than enough to match the growth in population. A report by IFPRI shows that between 1967 and 1997, global cereal production increased 84 percent at a time when population increased by 67 percent and that malnutrition among children under the age of five in developing countries declined from an aggregate rate of over 45 percent to 31 percent during this period. India, a historically impoverished country, has not had a major famine since the 1960s. There are a number of reasons for this increase in food production, including high yield varieties of seed and increased use of fertilizers. However, the role of water development in providing irrigation water to cropland has also been significant.

Water projects are generally composed of a system of reservoirs designed for storing water and canals designed for transporting water. Projects that provide water for irrigation have benefited developing countries in many ways. Benefits include the expansion of food supply, stabilization of water supply, the improved welfare of some native populations, and a relative decrease in deforestation of land for agriculture (FAO, 1999).

2.1.2 - Food Supply Expansion

Irrigation and agricultural land expansion. One clear benefit of water projects is an expansion in the feasible land base for agricultural production. Worldwide, cropland under irrigation increased from 94 mha in 1950 to 271 mha in 1986 (Repetto,1986). A region might have high quality soil for growing crops, but if it doesn't receive enough rainfall at the right times of the year, it can’t be used for crop production. For areas that receive rainfall during the wrong season, the development of reservoirs allows water to be stored during the rainy time of the year, and then used for farming during a dry part of the year. For those areas that don’t receive enough water for growing crops, canals allow water to be transported from a water-richarea to an arid area. Irrigation and increased crop yields. There is indisputable evidence that irrigating land leads to increased productivity. Irrigation is a necessary input into the high yield varieties developed during the Green Revolution. One acre of irrigated cropland is worth multiple acres of rain-fed cropland. Globally, 40% of food is produced on irrigated land, which makes up only 17% of the land being cultivated. Dregne and Chou estimate the value of production of irrigated cropland at $625/ha/year ($95/ha/year for rain-fed cropland and $17.50/ha/year for rangelands)(Repetto, 1986).

Irrigation is generally used to produce high-value crops. In Asia, yields from most crops have increased 100-400% after irrigation (FAO, 1996). Irrigation allows farmers to apply water at the most beneficial times for the crop, instead of being subject to the timing of rainfall. One recent study shows this result for crop production data from India. Production data from 1956 through 1987 shows that irrigation affects total factor productivity (TFP) beyond the input value of the water (Repetto, 1986).

Another benefit of reservoirs is that stored water can be used for double cropping of fields. There are many tropical areas that are warm throughout the year, but have seasonal rains for a portion of the year while remaining dry and arid for the other part. The ability to store water during the rainy season for use in the dry season could allow a farmer to move from one annual crop to two or three. One area where this occurs is in the central plain of the main island of the Philippines. This area has a rainy season from mid-June into November, and more than 70% of the total rainfall falls in a 4-month period. The region has two cropping seasons in a year – the first is mainly dependent on rainwater, with irrigation water used to supplement times of drought, while the second, from December to May, is almost entirely dependent on irrigation water (Ferguson, 1992).

2.1.3 - Welfare Improvements

Irrigation and employment: There is evidence in many regions that employment opportunities have increased after the development of irrigation systems. This can occur either because labor is needed for new land brought into production, or for land that is being double cropped and therefore requires additional labor in planting and harvesting. One example of this occurred in Borletar, Nepal. The construction of a large public works project during the 1980s has doubled total labor demand in the region, improving productivity and welfare. Production potential has increased by 300% and income by 600%, leading to increased food security for the native population (FAO, 1999).

Irrigation and land values: Land values in a region are a function of the productive potential of the land. The development of irrigation systems allows farmers to grow higher yields of existing crops, or more profitable cash crops. Because of this, the benefits to landholders of irrigation development can be large. A 1997 study in Kenya and Zimbabwe showed that the average net increase in income from irrigation was $150 - $1000 per family farm (FAO, 1999). One question of importance in developing countries is that of land security. Areas where land rights are ill-defined will have lower benefits accruing to the local population than those areas with well-defined rights.

2.1.4 - Irrigation Supply Stabilization

The construction of a water storage and conveyance system decreases the risk associated with stochastic rainfall. Farmers are better able to plan their cropping patterns when they can predict the supply of water available. The planting of certain crops, such as tree crops, requires the assurance of a sufficient water supply. Irrigation also allows farmers to apply water at the times that are most beneficial for the crop, instead of being subject to the variation in rainfall. However, since the choice of crop and irrigation technology must be made before the weather is observed, the marginal benefit of water is the same in all years (Siamwalla,1997).

2.1.5 - Environmental Benefits

Irrigation and deforestation: The expansion of agriculture is a primary cause of deforestation in developing countries. For example, between 1975 and 1988 the forested area in Northeast Thailand decreased by almost 50% because of growth in cassava production (Siamwalla,1997). Increasing food production in a region requires either more intensive use of existing cropland or an expansion of agriculture onto new cropland intensive cropping practices, such as using high yield varieties, are a necessary means of feeding the world’s population without requiring large amounts of land to be deforested. Irrigation is a necessary input into many high-yield varieties of crops in production.

2.1.6 - Benefits of the Conjunctive Use of Groundwater and Surface Water

There is a large amount of literature on the benefits of conjunctive use of surface water and groundwater. These benefits accrue because of the different nature of the resources. Surface water usually has lower delivery and extraction costs, but is subject to variability in supply. Groundwater can be expensive to pump, but has a firm supply. In aquifers with recharge, the use of surface water during years with high levels of precipitation can recharge an existing aquifer and decrease future overdraft of groundwater supplies. In aquifers without recharge, the availability of surface water for irrigation can be a substitute for groundwater supplies. In either case, the conjunctive use of the two sources can decrease the risk associated with a stochastic surface water supply (Efrem,2006).

2.2 Irrigation practice in Ethiopia

Irrigation in Ethiopia dates back several centuries, if not millennia, even though, commercial Irrigated agricultural development started in the 1960s with the objective of producing industrial crops (sugar and cotton) on large-scale basis. These "modern" irrigation schemes started with the commercial irrigated sugar estate established in the early 1950s by the Imperial Government of Ethiopia and the Dutch company known as HVA-Ethiopia.

Based up on the various river basin master plans and land and water resources survey, the aggregate irrigation potential of Ethiopia (small, medium and large) have been estimated 3.5 million hectares. Out of this estimate the medium and large-scale irrigation potential together comprises about 81.4% of the aggregate. From this potential, only about 86,000 ha of land is currently developed under large-scale irrigation. This implies that still there is a need to encourage the development of large-scale schemes to alleviate poverty, prevail peace and stability in the region and for better livelihood of the people and the economic growth of the country (Emama *et. al.*,2007).

2.3 Structure of the suitability classification

In FAO’s Framework for Land Evaluation (1976), the structure of the suitability classification is described recognizing qualitative, quantitative and of current or potential suitability in four categories of decreasing generalization. Each category retains its basic meaning within the context of the different classifications and as applied it different kinds of land use.

2.4 Land suitability for Irrigation

2.4.1 - Land Suitability Orders

Land Suitability orders indicate whether land is assessed as suitable or not suitable for the use under consideration. There are two orders Suitable and not suitable represented in maps, tables, etc. by the symbols S and N respectively.

Order S suitable: Land on which sustained use of the kind under consideration is expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources.

Order N not suitable: Land which has qualities that appear to preclude (prevent) sustained use of the kind under consideration (FAO, 1976).

2.4.2 - Land Suitability Classes

Land suitability classes reflect degrees of suitability. The classes are numbered consecutively, by Arabic number, in sequence of decreasing degrees of suitability within the Order.

Class S1 Highly Suitable: Land having no significant limitations to sustained application of a given use, or only minor limitations that will not significantly reduce productivity or benefits and will not raise inputs above an acceptable level.

Class S2 Moderately Suitable: Land having limitations which in aggregate are moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantage to be gained from the use, although still attractive, will be appreciably inferior to that expected on class S1 land.

Class S3 Marginally Suitable: Land having limitations which in aggregate are severe for sustained application of a given use and will so reduce productivity or benefits, or increases required inputs, that this expenditure will be only marginally justified. With the order, Not Suitable, there are normally two classes:

Class N1 Currently Not Suitable: Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost.

Class N2 Permanently Not suitable: Land having limitations which appear so severe as to preclude any possibilities of successful sustained use of the land in the given manner (FAO, 1976).

2.4.3 - Land Suitability Subclasses

Land suitability subclasses reflect kinds of limitations, e.g. moisture deficiency, erosion hazard. Subclasses are indicated by lower-case letters. The number of subclasses recognized and the limitations chosen to distinguish them will differ in classifications for different purposes.

Subclasses are indicated by lower-case letters e.g.S2m, S2e, S3me. There are no subclasses in class S1(FAO, 1976).

2.5 Irrigation Potential of Ethiopia (Based on Basin)

In Ethiopia, under the prevalent rain fed agricultural production system, the progressive degradation of the natural resource base, especially in highly vulnerable areas of the highlands coupled with climate variability have aggravated the incidence of poverty and food insecurity. Water resources manage1Table 2.1: Irrigation Potential in the River Basins of Ethiopia for agriculture includes both support for sustainable production in rain-fed agriculture and irrigation (Awulachew et al. 2005). Not overlooked should be soil protection and maintaining soil fertility.

Table 2. 1 Small, medium and large scale irrigation practice in Ethiopia

Description	Small-scale schemes	Large- and medium-scale schemes	Total area
Short-term 1st 5 years: (2002-2006):	40,319	13,044	53,363
Medium-term 2nd 5 years: (2007-2012):	40,348	39,701	80,049
Long-term 3rd 5 years: (2012-2016):	46,471	94,729	141,200
Total area to be developed during 2002-2016:	127,138	147,474	274,612
Currently developed (approximate):	98,625	98,625	197,250
Grand total irrigated area by 2016:	225,763	246,099	471,862

Source(Meron ,2007)

Table 2. 2 Irrigation Potential in the River Basins of Ethiopia

Basin	Catchment area(km^2)	Irrigation Potential(Ha) (based on master plan)				Irrigation potential		
		small scale	Medium scale	Large Scale	total	Total Drainage area(km2)	Irrigable area	% of Irrigable area
Abbay	198 890	45 856	130 395	639 330	815 581	201 346	1 001 000	27
Tekeze	83 475	N/A	N/A	83 368	83 368	90 001	3 17 000	8.5
Baro-Akobo	76 203.12	N/A	N/A	1 019 523	1 019 523	74 102	9 85 000	26.5
Omo - Ghibe	79 000	N/A	10 028	57 900	67 928	78 213	4 45 000	12
Rift Vally	52 739	N/A	4000	45 700	139 300	52 739	1 39 000	3.7
Awash	110 439	30 556	24 500	79 065	134 121	112 697	2 05 000	5.5
Genalle Dawa	172 133	1 805	28 415	1 044 500	1 074 720	117 042	4 23 000	5.4
Wabi Sheble	202 219	10 755	55 950	171 200	237 905	102 697	200 000	5.4
Denakil	63 852	2 309	45 656	110 811	158 776	74 102		
Ogaden	77 121	-	-	-	-	-	-	-
Ayisha(Gulf Aden)	2 000	-	-	-	-	-	-	-
Total	1 118 074				3 731 222	982 060	3 715 000	100

Source: (Awulachew, Yilma et al., 2007)

2.6 GIS and remote sensing for Irrigation

Multi-criteria decision-making is the concepts, approaches, models and methods that aid in evaluation expressing by weights, values or intensities of preference which ultimately lead to better decisions. The main purpose of the Multi-Criteria Evaluation (MCE) techniques is to investigate a number of alternatives in the light of multiple criteria and conflicting objectives. In order to carry out the idea, it is necessary to generate compromise alternatives and a ranking of alternatives according to their degree of attractiveness. The integration of analytical techniques designed to work with MCE problems within GIS could give more functionality to the user. Consequently, the integration of MCE within a GIS context could help users to improve decision-making processes. In the last decade MCE has received renewed attention in the context of a GIS-based decision-making which could be useful in solving conflictive situations for individual or groups interested in spatial context. It is also a powerful approach to land suitability assessments (Shahada, T, etal ,2010).

The Weighted Linear Combination approach involves standardization of the suitability maps, assigning the weights of relative importance to the suitability's maps, and then combining the weights and standardized suitability maps to obtain an overall suitability score. Unlike the Boolean operations, WLC is a compensatory method in the sense that a low score on one suitability criterion can be compensated by a high suitability one (Malczewski, 2004).

2.7 Evapotranspiration and Factors affecting crop Evapotranspiration

Water can be lost from the soil surface and wet vegetation through a process called evaporation (E), whereby liquid water is converted into water vapor and removed from the evaporating surface. Energy is required to change the state of the molecules of water from liquid to vapor. The process is affected by climatologically factors such as solar radiation, air temperature, air humidity and wind speed. Where the evaporating surface is the soil surface, the degree of shading of the crop canopy and the amount of water available at the evaporating surface are the other factors that affect the evaporation process. The second process of water loss is called transpiration (T), whereby liquid water contained in plant tissues vaporizes into the atmosphere through small openings in the plant leaf, called stomata. Transpiration, like direct evaporation, depends on the energy supply, vapour pressure gradient and wind. Hence solar radiation, air temperature, air humidity and wind terms should be considered when assessing transpiration. The soil water content and the ability of the soil to conduct water to the roots also determine the transpiration rate, as do water logging and soil salinity. Crop characteristics, environmental aspects and cultivation practices also have an influence on the transpiration. The combination of these two separate processes, whereby water is lost on one hand by evaporation from the soil surface and on the other hand by transpiration from a plant, is called evapotranspiration (ET). Evaporation and transpiration occur simultaneously and there is no easy way of distinguishing between the two processes. When the crop is small evaporation is the main process, but once the crop is fully grown and completely covers the ground transpiration becomes the dominant process. It has been estimated that at crop sowing 100% of the total ET comes from evaporation, while at full crop cover evaporation accounts for about 10% of ET and transpiration for the remaining 90%(FAO,1977).

The main factors affecting evapotranspiration are climatic parameters, crop characteristics, management practices and environmental aspects. The main climatic factors affecting evapotranspiration are solar radiation, air temperature, air humidity and wind speed. The crop type, variety and development stages affect evapotranspiration. Differences in crop resistance to transpiration, crop height, crop roughness, reflection, canopy cover and crop rooting characteristics result in different evapotranspiration levels in different types of crops under identical environmental conditions. Factors such as soil salinity, poor land fertility, limited use of fertilizers and chemicals, lack of pest and disease control, poor soil management and limited water availability at the root zone may limit the crop development and reduce evapotranspiration. Other factors that affect evapotranspiration are groundcover and plant density. Cultivation practices and the type of irrigation system used can alter the microclimate, affect the crop characteristics or affect the wetting of the soil and crop surface. All this affect evapotranspiration (FAO, 1977).

2.7.1 Reference crop Evapotranspiration

The evapotranspiration from a reference surface not short of water is called the reference crop evapotranspiration and is denoted by ETo. The reference surface is a hypothetical grass reference crop with specific characteristics. The concept of ETo was introduced to study the evaporative demand of the atmosphere independently of crop type, crop development stage and management practices. As water is abundant at the evapotranspiring surface, soil factors do not affect evapotranspiration. Relating evapotranspiration to a specific surface provides a reference to which evapotranspiration from other surfaces can be related. It removes the need to define a separate evapotranspiration level for each crop and stage of growth. The only factors affecting ETo are climatic parameters. As a result, ETo is a climatic parameter and can be computed from weather data. Crop coefficient (Kc) is the ratio of Crop evapotranspiration and reference crop evapotranspiration.

ETo expresses the evaporative demand of the atmosphere at a specific location and time of the year and does not consider crop and soil factors (Savva & Frenken,2002)

2.8 Crop water requirements and Schedule

Crop water requirements (CWR) encompass the total amount of water used in evapotranspiration. FAO (1984) defined crop water requirements as ‘the depth of water needed to meet the water loss through evapotranspiration of a crop, being disease-free, growing in large fields under non-restricting soil conditions, including soil water and fertility, and achieving full production potential under the given growing environment. CWR is equal to ETc and refer to the water that must be supplied through the irrigation system to ensure that the crop receives its full crop water requirements.

The formula used in calculation of ETo using FAO Penman-Monteith Approach given below. The amount of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. Although the values for Crop evapotranspiration under standard conditions (ETc) and crop water requirement are identical, crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. Crop Water requirement is the difference between the amounts of water lost as evapotranspiration (ETc) and its effective rainfall used by the crop.

Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance, albedo and air resistance factors in the Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the Reference evapotranspiration (ETo). Experimentally determined ratios of ETc/ETo, called Crop coefficient (Kc), are used to relate ETc to ETo, therefore we can express crop evapotranspiration as ETc = Kc * ETo. This is known as the crop coefficient approach to calculate crop evapotranspiration (FAO, 1977).

$$ETo = \frac{0.408\Delta(Rn - G) + \gamma\frac{900}{T+273}\mathrm{u2}\ (\mathrm{es} - ea)}{\Delta + \gamma(1 + 0.34\mathrm{u2})} \text{--} 2.1$$

Where ETo= reference evapotranspiration [mm/day], Rn = net radiation at the crop surface [MJ/day m2] , G = soil heat flux density [MJ/day m2], T= mean daily air temperature at 2m height [O C], u_2 = wind speed at 2m height [m/s] ,e_s = saturation vapour pressure [k Pa]

e_a actual vapor pressure [k Pa] ,e_s – ea = saturation vapour pressure deficit [k Pa]

Slope vapor pressure curve [k Pa/ O C], psychrometric constant [k Pa/ O C]

Irrigation is required when rainfall is insufficient to compensate for the water lost by evapotranspiration. The primary objective of irrigation is to apply water at the right period and in the right amount. By calculating the soil water balance of the root zone on a daily basis, the timing and the depth of future irrigations can be planned (FAO, 1997).

To express the water content as root zone depletion is useful. It makes the adding and subtracting of losses and gains straightforward as the various parameters of the soil water budget are usually expressed in terms of water depth. Rainfall, irrigation and capillary rise of groundwater towards the root zone add water to the root zone and decrease the root zone depletion. Soil evaporation, crop transpiration and percolation losses remove water from the root zone and increase the depletion (FAO,1992).

CHAPTER 3: MATERIALS AND METHODS

3.1 Description of Study area

3.1.1 Location of study area

The study area is found under Tana Sub Basin of Blue Nile Basin which covers an area of 4,488 km^2.The watershed found between 10^0 55’ 10” to 11^0 54’ 01” N and $36^0$43’ 59” to 37^0 22’ 15” E. The study area covers an area of 464 050 hectares in nine different woreda. Merawi, Achefer, Bahir Dar, Dangla and Fagta Lekoma woreda accounts 98 % of the total study area.

Table 3. 1 Area Covered by Woreda's in the study area

Woreda	Estimated area (Ha)	Estimated area (%)
Merawi	147 940	31.88
Achefer	134992	29.09
Bahir Dar	84085	18.12
Dangla	34804	7.50
Sekela	29327	6.32
Fagta Lekoma	24873	5.36
Adet	5847	1.26
Banja	1 393	0.30
Quarit	789	0.17
Sum	464 050	**100**

Source: Estimated based on Area of Woreda and Area of watershed in Ethio GIS data

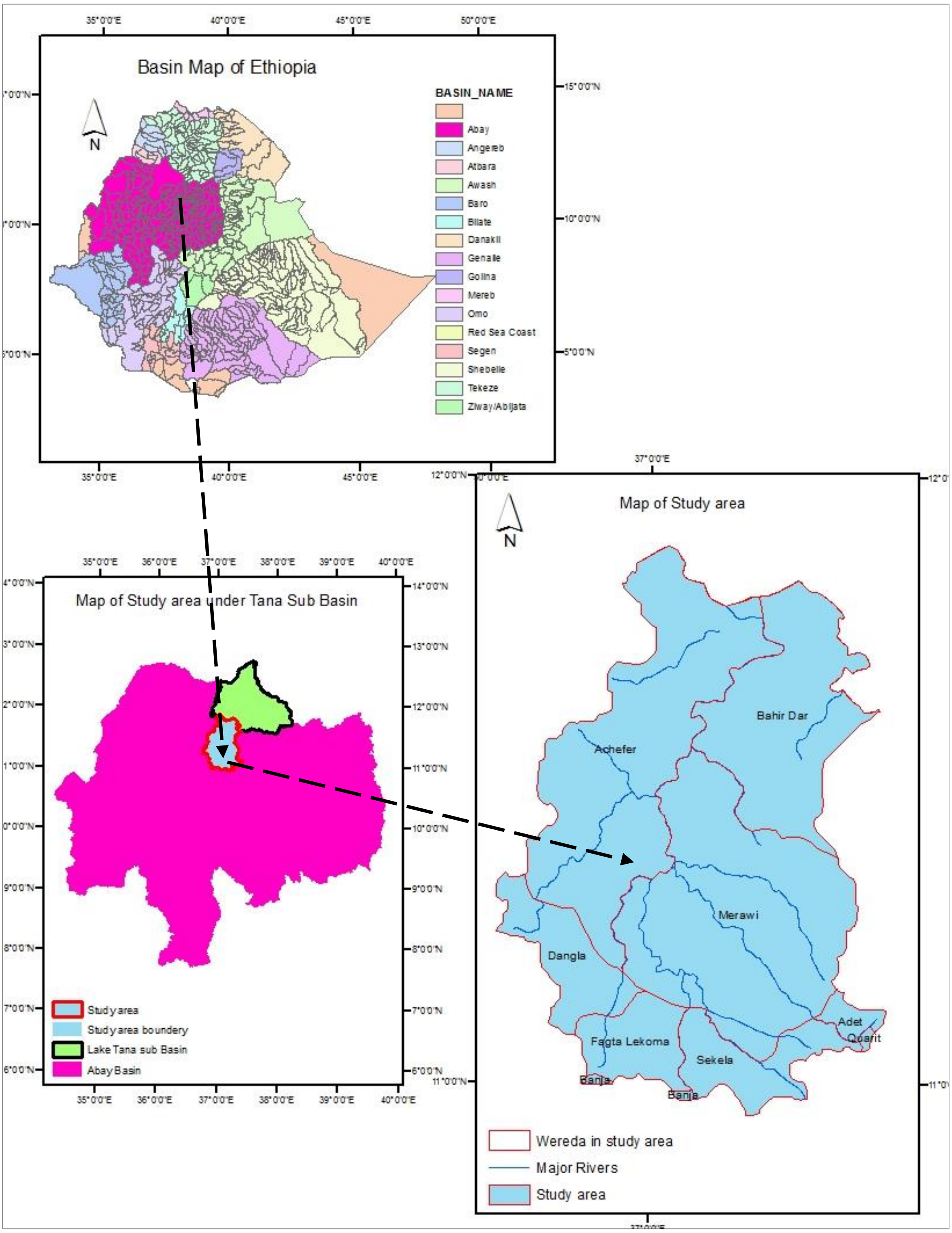

Figure 3. 1 Map of study area

3.1.2 Climate and Watershed characteristics

Climatic elements such as precipitation, temperature, humidity, sunshine and wind are affected by geographic location and altitude. Temperature and rainfall are the most important climatic factors for agricultural production in Ethiopia. Altitude is a factor that determines the distribution of climatic factors and land suitability; this influences the crops to be grown, rate of crop growth, natural vegetation types and their species diversity (Alemayehu, M. 2006).

Gilgel Abay watershed have average of 1656 mm rainfall in all of the six metrological station estimated for ten years. It has 18.6-degree centigrade mean monthly temperature, 59 monthly relative humidity, 36.11 monthly sun shine hours, and 0.7 m/s mean monthly wind speed computed from 2006 to 2015 years.

All the climate data were collected from six meteorological stations that are found inside and around the study area i.e. Adet, Bahir Dar, Dangila , Durbietie, Injibara, and Merawi.

Detail monthly average data found in Appendix (Appendix 1).

3.1.3 Crop production

According to Central Statistical report, the major Agricultural products West Gojam includes Cereal /Grain Crops (such as Teff, Barly, Wheat, Maize, Sorghum, Finger Millet, Rice), Pulses (such as Faba beans, Field peas, Chick-peas, Lentils, Gibto etc), Oil Seeds(such as Linseed, Nug, Groundnuts, Safflower etc), Vegetables(Lettuce, Head Cabbage, Tomatoes, Green peppers, Red peppers and others), Root Crop(such as Beet Root, Carrot, Onion, Potato's, Garlic etc), Fruit Crops(such as Avocados, Bananas, Guavas, Lemons, Mangoes Oranges, Papayas and Pineapples) were cultivated in different woreda.

3.1.4 Population

Based on CSA report in 2013(Table 3.3) the population distribution in each of woreda'vary in both Male, Female and Total. Large population size found in Mecha, yilma Na Densa, Bahir Dar Zuria and Achefer woredas. As the study area covers much of Mecha Woreda which covers 147 940 Ha of Land with estimated population of 350 757 in 2017, Achefer Woredas' covers an area of 134 991 Ha of land with estimated population 291 929 population, and Bahir Dar zuriya woredas have 211,051 estimated population in 2017 that covers 84 085 Ha of Land(CSA, 2013).

Table 3. 2 Population size of Woreda's in the study Area

Woreda	2014			2017		
	Male	**Female**	**Total**	**Male**	**Female**	**Total**
Semen Achefer	110,754	106,972	217,726	116,122	112,16	127,338
Bahri Dar Zuria	104,006	100,261	204,267	107,473	103,578	211,051
Yilma Na Densa	122,870	124,321	247,191	129,085	130,414	259,499
Mecha	168,724	166,065	334,789	176,868	173,889	350,757
Sekela	78,074	79,458	157,532	81,424	82,788	164,212
Quarit	64,081	65,983	130,064	66,761	68,639	135,400
Dega Damot	84,765	88,029	172,794	88,361	91,605	179,966
Dembecha	75,559	75,464	151,023	80,038	79,828	159,866
Jabi Tehnan	101,983	103,093	205,076	106,730	107,850	214,580
Bure	84,489	84,981	169,470	90,154	90,495	180,649
Wonberma	58,775	57,494	116,269	61,868	60,528	122,396
Goncha	60,549	60,281	120,830	63,051	62,702	125,753
Debub Achefer	79,280	77,586	156,866	83,177	81,414	164,591
Finote Selam/Town/	19,923	18,476	38,399	23,460	21,755	45,215
Dangila	94,707	92,502	187,209	100,814	98,383	199,197
Banja Shekudad	66,458	66,910	133,368	71,149	71,452	142,601
Fagita Lekoma	71,493	73,025	144,518	137,617	138,580	276,197
sum	1,446,490	1,440,901	2,887,391	1,584,152	1,463,900	3,048,052

Source :(CSA, 2013)

3.2 Software used for the Study

To analysis the land for irrigation using GIS and remote sensing, different software's used for different purposes. ArcGIS, ERDAS IMAGINE, CROPWAT, and IDRISI were used starting from data preprocessing up to advanced analysis of spatial data.

Table 3. 3 Types of software's used and their function for the study.

No	Types of Soft Ware	Used for
1	ArcGIS 10.3	Used for data management, projection & transformation, Preparation of map of factors, reclassification, overlay analysis, map production
2	ERDAS IMAGINE2014	Used to prepare band combination, classification, and area of final map result preparation
3	CROPWAT 8.0	Used to estimate reference crop evapotranspiration(ETo), Effective Rainfall, CWR and Schedule
4	IDRISI 32	Used to drive weight of parameters

3.3 Data types, Sources and Methods of Analysis for the study

To identify potential irrigable land and assess crop water requirement, various data were collected from different sources. Data from both primary and secondary sources were collected.

The different data have been employed for the study to fulfill the objectives which are *i.e*. land use/land cover, topography, soil type, soil depth, metrological data, and drainage. Landsat images with 30-meter spatial resolution obtained from USGS sites to prepare the land use/land cover map of the study area. The image was downloaded in March 06, 2015 with OLI sensor. DEM data with 30-meter spatial resolution also collected from USGS site to consider topography factors such as slope and Drainage of the study area. Soil data from Ministry of Agriculture and FAO was collected that used to prepare different soil map. The climatic data used in this project was collected from the National Metrological Service Agency (NMSA). The quality, quantity and characteristics of hydrological parameters were carefully assessed in order to make a sound decision on water resource allocation and utilization. Eight metrological stations were found in the study area with three types in its kind. Three of them were primary stations which contains all the metrological data sets to calculate Evapotranspiration and water requirement. Rainfall, maximum & minimum temperature, relative humidity, sun shine hour, and wind speed. Bahir Dar, Adet and Dangila were primary stations. Durbietie, Merawi and Zegie have only rainfall and temperature data sets. The rest of them (Yismala and Enjibara) contains only rainfall data.

Table 3. 4 Data type, their sources, spatial resolution and purpose for the study

	Data type	Sources	Spation Resolution	Purpose
Spatial Data	DEM	USGS website	30 meter	To prepare slope map To prepare derange density map
	Soil Data	FAO MoWR	1:1000000	To prepare soil depth map
			1:250 000	To prepare Soil type map
	River shape file	Ethio GIS		To prepare Proximity Map
	Satellite Imagery (Landsat 8 OLI sensor)	USGS website	30 meter	To prepare land use map
	Metrological data (Maximum % minimum Temperature, Humidity, sunshine hours, wind speed, rainfall)	NMSA		To prepare Temperature map To prepare Rainfall map To prepare CWR
Non spatial data	Soil characteristics	FAO website & Agriculture bureau		To prepare CWR
	Crop characteristics			To prepare CWR
	Identify parameters & their priority for irrigation	Abay River Authority, Bureau of Land Administration, water use & Irrigation		To identify parameters and prioritize them for final suitability analysis

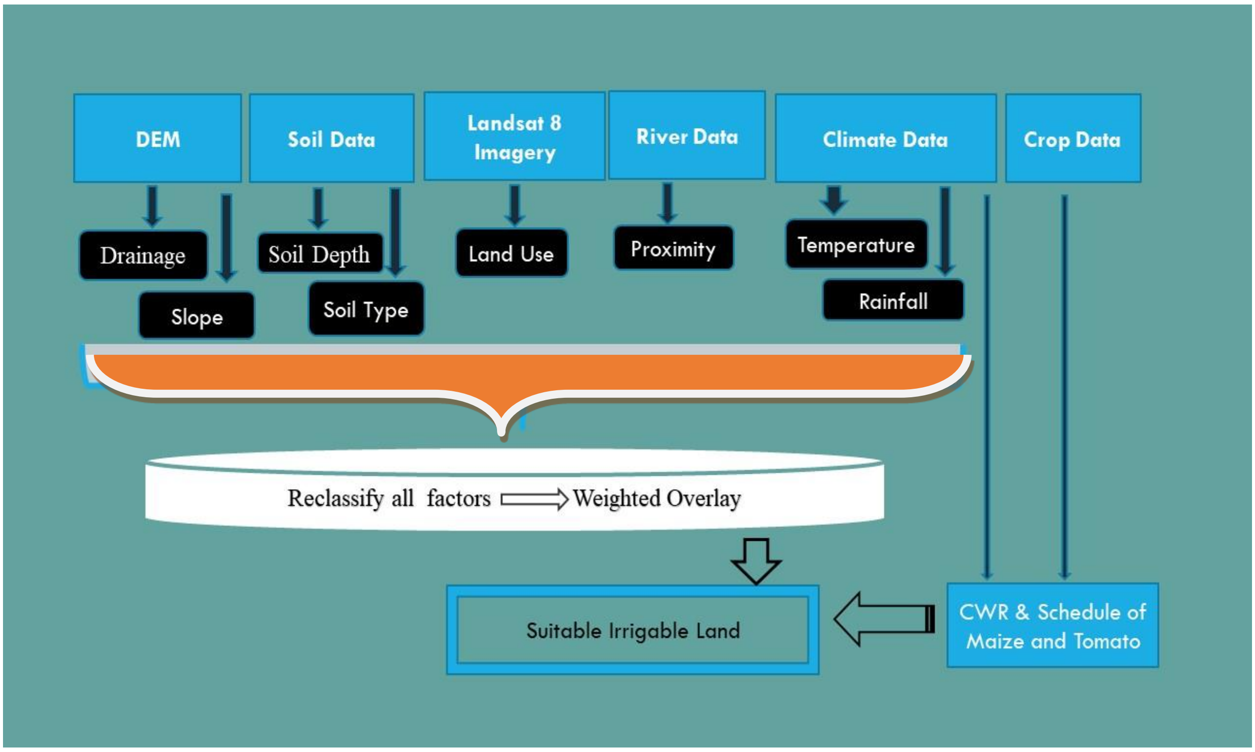

Figure 3. 2 General procedure to identify Suitable Irrigable Land and its CWR and Schedule

3.3.1 Meteorological data, CWR and Schedule

The climatic data used was collected from the National Metrological Service Agency (NMSA). There are about eight stations in and around the study area. All of the station were not found within the study area, due to lack of stations particularly primary station in the study area two stations were selected around the study area. All of the stations haven't the same time coverage as well as spatial distribution. The oldest station started in 1961 where as some starts in 1980's this leads inconsistency of the data in time perspective.

To calculate the water requirements of crop in the study area different data such as Rainfall (in mm), Maximum and minimum air temperature (in ^{O}C), Relative humidity (in %), Wind speed (in m/s) and Sunshine duration (in hours), crop characteristics, and soil characteristics were required.

Using ten years' monthly average meteorological data (2006 -2015), the ETo & Effective rainfall were estimated. Crop characteristics such as Kc value, Stage Days, rooting depth, critical depletion, and yield response and crop height were obtained from FAO website. Soil characteristics like total available soil moisture, rainfall infiltration, rooting depth and moisture depletion also adopted from FAO.

The selection of stations is based on the required data types in order to estimate reference evapotranspiration using FAO Pen man-Monteith method and their distribution in regions. The climatic data were used to drive crop water requirement, rainfall map and temperature map of the study area. Two of the stations with in the study area contain all required data types to estimate evapotranspiration and the rest of them contains only Rainfall and Temperature data types.

Procedures for calculation of the crop water requirements and irrigation requirements are based on methodologies presented in FAO Irrigation and Drainage Papers No. 24"Crop water requirements" and No. 33 "Yield response to water". The development of irrigation schedules and evaluation of rained and irrigation practices are based on Irrigation Suitability Analysis by Implementing GIS techniques a daily soil-water balance using various options for water supply and irrigation management conditions.

Rainwater is essential source for agriculture, human beings and animals that falls on the surface of earth. Not all that is useful rather a part of it is effective. This study deals with “effective rainfall”, i.e. useful rainfall. Agriculturists consider the portion of rainfall effective that directly satisfies crop water requirements. Effective rainfall means useful or utilizable rainfall. Rainfall is not necessarily useful or desirable at the time, rate or amount in which it is received. Some of it may be unavoidably wasted while some may even be destructive (Shahzada &Azmat, 2011).

According to FAO, the average rainfall data in Ethiopia is 848 mm. In the study area, the average rainfall ranges from 1184 to 2 484 mm which was calculated in 30 years’ average. After missing data were estimated using mean average methods during 1985 to 2015, the Rainfall and Temperature as a factor were analyzed. To drive Rainfall and Temperature factor map, IDW interpolation method used to estimate the values of rainfall and temperature in the study area. Reclassifying was used to prioritize its level of significance for irrigable land selection.

To estimate CWR using CROPWAT 8 window tools, ten years average monthly Temperature, Humidity, Wind speed, Sunshine hours and Rainfall as well as Crop and soil data were collected and analyzed.

Crop evapotranspiration can be calculated from climatic data and by integrating directly the crop resistance and air resistance factors in the FAO Penman-Monteith approach. As there is still a considerable lack of information for different crops, the Penman-Monteith method is used for the estimation of the standard Reference crop to determine its evapotranspiration rate, i.e., Reference evapotranspiration (ETo). Experimentally determined ratios of ETc/ETo, called Crop coefficient (Kc), are used to relate Crop evapotranspiration under standard conditions (ETc) to ETo. This is known as the crop coefficient approach.

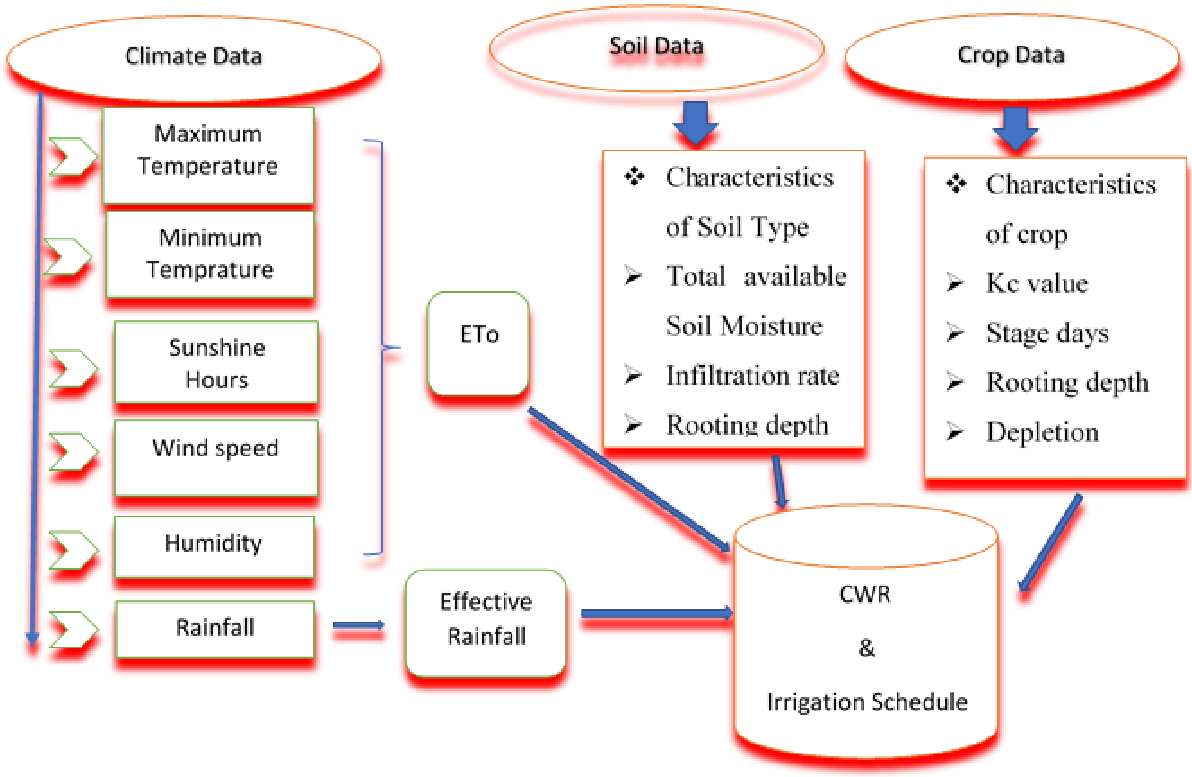

Figure 3. 3 CWR computation procedure in CROPWAT 8.0

3.3.2 Topographic Data

Topography is a major factor affecting irrigation, particularly surface irrigation. It influences drainage, erosion, irrigation efficiency, cost of land development, size and shape of fields' labors requirements, range of possible crops, etc. Topographic knowledge is basic to many earth surface process analyses, as a means of explaining processes and of predicting them through modeling. Our capacity to understand and model these processes depends on the quality of the topographic data that are available. In general terms, a model is a representation of reality. Due to the inherent complexity of the world and the interactions in it, models are created as simplified, manageable view of reality. Models help in understanding, describing, or predicting how things work in the real world.

Recording spot elevation values at significant points and intervals on the land surface is an approach in the production of a digital elevation model (DEM) for an area. A DEM is the representation of the elevation of the land at regularly spaced intervals, used for various applications, most notably for the production of topographic maps and three- dimensional visualization of the Earth's surface.

To prepare Slope and Drainage of the study area, DEM with 30-meter spatial resolution was obtained from US geological survey website. Hydrology tools (Fill, Flow Direction, Flow Accumulation, stream order, stream to feature and Watershed), Raster to polygon, Feature to Raster and Focal Statistics tools used to drive Derange density map of the study area using ArcGIS10.3 software. The detailed methodology described in Figure 3.4.

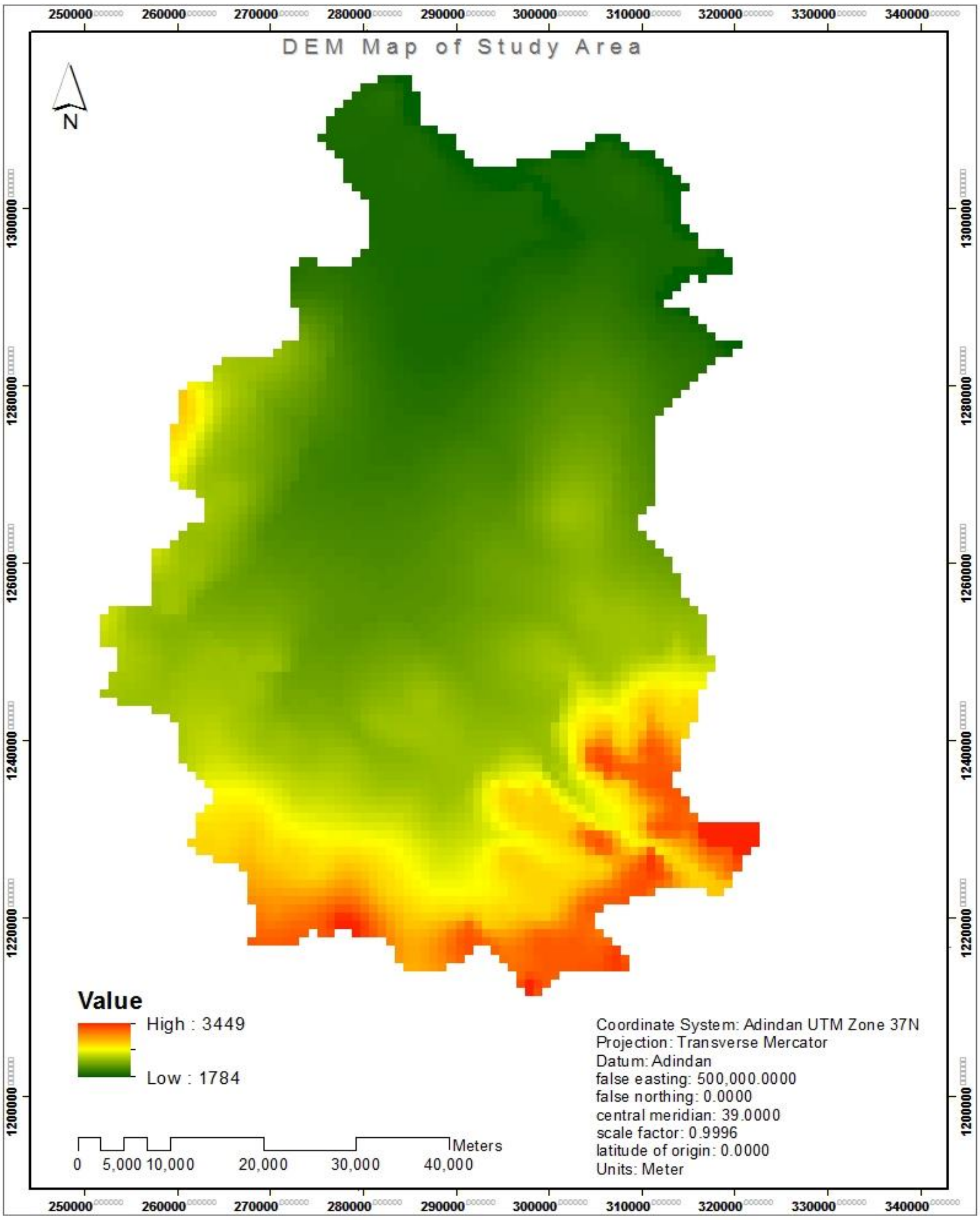

Figure 3. 4 DEM Map of Study Area

3.3.3 Soil Data

Agricultural land has value only because of its ability to grow crops. Most evaluations are based on factors that affect this ability. Assessment of land resource, with particular regard to soil survey is a necessary prerequisite for all agricultural developments, particularly where irrigation is concerned.

The major soils in the Abbay Basin were found to be Leptosols, Alisols, Nitisols, Vertisols, Cambisols, and Luvisols in order of decreasing aerial coverage. Others found in relatively lesser aerial coverage are Arenosols, Acrisols, Fluvisols, Phaeozons, and Regosols (Meron, 2007). Among them Leptosols, Nitisols,Vertisols,Cambisols, and Luvisols covers the major area.

The characteristics of soil for Agricultural production in consideration of its productivity nature and depth.

Land evaluation is one approach to interpreting this technical soil information to provide understandable and readily useable information for the planning process. It involves evaluation of land units, usually based on soil mapping units, for defined potential uses.

As soil have different characteristics for different purpose. Its agricultural productivity varies in different soil types. Based on soil type and their characteristics for Agricultural Productivity, soil map of the study were analyzed and identified.

In addition to soil type, the depth of soil was used as one of the factor to consider the root length of different crops used for irrigation purpose. The highest depth was important for varies crop cultivation practice as it allow for normal growth of plants. Most commercial crops & plants such as sugarcane requires the maximum soil depth which requires more than 120 cm depth of soil as experts suggested.

In the study area, the soil depth has 3 classes based on FAO Soil data. Depth less than 30 centimeters, 90 -120 centimeters, and more than 120 centimeters.

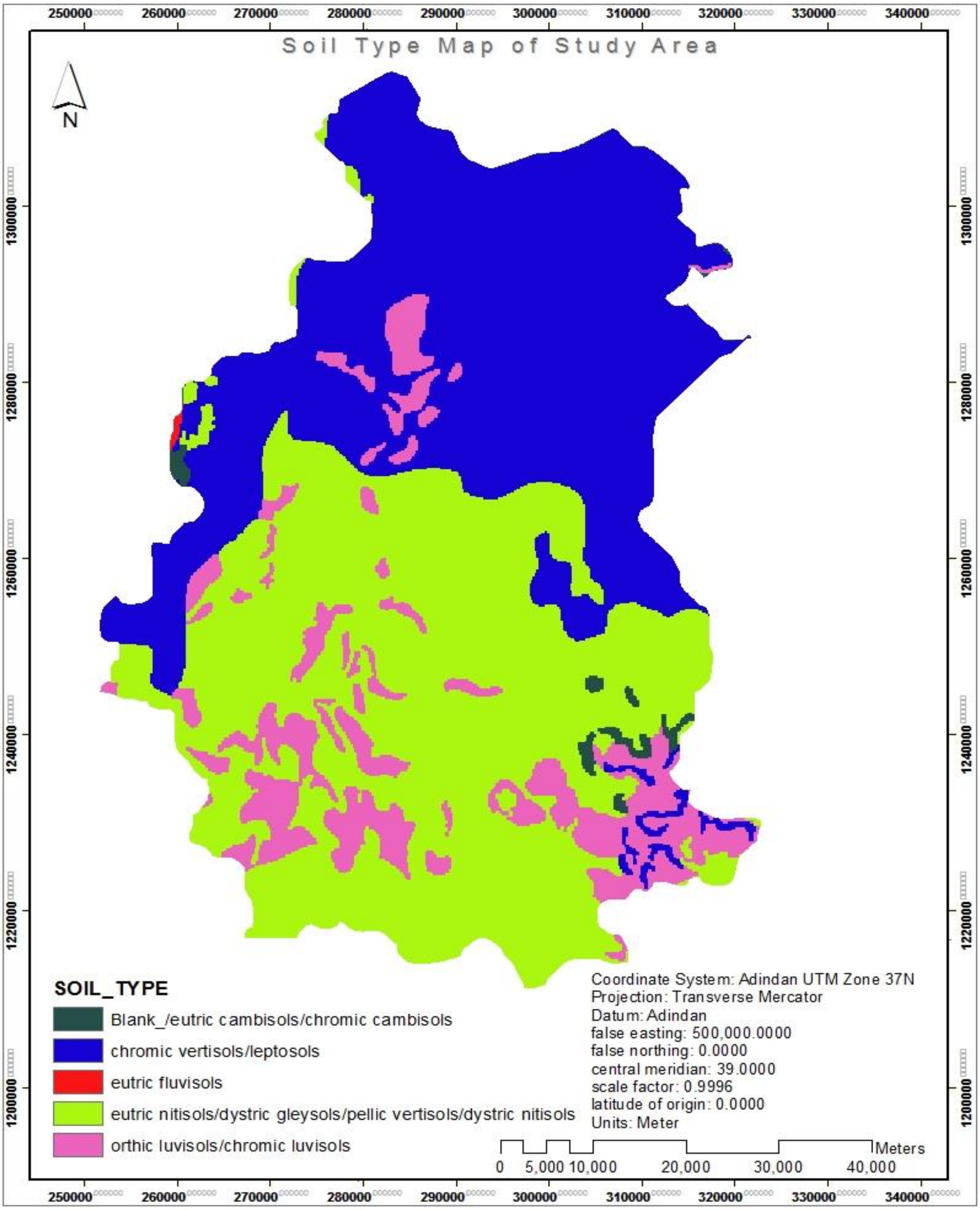

Figure 3. 5 Soil Map of the Study Area

Source: Prepared based on MoWR Soil Data

Table 3. 5 Soil Type and their characteristics in the Study Area

Soil type	Characteristics	For agriculture
❖ Chromic cambisols ❖ Eutric cambisols	✓ High base status ✓ High resistance to degradation ✓ Moderate resistance to yield reduction	Low
❖ Chromic luvisols ❖ Orthic luvisol	✓ Easy of cultivation ✓ Greatly affected by erosion and loos in fertility	Less Moderate
❖ Chromic vertisols ❖ Pellic vertisols	✓ Highly fertile but difficult to manage ✓ Easily degraded	High
❖ Dystric gleyasol	✓ Used for arable crop and horticulture if drained well ✓ Used for agriculture when water table is reduced at lower levl using appropriate drainage	Moderate
❖ Dystric nitisol ❖ Eutric nitisol	✓ Most fertile soil type ✓ Moderate resilence and to low sensitivity ✓ Very erodible when when carbob degrease but little effect on crop ✓ Suffer accidity	Very high

❖ Eutric fluvisols	✓ Much prized for intensive agriculture ✓ Higher resilence and low sensitivity for degradation	Very High
❖ leptosols	Have resource potential Higly Pron for erosion More fertile in hil slope than level ground Exesssive internal drainage leads drought	High

Source: FAO , 1976, FAO,1979, FAO,2001 and Young, A. 1976.

3.3.4 Land Use/land cover

To prepare and analyze the land use type in the study area for suitable irrigable land selection, Landsat imagery were obtained from US geological website Archives. Landsat 8 satellite imagery, which have OLI sensor, were obtained for the march 06, 2015 after investigation of cloud free data USGS earth explorer website. The preprocessing and processing of data was carried out using ERDAS Imagine software.

These two terms, land cover and land use, are often used interchangeably, but the distinction between land use and land cover is an important one. Land use refers to the actual economic activity for which the land is used *i.e.* food production, commercial forestry, etc. land cover refers to the cover of the earth's surface *i.e.* Vegetation (by type), bare soil, urban development, etc. without reference to how that cover is used.

People use of the land is not random; it reflects the complex interaction between biophysical potential of the land, the socio-economic condition of the people (the land users), and the institutional and policy environment within which the land is used.

Different combination of bands can be applied depending on the purpose/functions intended for. According to Kevin Butler, a band combination of **6 (**SWIR 1**) 5(**NIR**) 2(**BLUE**)** used for Agriculture (Kevin, B., 2013). For my study, the aim was to identify suitable irrigable land hence a band combination of band 6, band 5 and band 2 was used using ERDAS IMAGINE 2014.

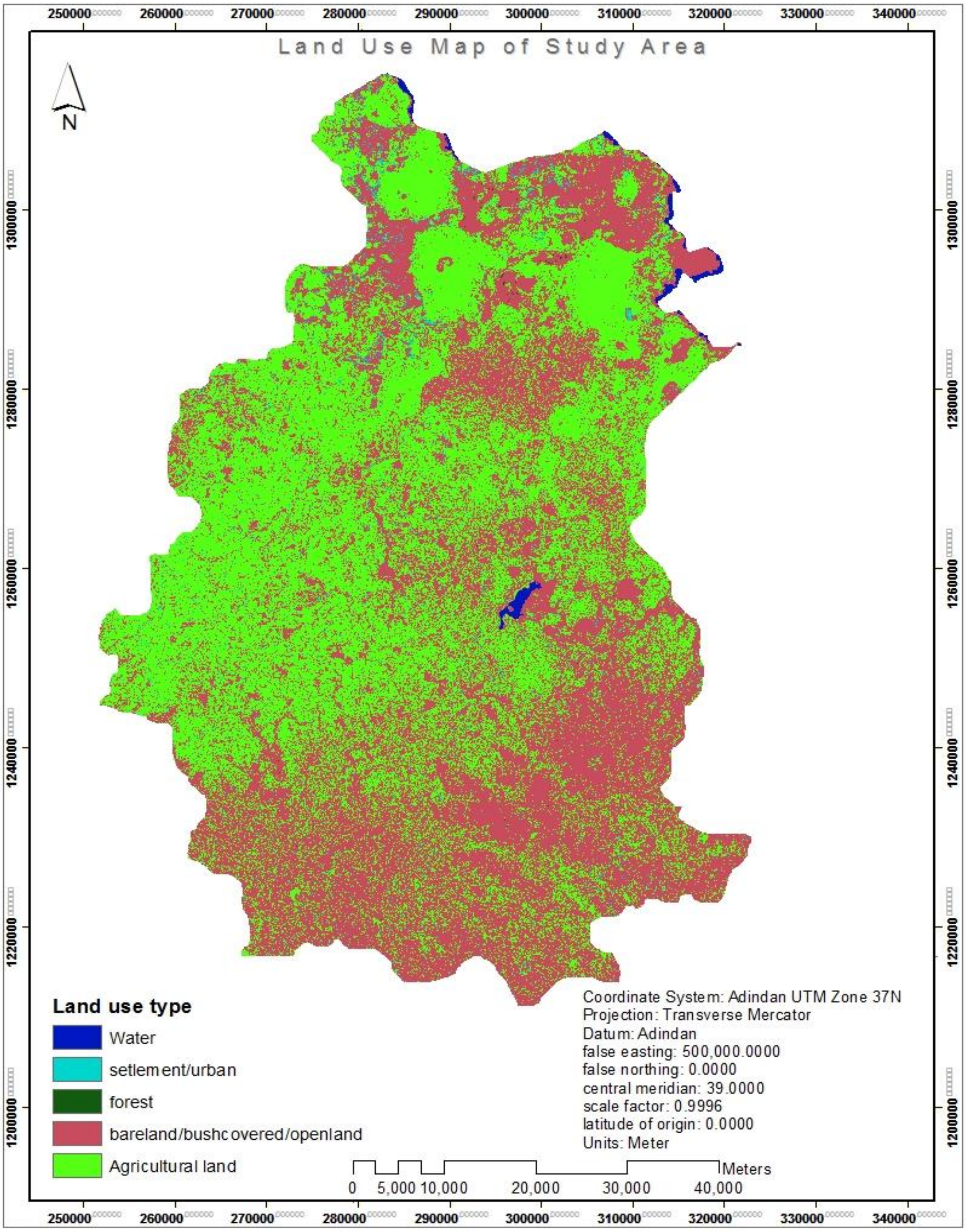

Figure 3. 6 Land use Map of Study Area

3.3.5 Hydrology (River network)

In irrigation practice, distance from the river (sources of water) have significance contribution to control the cost of diverting water, amount of water loose during transportation, loose of water as evaporation, costs for compensation and other factors.

Moving water long distance is costly, energy intensive, and can have significant environmental, social, and cultural impacts. Due to canals requires contour line, it requires long distance during irrigation development, as the result the cost of canal construction increase in addition to wastage of water as evaporation (Australia Water Assosation, 2007).

The river data obtained from Ethio GIS to analyze the distance from the rivers using GIS software. The distance from the rivers were calculated using Spatial Analyst tools (Euclidian distance). After clipping the result with study area boundary, the proximity map was prepared using reclassify tool GIS software.

3.4 Multi-criteria Decision Analysis

Multi Criteria Decision Methods (MCDM) incorporate explicit statements of preferences of decision-makers like such preferences are represented by various quantities, weighting scheme, constraints, goal, utilities, and other parameters. MCDM method is very important since it has a significant effect on the final output. However, it assumes that homogeneity within the study area, which is unrealistic for site selection problems if there is conflict between the various factors. It can negotiate the subjective parameters, like the weights associated with each criterion before adopting a common set of values. It is also possible to repeat the MCDM process and thus select, for each different group of stakeholders, a solution that is adapted to its specific needs. MCDM results can be mapped in order to display the spatial extent of the best areas or index of land suitability and used to compare the results by overlaying various parameters.

To analyze and identify irrigable land using GIS, different experts were interviewed and discussed in group to identify and prioritize the parameters. Experts were from Abay River Authority in Bahir Dar, Bureau of Land Administration, water use & Irrigation in Bahir Dar zuria woreda and Irrigation experts in Bahir Dar University. Based on the result of their discussion, eight parameters were identified to select potentially suitable irrigable land using GIS. The parameters were Soil Type, Land Use, Slope, Drainage Density, Proximity, Soil depth, Rainfall and Temperature.

3.5 Weighting

3.5.1 - The Analytical Hierarchy Process (AHP)

The Analytic Hierarchy Process (AHP) is a comprehensive, logical and structural framework, which allows improving the understanding of complex decisions by decomposing the problem in a hierarchical structure. For the use of MCDM, weights for each of the parameter based on its importance for irrigation were analyzed to prioritize multiple criteria using IDRISI software's. According to experts in Abay River Authority and Bureau of Land Administration, water use & Irrigation as well as literature, the factors to be considered to identify suitable irrigable land were identified. The order of each factor for irrigation suitability were Land use, slope, Drainage density, Soil depth, Distance from main rivers, rainfall and temperature were second, third, fourth, fifth, sixth, seventh and eighth important considerations respectively.

The second order of parameter was land use which is the most important aspect that needs to be considered. Without suitable land use, such as agricultural land, practicing irrigation is vague. Moreover, the type of topography such as flat was also considered due to financial, technological and environmental benefits as compared with mountainous land. For this instance, slope was considered as third parameters. To control the removal of water flow soil and drainage density has been considered the other contributing factor. Inconsideration of financials as well as management of water, distance from main rivers to divert the river was the most important factors that we should consider. The availability of rainwater and temperature also plays an important role and temperature may affect the evapotranspiration. Distance from the rivers has used to prioritize the final suitability result.

3.5.2 - Pair Wise Comparisons Method (PWC)

The Pair Wise Comparison method has been developed by the context of the Analytical Hierarchy Process (AHP) using IDRISI software. This method involves pair wise comparisons to create a ratio matrix. As input, it takes the pair wise comparisons of the parameters/factors for irrigation and produces their relative weights as output. The weights for soil type, land use, Slope, Drainage Density, Soil Depth, Distance, Rainfall and temperature were obtained and arranged orderly based on their importance for irrigation (Table 3.7) and acceptable with consistency ration of 0.09.

Table 3. 6 Weight of factors to identify irrigable land using Idrisi software.

No	Parameters	Weight (%)
1	Soil Type	41 %
2	Land Use	25 %
3	Slope	14 %
4	Drainage Density	9 %
5	Soil Depth	5 %
6	Distance(proximity)	3 %
7	Rainfall	2 %
8	Temperature	1 %
Sum		

CHAPTER 4: RESULT AND DISCUSSION

4.1 Factors considered for Irrigable Land selection

GIS based Multi-criteria analysis for identification of potentially suitable irrigable land was carried out by considering Soil Type, Land Use, Slope, Drainage Density, Soil Depth, Proximity, Rainfall and Temperature as a parameter.

4.2.1 Soil type

The type of soil and their contribution for irrigation suitability were analyzed and map has been produced based on detailed investigation in various literatures about their role for agricultural productivity (Table 3.5).

Based on investigation of each soil type for agricultural production in the study area, five categories were identified as very highly suitable, highly suitable, moderately suitably, low, and very low (Table 4.1) based on their characteristics with regards to fertility, prone to degradation, acidity/base status and related properties.

Table 4. 1 Soil Type Suitability Map of the Study Area

Soil type	Suitability	Area(hectare)	Area (%)
Eutric cambisols/chromic cambisols	Very Low	3835.53	0.82
Orthic luvisols/chromic luvisols	low	54963.72	12.01
Eutric nitisols/dystric gleysols/pellic vertisols/dystric nitisols	Moderate	210529.35	45.06
Chromic vertisols/leptosols	High	194432.31	41.07
Eutric fluvisols	Very high	289.44	1.04
Sum		464 050.37	100

According to Table (4.1) and in Figure (4.1) almost 1.04 % soil type of the study area were very high suitable, 41.07 % is highly suitable, 45.06% of moderately suitable and remaining 13% of the soil is under low suitability class. As this indicates that most of the study area has suitable soil types that can be used for agricultural activity. It indicates around 87% of the area can be used for irrigation as it have more productive soil types , less prone for degradation and yield resistance(Table 3.6:-FAO ,1976, FAO,1979, FAO, 2001 and Young, A. 1976).

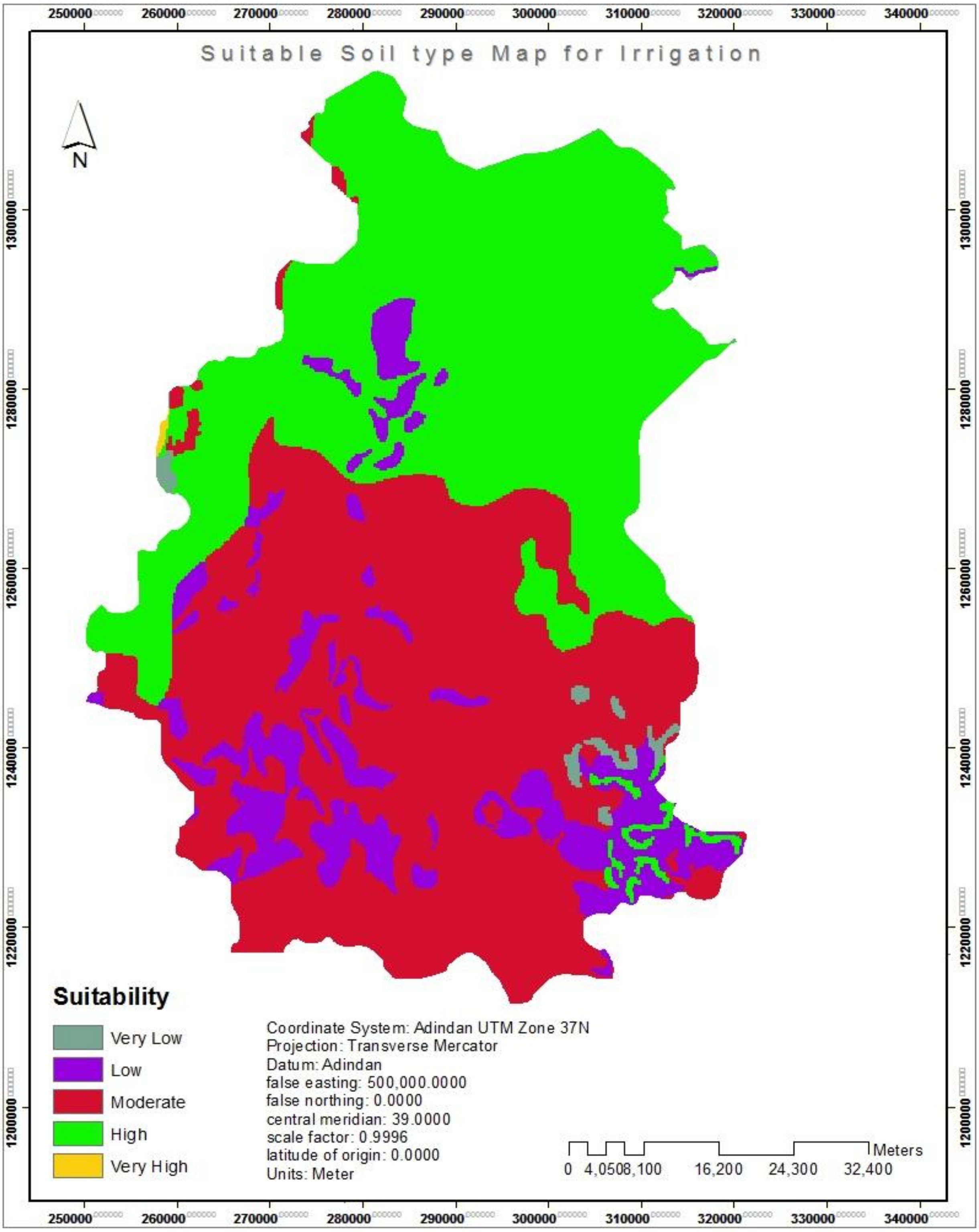

Figure 4. 1 Suitable soil type map for irrigation

4.2.2 Soil Depth

A soil depth variation from place to place determines the growth of plants and also affects the growing of plant roots. The thickness of the soil materials, which give structural support, nutrients and water for crops, is referred as soil depth (FAO, 1998). The soil depth of study area was classified in to three (Figure.4.2) as only three classes of soil depth found in the study area. Water uptake by a specific crop is closely related to its root distribution in the soil. About 70 percent of a plant's roots are found in the upper half of the crop's maximum rooting depth. Deeper roots can extract moisture to keep the plant alive, but they do not extract sufficient water to maintain optimum growth (Robert and Donald, 1996).The depth was given in centimeter. Soil series that have bedrock less than 30 from the surface were described as shallow which is not suitable to for all types of agricultural production. Based on expert's knowledge and FAO documents of root length of crops, the surface between 90 and 120 centimeters was described as Deep that can be used as highly suitable class. The surface above 120 centimeter depth of soil as very Deep that can be used for all types of crop having long root length(FAO,1998).

Table 4. 2 Soil Depth Suitability of the study area

Soil Depth	Suitability	Area(hectare)	Area (%)
<30 cm	Low	3 289.775	0.71
Between 90 & 120 cm	Moderate	273 580.345	59.28
>120 cm	High	187180.2592	40.0
Sum		464 050.379	100

Based the result of reclassification map (Figure 4.2) and their suitability classes (Table 4.2), almost all of the study area were suitable to cultivate any crop since it contains more than 90 centimeter depth of soil. Specifically, 40 % of the study area has a soil depth of greater than 120 centimeters which matured enough for Agricultural crops (FAO, 1998, FAO, 2001 and Robert and Donald, 1996). Only 0.7% of the study area which was found at the periphery of Lake Tana has a soil depth less than 30 centimeters. Hence, almost 99% of the study area were under High and moderate class of suitability for agricultural practice.

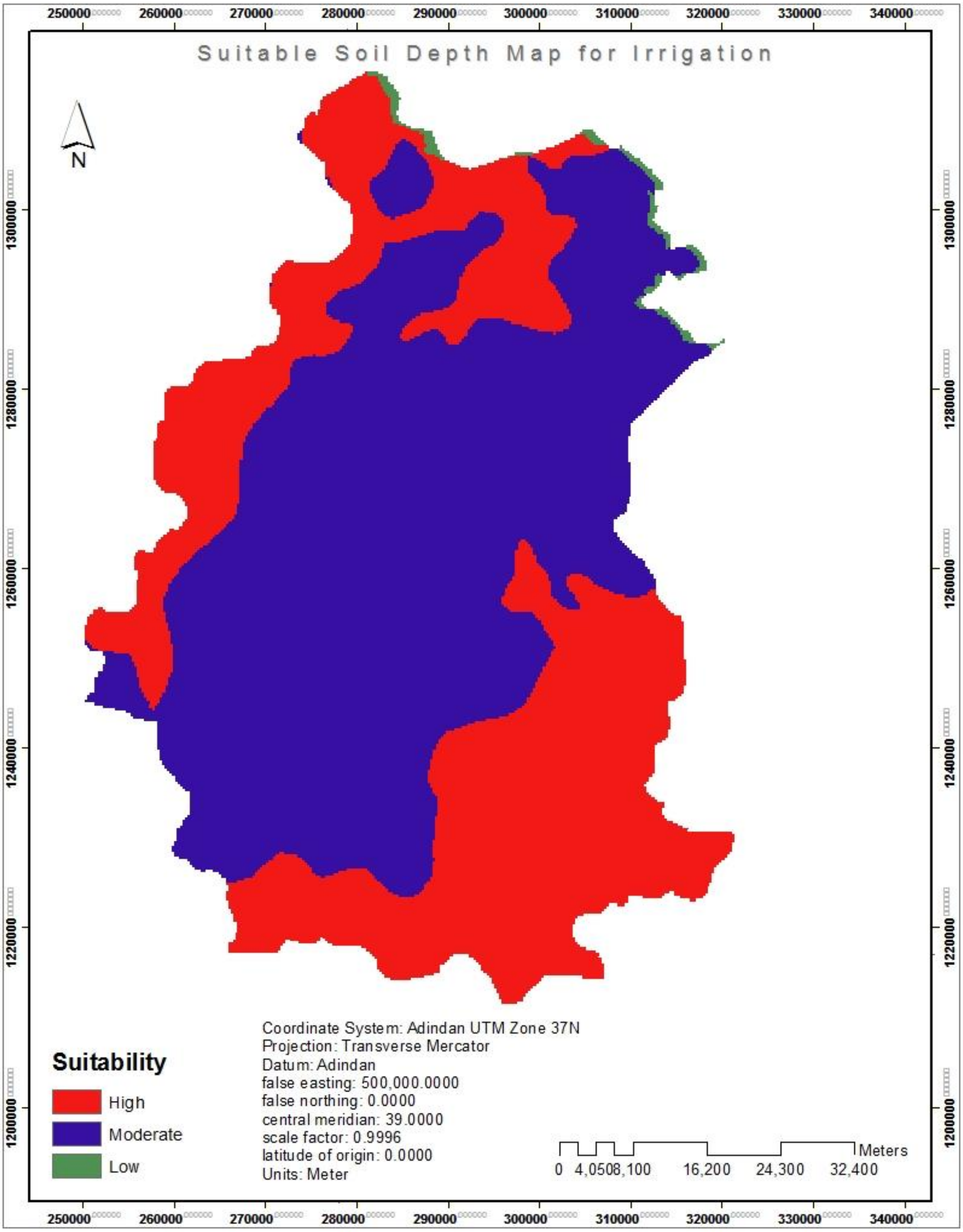

Figure 4. 2 Suitable Soil Depth Map for Irrigation

4.2.3 Land use

Land use type play a crucial role for the selection of potential lands for irrigation. In consideration of limiting factors, the type of land and land cover will be identified and its suitability for irrigation as suitable and not suitable orders based on the most limiting factors. This limiting factor includes, lands that are already irrigated, dense forest, and woodlands, and urban areas. For each suitable order, there are two classes that reflect the limitation that restrict the suitability of that land mapping unit for the irrigation purpose due to its environmental, social or economic cost, unless some important measures are taken. These two classes are highly suitable (S1) and moderately suitable (S2), marginally suitable (S3) and also the unsuitable has two classes (N1 currently not suitable and N2 permanently not suitable). To reflect the limitations imposed on the land, subclass techniques were used by assigning lowercase letters. For instance, S2e may be used to indicate erosion as limitation factor by assigning e for it.

According to the result of reclassification (Figure 4.3) and Table (4.3) shows, 50.06% of the study area was Agricultural Land which was highly suitable for irrigation practice. Similarly, 48.3% of the area covered with open land, bare and bush covered land which has a potential of irrigation practice. Only 1.4% of the study area was not suitable for irrigation and 0.4 % was permanently not suitable for irrigation.

Table 4. 3 Land Use suitability of the study area

Land suitability(FAO)	Land use type assigned	Interpretation (FAO)	Area (Hectare)	Area (%)	Suitability
N2	Water/Reservoir	permanently not suitable	1969.74	0.4	Very Low
N1	Settlement/urban	Currently not suitable	6563.90	1.4	Low
S3	Forest	Marginally suitable	109.11	0.02	Moderate
S2	Open/bush covered land/bare land	Moderately suitable	224103.13	48.3	High
S1	Agricultural land	Highly suitable	231304.48	50.06	Very High
Sum			464050.36	100%	

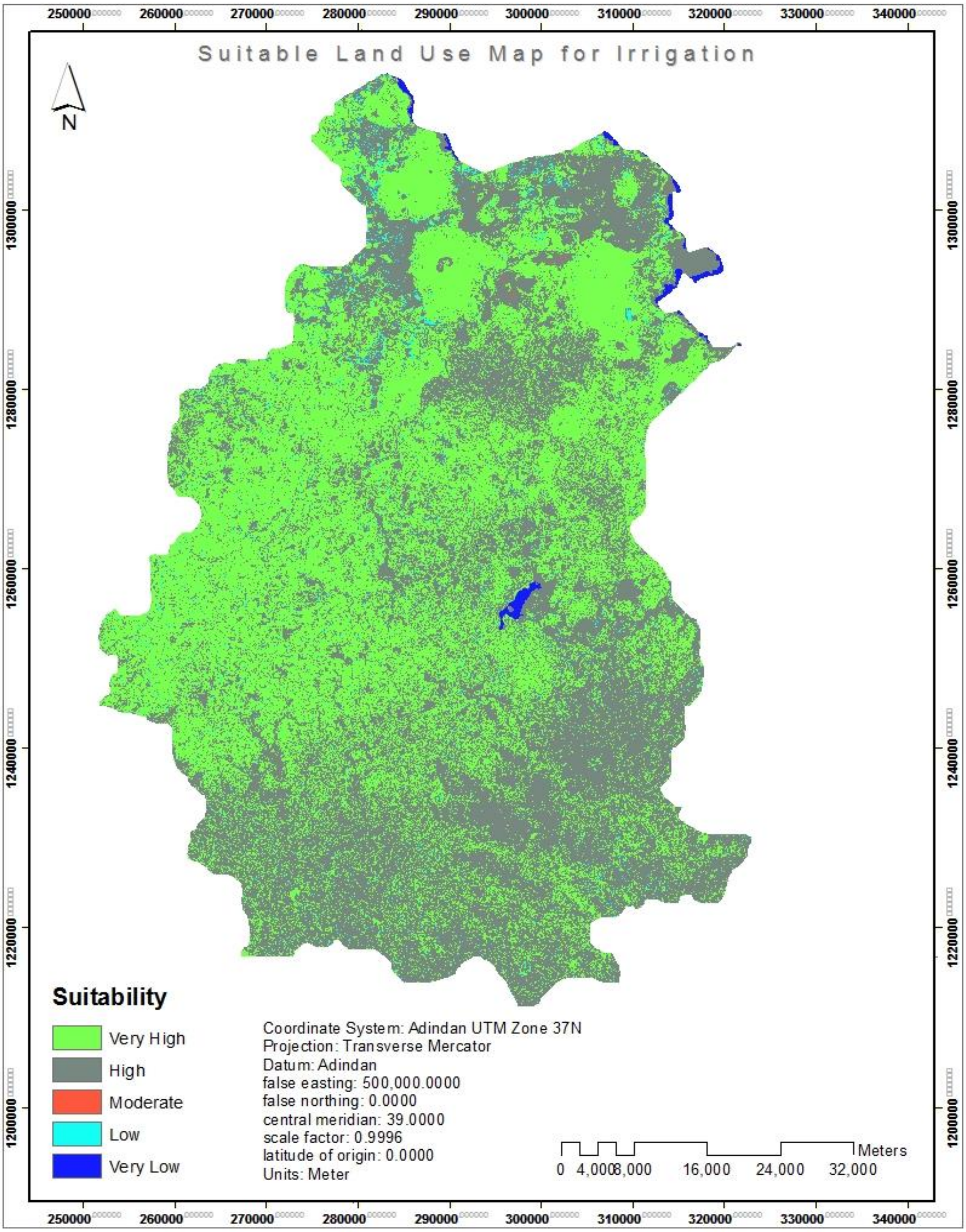

Figure 4. 3 Suitable Land use Map for Irrigation of Study area

4.2.4 Slope

Topography is one of the critical aspects that should be considered for the selection of suitable land for irrigation. Elevation is an important element in determining the climate, but not only that, with higher elevations, the winds get pushed up and clouds are being formed, which further lowers the temperatures in daytime.

Slope is important to soil formation and management because of its influence on runoff, soil drainage, and erosion, the use of machinery and choice of crops (Thomas,1996). It has direct implication on cultivation; steeper slope is more difficult to cultivate than gentler slopes. FAO guidelines suggest that slopes above 30% should not be cultivated, although such slopes are frequently cultivated in Ethiopia. Soil conservation methods directly related to slope. On slope <15%, agronomic and biological conservation methods should normally be sufficient. Above 15%, conservation structures become increasingly important because the steeper the slope is affected by highly erosion.

Hence, the FAO guideline for land slope ranges has been used and it states suitable order which further divided in highly suitable (S1) for slope up to 5% and moderately suitable (S2) for slope range between 5% and 8%. Land slope more than 8% is classified as not suitable for surface irrigation (FAO, 1994). Slope map of the area was prepared from DEM which was obtained from USGS site with 30m spatial resolution. According to FAO (1994) criteria of slope for irrigation, 90 % of the study area is flat enough (< 5% of slope) to be used for irrigation practice and 5.8 % of them were moderately suitable. As compared with suitable land for irrigation in the study area, only 4.2 % of the total area was not suitable due to high slope and steepness of the area. Hence, based on FAO (1994) , 90 % of the area have slopes less than 5% Gradient which have High class of suitability for surface irrigation.

Table 4. 4 Slope Suitability Map of the study area

Slope Gradient (%)	Suitability	Area (hectare)	Area (%)
<=5 %	High	417645.34	90
>5 &<8 %	Moderate	26914.92	5.8
>8 %	Low	19490.11	4.2
Sum		464050.37	100

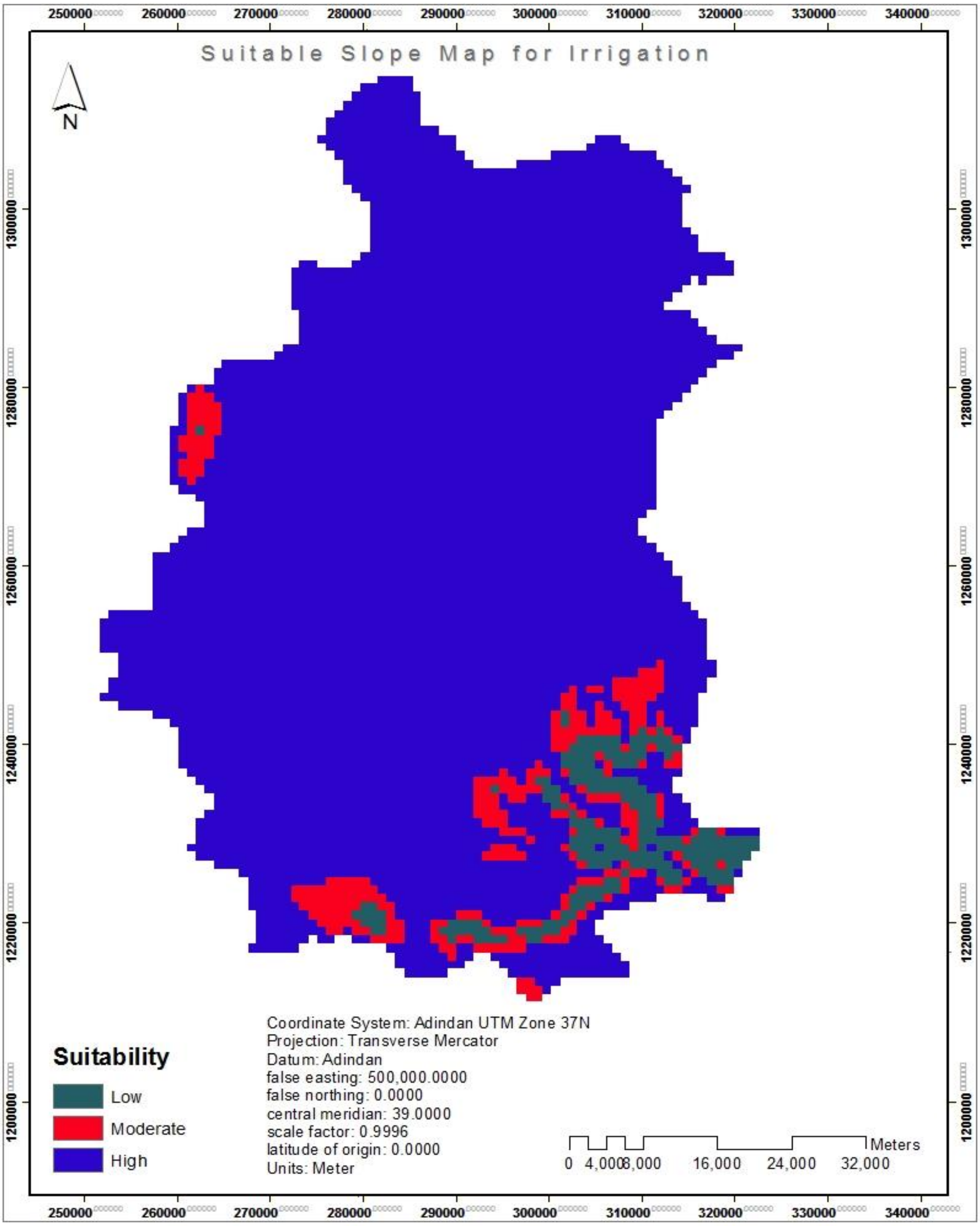

Figure 4. 4 Suitable Slope Map for Irrigation

4.2.5 Drainage

The drainage density affects the selection of suitable irrigable land as it reflects erosion, and flood as well as accumulation of flood plain in the catchment areas, and watershed tools of Hydrology tools in GIS software. There were various methods to determine drainage density. Due to lack of detailed stream shape file in the study area, stream networks were derived from DEM data. There was a high correlation between drainage density and erosion in most of the watersheds (Moeini, N. ,K. Zarandi, E. et al ,2015).

Hence, class of drainage density was classified as highly suitable to low suitable in consideration of water infiltration rate, and its effect in terms of soil erosion. This shows the density of streams with in the area, the higher the number of streams the more erosion will occurred around here based on visualization. The number of streams increases in the higher slope areas and higher elevation as shown in the watershed and slope map of the area.

In this watershed approximately 19.24 km^2 has length of the streams with 4640.62 km that falls in 0.455711 drainage density. In central parts, higher drainage density was fined whereas low density found within the periphery. The drainage density has been considered related with infiltration rate and runoff. Hence, higher infiltration rate was required in addition as water from the river for irrigation and therefore, low drainage density has more significance.

Table 4. 5 Suitability of Drainage Density of the study area

Suitability	Area(Hectare)	Area (%)
Very Low	65 013.45	14.01
Low	108 866.21	23.46
Moderate	120 189.04	25.9
High	82 972.20	17.88
Very High	87 009.44	18.75
Sum	464 050.36	100

Based on the result obtained (Figure 4.5) and their suitability class (Table 4.5), 18.75% of the study area fall as very highly suitable that to be used for Irrigation since it has the lowest Drainage Density. This characterize low run off and high infiltration rate to increase soil moisture contents (Fiona, J., Simon, M. et al, 2013). This area would have low erosion possibility as the numbers of streams are less that indicates flat topography too. Inconsideration of Drainage Density, 63 % of the area can be used for irrigation.

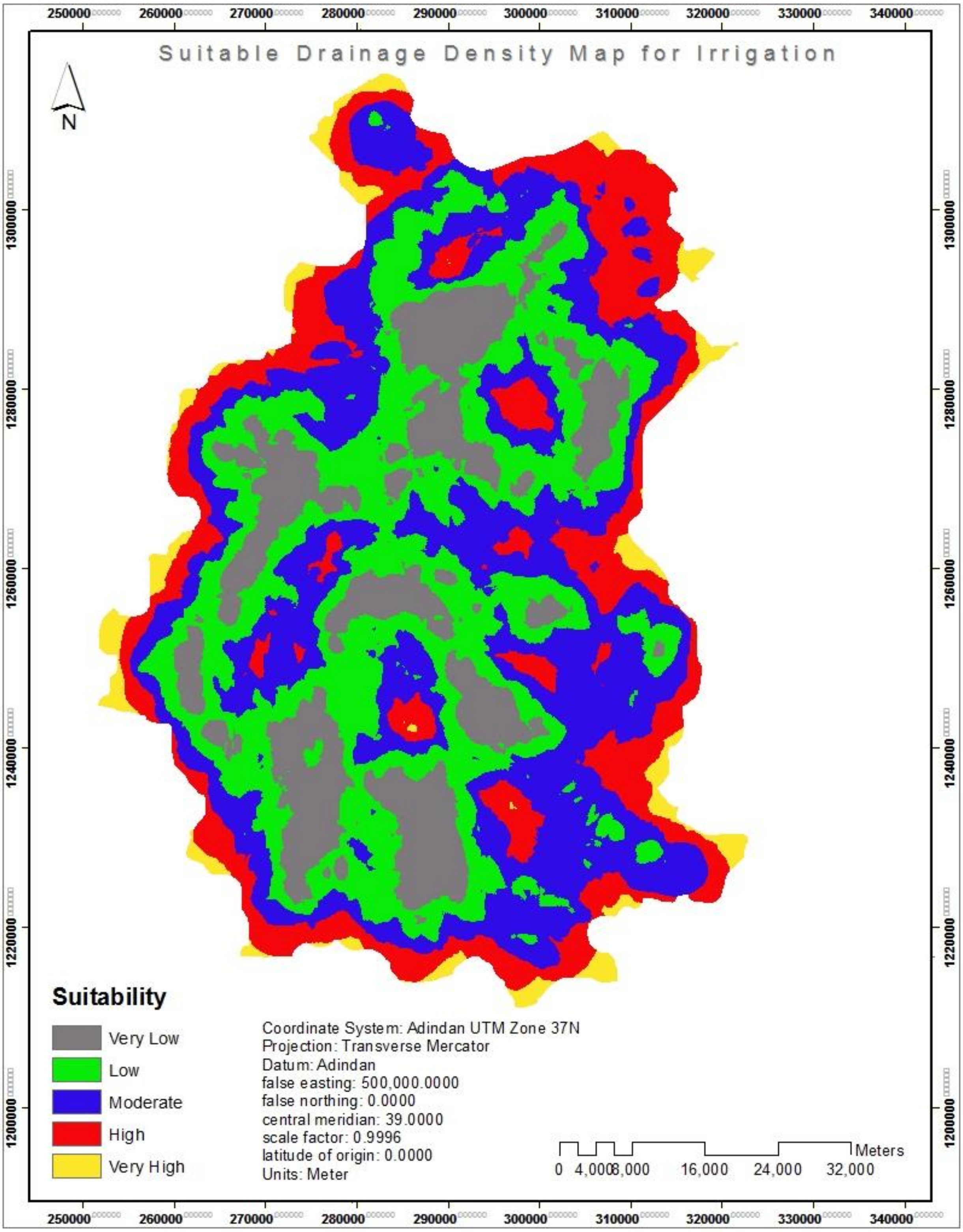

Figure 4. 5 Suitable Drainage Density Map for Irrigation of the study area

4.2.6 Proximity

As distance from river increases, so the cost of diverting water for irrigation and wastage of water also increases. Inconsideration of this factor, the proximity to irrigable land from Gilgel Abay River was used to reduce costs and wastage.

Quantifying the amount of water available for irrigation and determining the exact locations to which water can be economically transported are important in the decision to expand its use. It is also desirable that the water source be near the centre of the irrigated area to minimize the size of the delivery channels and pipelines. Therefore, distance from water sources to command area, nearness to rivers, is useful to reduce the conveyance system (irrigation canal length) and thereby develop the irrigation system economical (Carver, 2000).

Five classes from very high suitable (short distance) to very low (longest distance) were obtained. The cost of diverting water for irrigation & wastage of water for transportation reasons, distances up to 1000 meter considered as very highly suitable, from 1000 to 2000 meter as High, from 2000 to 4000 meter as Moderate, from 4000 to 6000-meter low & more than 6 km very low suitability order have been considered.

Table 4. 6 Proximity Suitability of the study area

Suitability	Area(Hectare)	Area(%)
Very Low	4 566.256	0.984
Low	183 559.77	39.556
Moderate	153 879.10	33.16
High	107 845.30	23.24
Very High	14 199.94	3.06
Sum	464 050.36	100

Depending on result (Figure 4.6), the coverage of suitability (Table 4.6), most of suitable irrigable lands were found far from the rivers. Almost 3.06% of the study area were found within1 km from River which was very highly suitable for irrigation. 4 km Distances from the rivers cover under highly and moderately suitable class which covers 56 % of the study area. Around 40 % of the study area was found away 6 km which incur costs for land preparation, canal development also wastage of water resources that characterize the area under low suitability.

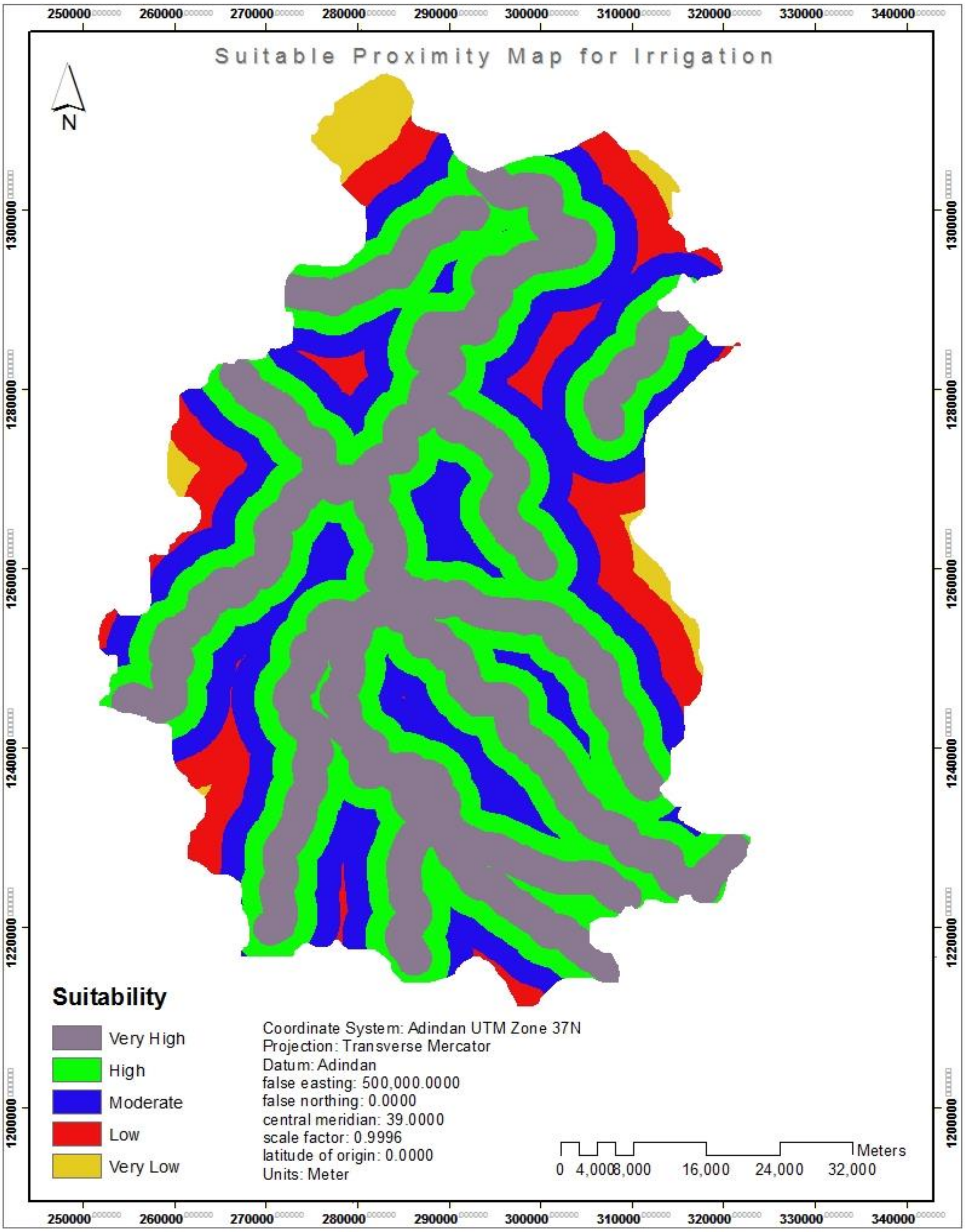

Figure 4. 6 Suitable Proximity Map for Irrigation of the study area

4.2.7 Rainfall

The minimum annual rainfall recorded in Adet is 1179 mm/year. While the largest amount recorded in Dangila with an amount of 2484 mm/year. This was an average of 30 years' measurement. The large amount of rainfall contributes for better irrigation water requirement practice. Even though there is no as such discrepancy in its distribution in the area, its amount as well as its spatial distribution should be considered for the selection of best irrigable land.

The amount of rainfall has significant contribution for irrigation in terms of increasing water consumption from rivers, increase soil water content and compensate the Evapotranspiration. It has also used to increase the intensity of crop pattern, irrigation water requirement, and irrigation scheduling. Availability of Large rainwater water will increase effective rain which reduces the wastage of water from irrigation (FAO, 1986). With regards to this contribution, the amount of rainfall map was produced and their classified map was produced with five suitability class. In the reclassification scheme, the higher suitability order has been assigned for areas that receive higher amount of average rainfall.

Table 4. 7 Rainfall Suitability Map of the study area

Suitability	Area (Hectare)	Area (%)
Very Low	47379.54	10.2
Low	250123.15	54.0
Moderate	112949.86	24.3
High	36752.79	7.9
Very High	16845.03	3.6
Sum	464050.36	100

As the result of reclassification indicated in (Figure 4.7) as well as their suitability order shows (Table 4.7), 3.6 % of the study area contributes very higher amount of rainfall for irrigation practice (from 2086 mm/year to 2484 mm /year average annual rainfall), 7.9 % and 24.3% have also contribute for high and moderate suitability class for irrigation (1811 to 2086, & 1612 to 1811 mm/year average rainfall respectively). More than half of the study area has got average rainfall between 1184 mm/year and 1612 mm/year which have low suitability orders. The availability of rainfall compensate water required for crop water requirement and hence enhances crop productivity.

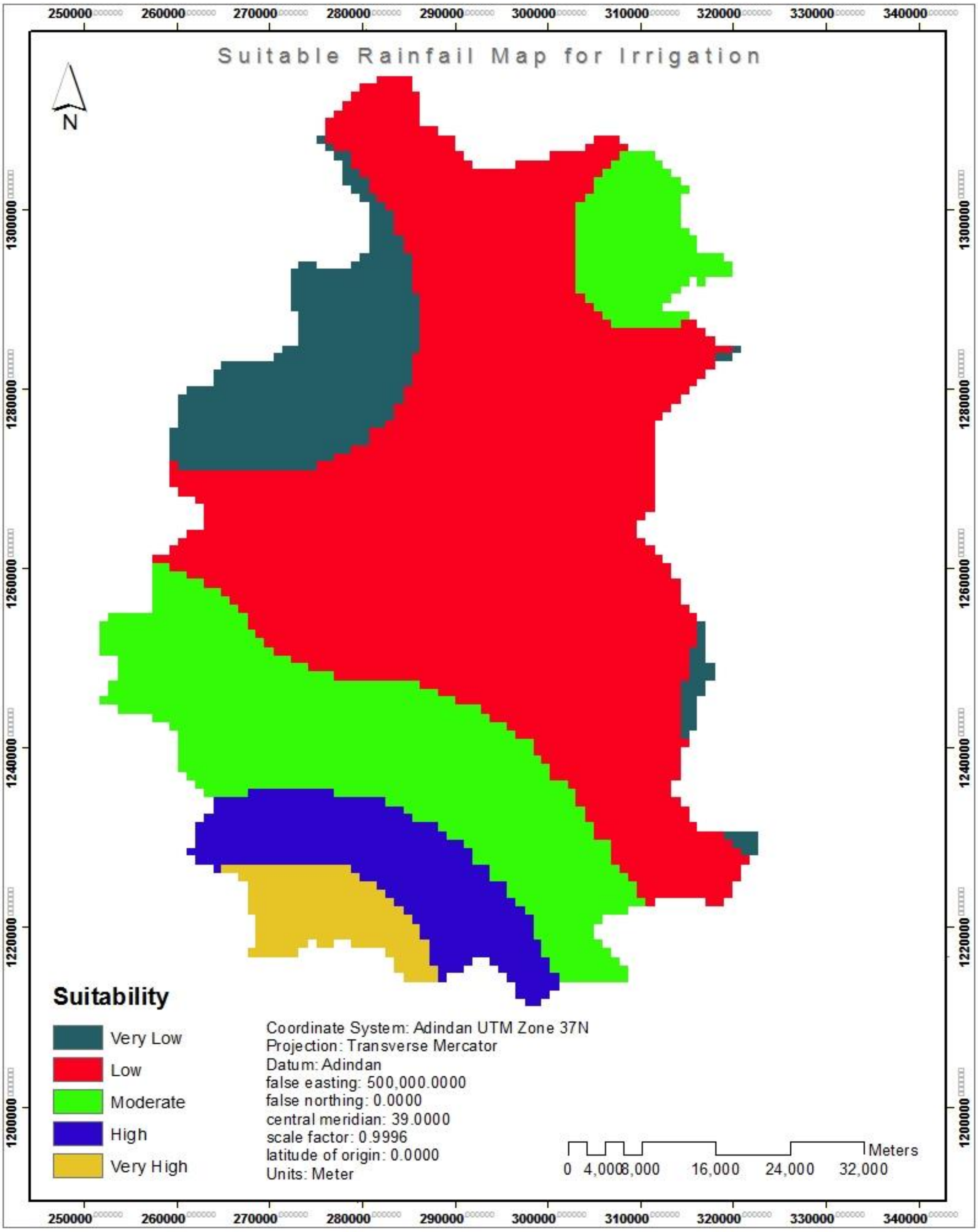

Figure 4. 7 Suitable Rainfall map for Irrigation of the study area

4.2.8 Temperature

The amount of temperature has an effect on plant growth in evapotranspiration process. The high temperature has increase evapotranspiration process which increases the demand of water. As a result, this parameter has direct relation with crop water requirement and irrigation scheduling.

The average temperature varies from 23 to 27 ^{o}C in the study area. As it has effect on evapotranspiration it was classified in to 3 categories. The high temperature has higher impact hence low class of temperature have higher weight. As Temperature have a direct effect on crop production, its amount should be considered that affect the amount of evapotranspiration. More water lost as evaporation when there is high temperature. Due to this, higher class of suitability given for low temperature. Based on this, temperature map of the study area is classified in three class of suitability. Almost 11.6 % of the study area has low class of temperature with higher suitability, 37% were moderately suitable & the rest 51% is under higher temperature which has lower class of suitability for irrigation (Figure 4.8 & Table 4.8).

Table 4. 8 Temperature suitability map of the study area

Suitability	Area in hectare	Area in %
Low	53 829.84	51.3
Moderate	172 162.69	37.1
High	238 057.84	11.6
Sum	464 050.37	100

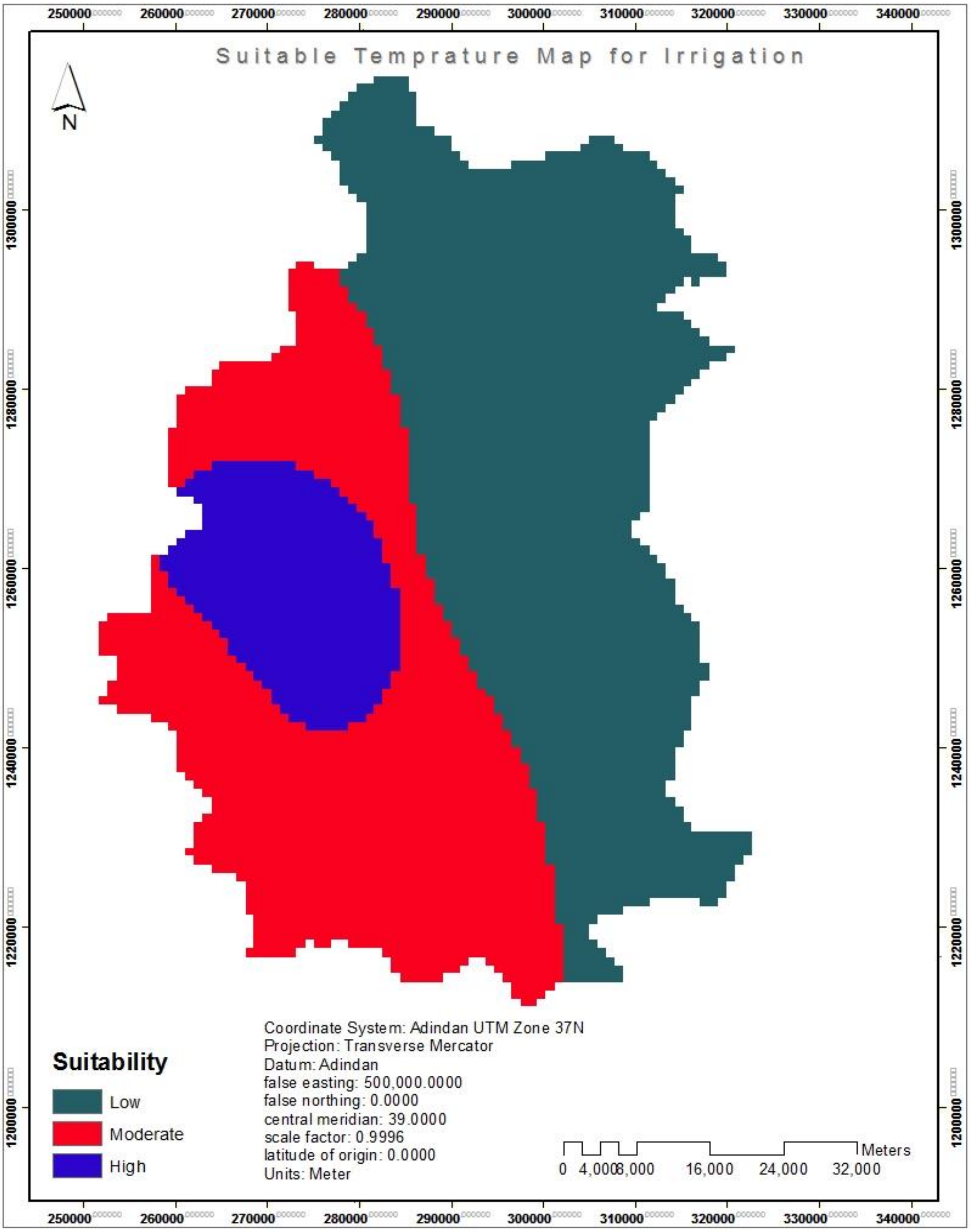

Figure 4. 8 Suitable Temperature map for Irrigation of the study area

4.2. Suitable Land for Irrigation

4.2.1 Result of Weighted Overlay

Based on critical analysis of all the factors that affect land analysis for irrigation, the priority of each of them for importance of final suitable land selection was done after discussion with experts and literature investigation (Meron, 2007, FAO, 1977). Their significance order is *i.e. soil type, land use, slope, drainage density, Soil Depth, proximity, rainfall and temperature* with their weights 41 ,25, 14, 9 ,5, 3 ,2 and 1 % respectively which were derived from IDRISI software. This implies that the total result was influenced by soil type as its significance is 41%.

After weight derivation for each of the factors, reclassification has been done. Further, the final suitable land for irrigation was produced by using weighted overlay technique of 1 to 9 by 2 evaluation scale. The weight of parameter and its assigned value for final result is based on its suitability order of each parameter during Weighted Overly as shown in Table 4.9.

Table 4. 9 Suitability of all parameters and their new value for Weighted Overlay

No	Parameter	Suitability	New value for Overlay	Weight (%)
1	Soil Type	Very Low	1	41
2	Drainage Density	low	3	9
3	Rainfall	Moderate	5	2
4	Proximity	High	7	3
5	Land Use	Very high	9	25
6	Soil Depth	Low	3	5
7	Temperature	Moderate	5	1
8	Slope	High	7	14

Five potential classes of suitability map for irrigation was produced using weighted overlay which are very high, high, moderate, low and very low suitability class with 14, 38, 36, 10 and 2 % of area coverage for irrigation (Table 4.10).

Based on visual Analysis of potentially suitable irrigable map result (Figure 4.10) and other factor maps (Figure 4.1 up to Figure 4.8), 62 % of the study area was under very high & high classes of suitability for irrigation (Table 4.11). This indicates that the area has productive soil types, Agricultural & Open land use type, deep soil, flat areas, low drainage Density, shorter distance from rivers, high amount of rainfall, and low Temperature qualities. Based on the result, 12 % (Low and very low suitability class) of the study area were not suitable for irrigation.

Table 4. 10 Suitability of reclassified weighted overlay result

value	Suitability	Area covered(ha)	Area covered (%)
1	Very Low	9 281.22	2
3	Low	46 405.61	10
5	Moderate	167 058.01	36
7	High	176 339.21	38
9	Very High	64 965.63	14
Sum		464 050.68	100 %

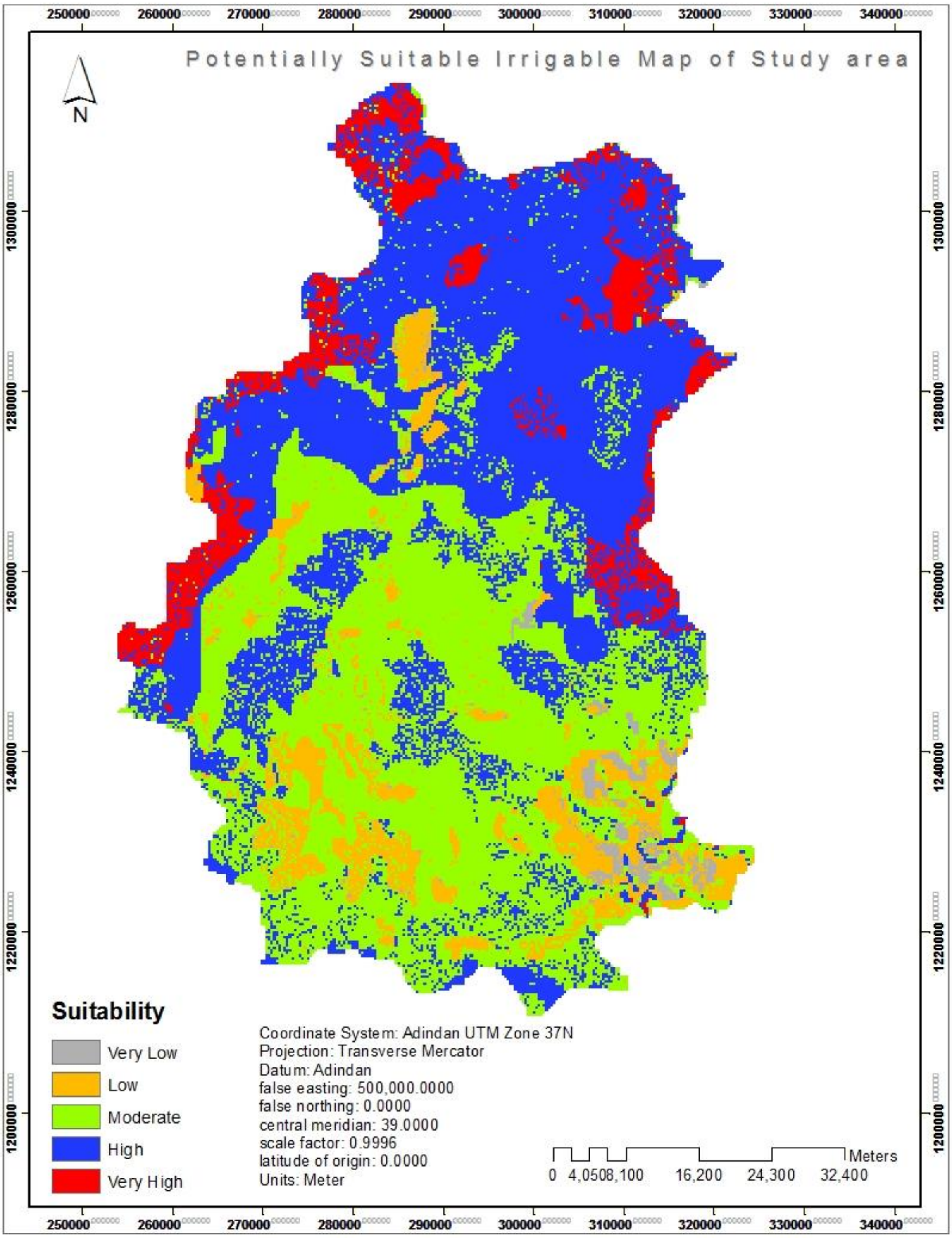

Figure 4. 9 Suitable Irrigable land

4.3 Water Requirement and Schedule in Irrigable Land

Study has found the suitable location for irrigation and subsequently sample crops were selected and the amount of water required and schedules for irrigation was analyzed using FAO CROPWAT 8.0. This used to propose the significance of irrigation in the site. The estimation of Crop Water Requirement needs the selection of appropriate crops that are likely to be grown in the specific climatic condition with their appropriate crop coefficients and the corresponding reference evapotranspiration.

The estimation of reference evapotranspiration (ETo) for the selected climatic stations is made using CROPWAT 8 Windows model. Calculations of the crop water requirements and irrigation requirements are carried out with inputs of climatic (evapotranspiration, rainfall, temperature, sunshine and humidity), crop and soil data. In order to analyze the difference of crop water requirement and irrigation schedule in different location of the study area, two locations (Bahir Dar and Dangila) which have different weather characteristics were identified.

$K_{c\ is}$ crop coefficient which shows the characteristics of crop and it varies in different crops as well as depending on its stage (Initial, mid, end stage) of each crop type. KC affected by three stages which were at initial stage (affected by soil evaporation), middle (ground cover plant development, crop type, humidity and wind speed) and end stages (harvesting date). The Kc used to estimate the Evapotranspiration of Crops (ETc) (ETc = Kc * ETo). Crop water requirement and schedule was calculated only for vertisol soil type which was the most favorable soil for irrigation and also covers large area in the study. The characteristics of this soil type (Appendix 3, Figure 7.3) and crops (Maize and Tomato) obtained from FAO sample data which comes with CROPWAT 8 window tool (Appendix 4, Figure 7.1 & Figure 7.2).

Maize and Tomato were used to estimate CWR in the study area as Maize is the dominant crop type and Tomato is also used as a major commercial crop in the region. The amount of water required as irrigation was the difference between Evapotranspiration undertaken by the crop and its effective utilization of water as rain. The water requirement in Bahir Dar and Dangila were calculated using Tomato and Maize crops.

Based on the result obtained from CWR, the amount of water loss as evapotranspiration by the crop (ETc) for Maize was 506.2 (mm/dec), and uses rainfall effectively (23.9 mm/dec). It requires 482.2 mm/decade water for irrigation in Bahir Dar. This crop has also lost 519.6 mm/decade as ETc which uses 46.9 mm/decade rainfall effectively and requires 473.3

mm/decade of water as Irrigation in Dangila (Table 4.11 & Details found in Appendix 4, Table7.4 and table 7.6). The result indicates that CWR in Bahir Dar is higher than Dangila.

The CWR (Table 4.11 & Details found in Appendix 5, Table 7.5 and table 7.7) of Tomato loses 188.4 mm/decade as evapotranspiration and used 7.6 mm/decade effective rainfall. But it requires 180.7 mm/decade water for irrigation in Bahir Dar. In Dangila station, the amount of water loss as ETc was 195.8 mm/decade, its effective rainfall consumption was 20.5 mm/decade and the amount of water required for the crop was 176.9 mm/decade. This result shows that CWR of Tomato in Bahir Dar is higher than Dangila due to lower effective rainfall and higher crop evapotranspiration in Bahir Dar. As a result of higher ETc of Tomato in its development season needs high CW in both Bahir Dar and Dangila.

According to the obtained result's, CWR of Maize is much higher than Tomato in Bahir Dar & Dangila (Table 4.11). This discrepancy is due to the variation of Maize and Tomato characteristics using the same Soil (Vertisol) type (Appendix 4, Figure 7.1 & Figure 7.2). Interestingly, this result showed by the different effective rainfall consumption of Maize and Tomato even the same amount of rainfall and soil type found in Bahir Dar. This major change of CWR of different crops (Maize & Tomato) in one location (both in Bahir Dar and Dangila) is due to variation of crop characteristics particularly the number of days required to grow and harvest varies (125 days required for Maize and 145 days required for Tomato).

As CWR was estimated based on decade basis, it has four stages which are initial, development, mid and late seasons. The CWR of Crops (Maize & Tomato) varies from each stages due to variation in Kc, ETc, and Effective rainfall. More water required during Development and Mid-season for Maize in both Bahir Dar and Dangil due to the crop evapotranspiration increases in this season, particularly in January, February &March (Appendix 5).

Table 4. 11 Summary of CWR for Maize and Tomato in Bahir Dar and Dangila

		Stations			
		Bahir Dar		Dangila	
Assessment items	Units	Maize	Tomato	Maize	Tomato
ETc	mm/dec	506.2	188.4	519.6	195.8
Effective rain	mm/dec	23.9	7.6	46.4	20.5
CWR	mm/dec	482.2	180.7	472.3	176.9

Based on the result obtained in crop irrigation (Appendix5 and Table 4.15), the schedule of Maize and Tomato in Bahir Dar and Dangila were estimated based on the amount of water required (flow) for each days (from growing to harvesting) with field efficiency of 70%.

Similarly, the result obtained in schedule the total gross irrigation, total net irrigation, flow & actual irrigation requirement of Maize was different from Tomato both in Bahir Dar and Dangila. Amount of continuous water discharge needed to satisfy crop irrigation requirements over the irrigation interval period (Flow) of Maize in Bahir Dar is 8.5 liter per second per hectare (l/s/ha) which was higher in Dangila. This discrepancy has noticed due to the variation of total gross irrigation in these locations. Similarly, the amount of water discharge for Tomato in Bahir Dar was higher than Dangila (Table 4.12 & details in Appendix 6).

The amount of water discharge for crop irrigation requirement of Tomato is 4.24 (l/s/ha). This high difference of flow varies as per the crop characteristics/stage days, rooting depth, Kc, crop height and depletion/ (Table 4.12 & details in Appendix 6).

The distribution of total gross irrigation as well as discharge of water as Flow varies from one season to the others (Initial, development, mid and late) in both Maize and Tomato at Bahir Dar and Dangila stations. More flow & total gross irrigation occurs during development and mid-season for Maize in both Bahir Dar Dar and Dangila, particularly in the months of January, February & March (Appendix 6).

Table 4. 12 Summary of Crop Irrigation schedule

Assessment items	Units	Stations			
		Bahir Dar		Dangila	
		Maize	Tomato	Maize	Tomato
Total Gross irrigation(TGI)	mm	799.4	266.8	768.5	274.7
Total net irrigation	mm	559.6	186.7	538	192.3
Total irrigation loss	%	0	0	0	0
Flow	l/s/ha	8.5	4.24	7.14	3.91
Actual water use by crop/ETc	mm	504.4	187.1	517.9	194.4
Potential water use by crop	mm	504.4	187.1	517.9	194.4
Efficiency irrigation schedule	%	100	100	100	100
Total rainfall	mm	23.8	7.4	47.1	21.7
Effective rainfall	mm	23.8	7.4	47.1	21.7
Total rain loss	mm	0	0	0	0
Efficiency rain	%	100	100	100	100
Moist deficit at harvest	mm	10.9	17.9	22.8	5.4
Actual irrigation requirement/CWR (ETc –effec.rainfall)	mm	480.5	179.6	470.8	172.7

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1. Conclusion

The GIS based Multi-criteria analysis for irrigation of potentially suitable irrigable land has been carried out in Gilgel Abay to analyze the suitable irrigable land and also computed CWR for the Maize and Tomato in Bahir Dar and Dangila regions. The weight for each parameter were derived using IDRISI software after their level of significance for land analysis was prioritized according to experts in this area with their respective weights.

Based on the final result, 62% of the study area has been found under very high & high classes of suitability for irrigation which indicates that this area has productive soil types, Agricultural & Open land land use type, deep soil, flat areas, low drainage Density, shorter distance from rivers, high amount of rainfall, and low temperature. Approximately 36 % of the area was moderately suitable and remaining 12% covers under low suitability order.

CWR of Maize in Bahir Dar was estimated 482.2 mm/decade which is larger than in Dangila (472.3 mm/decade). Moreover, the result obtained for Tomato in Bahir Dar and Dangila manifested 180.7 mm/decade of CWR is needed for Tomato in Bahir Dar which is greater in small extent with its CWR (176.9 mm/decade). Interestingly, this result showed by the different effective rainfall consumption of Maize and Tomato, even the same amount of rainfall and soil type found in Bahir Dar. Different crops have different CWR potential in similar locations according to the result obtained. As CWR of Maize (482.2 mm/decade) and Tomato (180.7 mm/decade) in Bahir Dar shows that different crops required different water amount for irrigation due to variation of crop charchetrstics. This result also supported by the result of CWR variation of Maize and Tomato in Dangila. Particularly the number of days required to grow and harvest them varies (125 days required for Maize and 145 days required for Tomato).

5.2 Recommendation

Based on the result of this paper, the following points were recommended for further investigation

- The analyses of land for irrigation did not consider the chemical characteristics of soil, quality of water and amount of water from rivers, Hence, it would be better to include to increase the productivity nature of the land using GIS based Multi-critrea Analysis.
- GIS based Multi-criteria land analysis for irrigation was not practiced in agricultural practice in Ethiopia. Identifying irrigable agricultural land and also consideration of type of crop in terms of water requirement and irrigation scheduling should be adopted.
- Crop water requirement of Maize and Tomato was carried out using FAO previously studied Crop and Soil characteristics. Hence it is recommended to apply Crop and Soil characteristics of the study area.
- The respective officials should adopt CWR and Schedule methods to manage water resources in irrigation areas as CWR and its water discharge varies for different crop types and locations.

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APPENDICES

Appendix 1 Metrological Data

Table 7.1 Metrological data of the study area

Type	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Average	Annual	
Rainfall	5.15	1.90	21.63	44.63	111.32	157.45	293.68	260.02	151.08	104.56	20.11	7.55	98.26	1179.08	Adet
Min.Temp	7.48	9.54	11.46	13.00	14.19	13.28	12.84	12.09	11.50	10.71	9.41	8.92	11.20	134.42	
Max.Temp	27.06	29.46	30.04	30.10	28.30	26.40	23.96	23.33	24.77	25.50	26.73	26.91	26.88	322.56	
RH	45.65	39.80	38.04	39.20	49.33	65.75	76.72	76.13	72.69	65.06	59.53	53.53	56.79	681.43	
SS	8.21	8.09	8.54	7.27	8.03	5.55	4.34	4.14	7.26	8.10	7.91	7.10	7.04	84.54	
WR	0.42	0.50	0.58	0.60	0.59	0.38	0.30	0.29	0.35	0.39	0.41	0.41	0.43	5.21	
Rainfall	1.82	0.10	10.60	25.81	85.22	158.76	424.40	399.55	188.06	88.59	10.79	4.71	116.53	1398.41	Bahir Dar
Min.Temp	7.82	9.24	12.24	14.11	15.08	13.66	13.83	13.69	13.17	13.47	11.13	8.16	12.13	145.61	
Max.Temp	27.15	29.13	30.10	30.33	29.35	28.18	24.01	24.76	25.65	26.64	26.81	26.59	27.39	328.69	
RH	46.46	41.77	40.95	41.00	55.49	66.20	76.42	89.72	73.17	64.67	57.41	52.76	58.83	706.01	
SS	9.31	9.59	9.18	9.31	7.34	6.17	4.64	4.77	6.26	8.77	9.38	9.64	94.37	7.86	
WR	0.86	0.96	1.20	1.31	1.11	1.14	0.93	0.89	0.91	0.89	0.86	0.78	0.99	11.84	
Rainfall	4.99	1.38	16.70	41.78	188.55	269.43	377.22	423.53	262.67	107.06	42.52	7.17	145.25	1743.00	Dangila
Min.Temp	5.92	7.20	9.17	10.90	11.34	12.50	12.31	12.28	11.61	10.50	8.13	6.03	9.82	117.87	
Max.Temp	26.63	28.39	28.84	28.49	26.41	24.07	22.39	22.23	23.52	24.46	25.21	25.75	25.53	306.39	
RH	46.10	40.85	40.89	42.73	60.99	74.19	81.41	81.23	78.02	72.18	62.82	55.75	61.43	737.17	
SS	8.62	8.87	8.07	8.21	6.88	5.86	3.88	4.13	5.74	6.61	7.93	8.31	6.93	83.10	
WR	0.61	0.68	0.81	0.87	0.83	0.73	0.70	0.70	0.59	0.49	0.46	0.52	0.67	8.00	
Rainfall	7.18	3.64	17.11	31.17	150.03	295.61	391.64	365.21	194.49	74.72	18.99	8.71	129.88	1558.50	Durbietie
Min.Temp	8.60	10.03	11.42	11.75	12.73	12.54	12.38	12.07	12.00	11.43	9.39	7.95	11.03	132.30	
Max.Temp	19.37	25.03	26.72	25.90	21.80	22.94	21.21	21.38	22.31	23.11	23.66	22.44	22.99	275.85	
Rainfall	4.95	3.90	13.62	40.64	161.12	305.54	397.01	319.82	203.42	82.59	20.30	4.09	129.75	1557.00	Merawi
Min.Temp	7.40	8.73	10.43	12.17	13.95	13.42	13.10	12.87	11.80	11.22	9.12	7.26	10.96	131.48	
Max.Temp	28.06	31.26	30.80	30.15	28.65	25.73	24.35	23.68	26.07	27.53	28.02	27.51	27.65	331.79	
Rainfall	5.96	2.62	26.56	41.18	241.86	171.87	246.69	258.21	206.48	86.49	30.76	14.79	111.12	1333.47	Injibara

Appendix 2 ETo Estimation in Bahir Dar and Dangila

Table 7. 2 ETo of Bahir Dar Station

Month	Station Bahir Dar		Altitude 1800	Latitude 11.59 E	Longitude 37.38 E		ETo
	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	7.8	27.1	46	78	9.3	20.6	3.73
February	9.2	29.1	42	86	9.6	22.5	4.34
March	12.2	30.1	41	104	9.2	23.2	4.92
April	14.1	30.3	41	112	9.3	23.9	5.25
May	15.1	29.4	55	95	7.3	20.5	4.52
June	13.7	28.2	66	95	6.2	18.5	4.04
July	13.8	24	76	78	4.6	16.2	3.25
August	13.7	24.8	90	69	4.8	16.7	3.18
September	13.2	25.6	73	78	6.3	18.8	3.65
October	13.5	26.6	65	78	8.7	21.4	4.05
November	11.1	26.8	61	69	9.4	20.9	3.81
December	8.2	26.7	65	61	10	20.9	3.57
Average	12.1	27.4	60	84	7.9	20.3	4.03

Table 7. 3 ETo of Dangila station

	Station Dangila		Altitude	2128	Longitude 36.8 E	latitude 11.04 E	
Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	5.9	26.6	63	52	11.9	24.3	3.92
February	7.2	28.4	63	52	12.3	26.5	4.53
March	9.2	28.8	65	69	11.9	27.4	5.01
April	10.5	28.5	66	69	11.4	27.1	5.08
May	11.3	26.4	70	69	10.2	24.8	4.62
June	12.5	24.1	74	61	8.3	21.6	3.98
July	12.3	22.4	76	52	7.3	20.2	3.65
August	12.3	22.2	77	52	7.2	20.4	3.65
September	11.6	23.5	74	43	8.2	21.8	3.85
October	10.5	24.5	71	35	9.2	22.2	3.83
November	8.1	25.2	67	35	10.5	22.6	3.7
December	6	25.7	64	43	11.5	23.1	3.65
Average	9.8	25.5	69	53	10	23.5	4.12

Appendix 3 Effective Rainfall

Table 7. 4 Effective Rainfall Estimation using CROPWAT

Station Bahir Dar			Station Dangila	
	Rain mm	Eff rain mm	Rain Mm	Eff rain mm
January	9.3	9.2	9.3	9.2
February	0.1	0.1	1.4	1.4
March	10.6	10.4	16.7	16.3
April	25.8	24.7	41.8	39
May	85.2	73.6	188.5	131.6
June	158.7	118.4	269.4	151.9
July	424.4	167.4	377.2	162.7
August	399.5	164.9	423.5	167.3
September	188	131.4	262.6	151.3
October	88.6	76	107	88.7
November	10.8	10.6	42.5	39.6
December	9.6	9.5	9.6	9.5
Total	1410.6	796.4	1749.5	968.5

Appendix 4 Crop and Soil charchetrstics

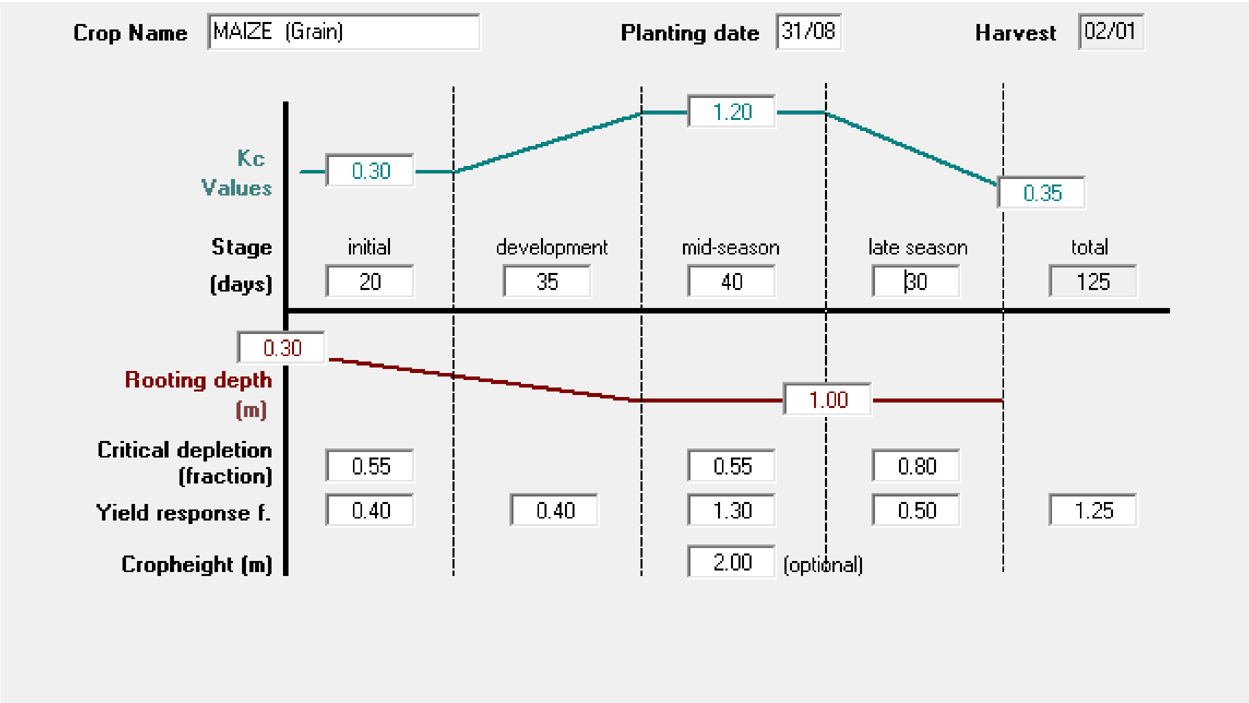

Figure 7. 1 Maize Crop Characteristics

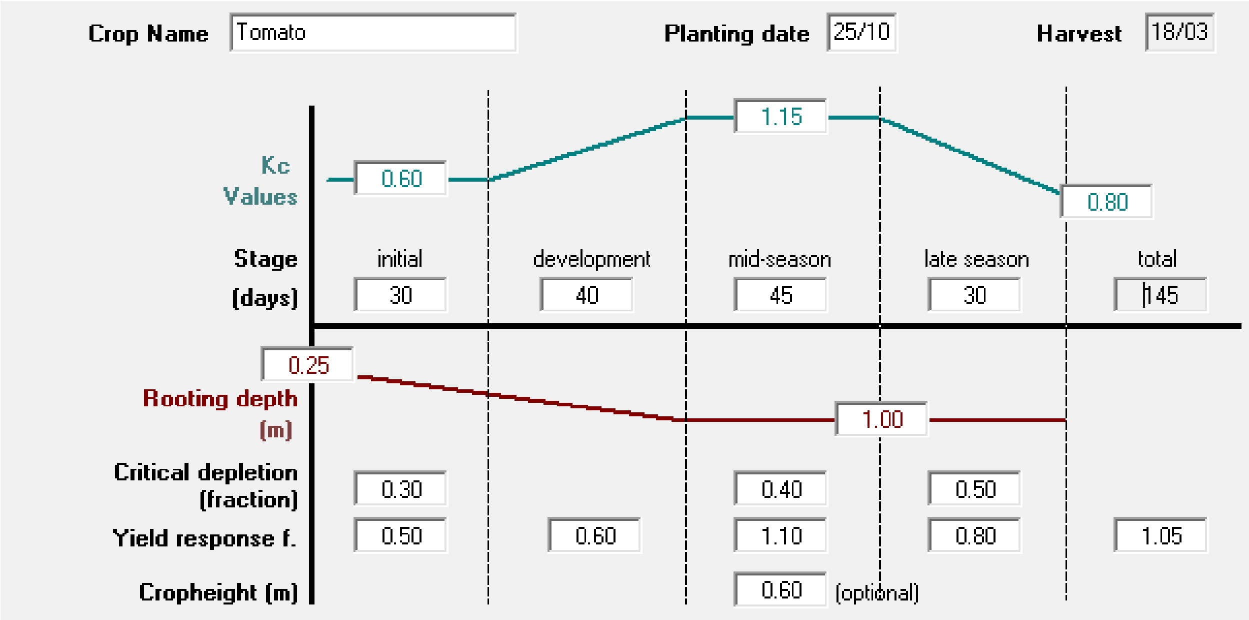

Figure 7. 2 Tomato crop characteristics

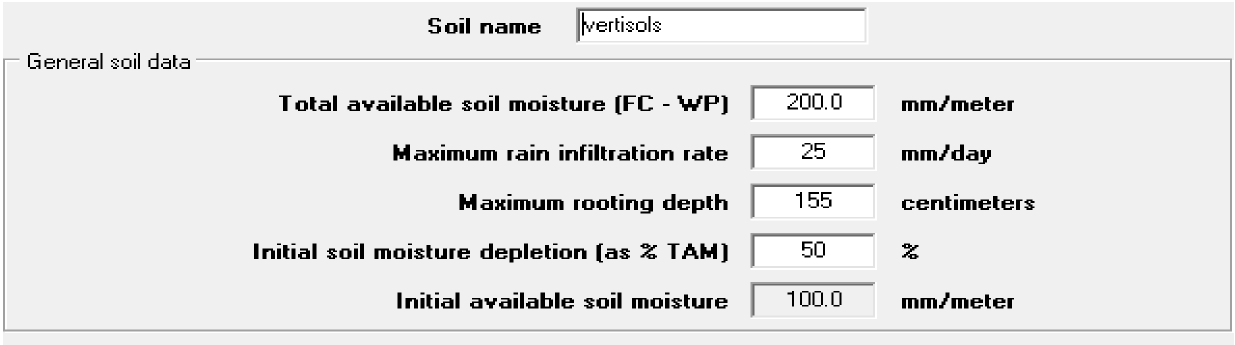

Figure 7. 3 Vertisol Soil Type Characteristics

Appendix 5 Crop water requirement

Table 7. 5 Crop water requirement for Maize around Bahir Dar

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	3	Init	0.4	1.49	13.4	0.9	12.4
25Dec	1	Init	0.4	1.46	14.6	2.1	12.4
Dec	2	Deve	0.46	1.65	16.5	1.5	15
Dec	3	Deve	0.6	2.19	24.1	1.2	22.9
Jan	1	Deve	0.75	2.75	27.5	0.9	26.6
Jan	2	Deve	0.88	3.3	33	0.6	32.4
Jan	3	Deve	1.03	4.04	44.4	0.4	44
Feb	1	Mid	1.17	4.83	48.3	0	48.3
Feb	2	Mid	1.22	5.28	52.8	0	52.8
Feb	3	Mid	1.22	5.51	44.1	0.2	44
Mar	1	Mid	1.22	5.75	57.5	2.2	55.3
Mar	2	Mid	1.22	5.98	59.8	3.3	56.5
Mar	3	Late	0.94	4.72	51.9	5	46.9
Apr	1	Late	0.35	1.83	18.3	5.6	12.7
					506.2	23.9	482.2

Table 7. 6 Crop water requirement for Tomato around Bahir Dar

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	3	Init	0.2	0.75	6.7	0.9	5.7
Dec	1	Init	0.2	0.73	7.3	2.1	5.1
Dec	2	Deve	0.32	1.15	11.5	1.5	10
Dec	3	Deve	0.67	2.44	26.9	1.2	25.7
Jan	1	Deve	1.03	3.79	37.9	0.9	37
Jan	2	Mid	1.22	4.54	45.4	0.6	44.8
Jan	3	Late	1.06	4.19	46	0.4	45.6
Feb	1	Late	0.32	1.34	6.7	0	6.7
					188.4	7.6	180.7

Table 7. 7 Crop water requirement for Maize around Dangila

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	3	Init	0.4	1.47	13.3	8.2	4.2
Dec	1	Init	0.4	1.47	14.7	5	9.6
Dec	2	Deve	0.46	1.69	16.9	1	15.9
Dec	3	Deve	0.6	2.26	24.9	1.2	23.7
Jan	1	Deve	0.75	2.86	28.6	1.9	26.7
Jan	2	Deve	0.88	3.46	34.6	1.7	32.9
Jan	3	Deve	1.02	4.22	46.5	1.3	45.2
Feb	1	Mid	1.17	5.04	50.4	0.4	50
Feb	2	Mid	1.21	5.49	54.9	0	54.9
Feb	3	Mid	1.21	5.69	45.5	1.2	44.4
Mar	1	Mid	1.21	5.89	58.9	3.5	55.4
Mar	2	Mid	1.21	6.09	60.9	5.1	55.8
Mar	3	Late	0.94	4.71	51.8	7.7	44.1
Apr	1	Late	0.35	1.77	17.7	8.3	9.5
					519.6	46.4	472.3

Table 7. 8 Crop water requirement for Tomato around Dangila

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Nov	3	Init	0.2	0.74	6.6	8.2	0
Dec	1	Init	0.2	0.73	7.3	5	2.3
Dec	2	Deve	0.32	1.18	11.8	1	10.8
Dec	3	Deve	0.67	2.52	27.8	1.2	26.6
Jan	1	Deve	1.03	3.95	39.5	1.9	37.5
Jan	2	Mid	1.22	4.77	47.7	1.7	46
Jan	3	Late	1.06	4.38	48.2	1.3	46.9
Feb	1	Late	0.32	1.4	7	0.2	6.8
					195.8	20.5	176.9

Appendix 6 Crop irrigation Schedule

The field efficiency is 70% for all schedule

Table 7. 9 Crop irrigation schedule of Maize in Bahir Dar

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
22-Nov	1	Init	0	1	100	68	5.6	0	0	8	0.92
26-Nov	5	Init	0	1	100	61	10.4	0	0	14.8	0.43
5-Dec	14	Init	0	1	100	60	22	0	0	31.4	0.4
21-Dec	30	Dev	0	1	100	57	40.9	0	0	58.4	0.42
7-Jan	47	Dev	0.5	1	100	53	57.6	0	0	82.3	0.56
22-Jan	62	Dev	0	1	100	46	65.1	0	0	93	0.72
5-Feb	76	Dev	0	1	100	44	75.4	0	0	107.7	0.89
19-Feb	90	Mid	0	1	100	42	74.9	0	0	107	0.88
5-Mar	104	Mid	0	1	100	43	76.8	0	0	109.8	0.91
18-Mar	117	Mid	0	1	100	40	72.2	0	0	103.1	0.92
31-Mar	130	End	0	1	100	33	58.7	0	0	83.9	0.75
10-Apr	End	End	0	1	0	6					
Sum							**559.6**			**799.4**	**8.5**

Totals

Total Gross irrigation	799.4 mm	Total rainfall	23.8 mm
Total net irrigation	559.6 mm	Effective rainfall	23.8 mm
Total irrigation loss	0.0 mm	Total rain loss	0.0 mm
Actual water use by crop	504.4	Moist deficit at harvest	10.9 mm
Potential water use by crop	504.4 mm	Actual irrigation requirement	480.5 mm
Efficiency irrigation schedule	100 %	Efficiency rain	100 %
Deficiency irrigation schedule	0.0 %		

Table 7. 10 Crop irrigation schedule of Maize in Dangila

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
22-Nov	1	Init	0	1	100	68	5.6	0	0	8	0.92
30-Nov	9	Init	0	1	100	60	15.5	0	0	22.1	0.32
16-Dec	25	Dev	0	1	100	59	35.8	0	0	51.1	0.37
2-Jan	42	Dev	0	1	100	55	53.8	0	0	76.9	0.52
18-Jan	58	Dev	0	1	100	48	64	0	0	91.5	0.66
1-Feb	72	Dev	0	1	100	44	71.2	0	0	101.8	0.84
14-Feb	85	Mid	0	1	100	41	74	0	0	105.7	0.94
28-Feb	99	Mid	0	1	100	43	77.3	0	0	110.5	0.91
14-Mar	113	Mid	0	1	100	43	77.1	0	0	110.2	0.91
28-Mar	127	End	0	1	100	35	63.6	0	0	90.9	0.75
10-Apr	End	End	0	1	0	13					
	sum						**537.9**			**768.7**	**7.14**

Totals

Total Gross irrigation	768.5 mm	Total rainfall	47.1 mm
Total net irrigation	530.8 mm	Effective rainfall	47.1 mm
Total irrigation loss	0.0 mm	Total rain loss	0.0 mm
Actual water use by crop	517.9 mm	Moist deficit at harvest	23.8 mm
Potential water use by crop	517.9 mm	Actual irrigation requirement	470.8 mm
Efficiency irrigation schedule	100 %	Efficiency rain	100 %
Deficiency irrigation schedule	0.0 %		

Table 7. 11 Crop irrigation schedule of Tomato in Bahir Dar

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
23-Nov	2	Init	0.3	1	100	60	7	0	0	9.9	0.58
6-Dec	15	Init	0	1	100	61	13.4	0	0	19.1	0.17
21-Dec	30	Dev	0	1	100	62	20.9	0	0	29.9	0.23
31-Dec	40	Dev	0	1	100	65	26.9	0	0	38.5	0.45
7-Jan	47	Dev	0.5	1	100	60	28.2	0	0	40.3	0.67
14-Jan	54	Mid	0	1	100	61	30.3	0	0	43.3	0.72
21-Jan	61	Mid	0	1	100	62	31.1	0	0	44.5	0.74
28-Jan	68	End	0	1	100	58	28.9	0	0	41.3	0.68
5-Feb	End	End	0	1	100	36					
	Sum						**186.7**			**266.8**	**4.24**

Totals

Total Gross irrigation	266.8 mm	Total rainfall	7.4 mm
Total net irrigation	186.7 mm	Effective rainfall	7.4 mm
Total irrigation loss	0.0 mm	Total rain loss	0.0 mm
Actual water use by crop	187.1 mm	Moist deficit at harvest	17.9 mm
Potential water use by crop	187.1 mm	Actual irrigation requirement	179.6 mm
Efficiency irrigation schedule	100 %	Efficiency rain	100 %
Deficiency irrigation schedule	0.0 %		

Table 7. 12 Crop irrigation schedule of Tomato in Dangila

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr	Flow
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha
14-Dec	23	Dev	0	1	100	64	17.8	0	0	25.5	0.13
25-Dec	34	Dev	0	1	100	63	23.1	0	0	33	0.35
3-Jan	43	Dev	1	1	100	66	29	0	0	41.5	0.53
11-Jan	51	Dev	0	1	100	68	34.2	0	0	48.9	0.71
18-Jan	58	Mid	0	1	100	63	31.7	0	0	45.2	0.75
25-Jan	65	Mid	0	1	100	62	30.8	0	0	44	0.73
31-Jan	71	End	0	1	100	51	25.7	0	0	36.7	0.71
5-Feb	End	End	0	1	100	11					
	sum						**192.3**			**274.8**	**3.91**

Totals

Total Gross irrigation	274.7 mm	Total rainfall	21.7 mm
Total net irrigation	192.3 mm	Effective rainfall	21.7 mm
Total irrigation loss	0.0 mm	Total rain loss	0.0 mm
Actual water use by crop	194.4 mm	Moist deficit at harvest	5.4 mm
Potential water use by crop	184. mm	Actual irrigation requirement	172.7 mm
Efficiency irrigation schedule	100 %	Efficiency rain	100 %
Deficiency irrigation schedule	0.0 %		