GROUNDWATER IRRIGATION POTENTIAL ASSESSMENT OF THE LAKE HARAMAYA WATERSHED, OROMIYA, EASTERN ETHIOPIA

M.Sc. THESIS

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This is to certify that the thesis/dissertation entitled "GROUNDWATER IRRIGATION POTENTIAL ASSESSMENT OF THE LAKE HARAMAYA WATERSHED, WABISHEBELE RIVER BASIN, EASTERN ETHIOPIA" submitted in partial fulfillment of the Requirements for the degree of Master of Science (M.Sc.)) with specialization in, the Graduate Program of the Department of WATER resource and irrigation engineering, and has been carried out By Ashenafi Berhanu ID. No. PGIrDrR/0003/11, under our supervision. Therefore, we recommend that the student has fulfilled the requirements and hence hereby can submit the dissertation to the department.

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STATEMENT OF AUTHOR

I hereby declare that this Master of Science 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: Ashenafi Berhanu

Signature________________DATE________________

LIST OF ABBREVIATIONS AND ACRONOMYS

ADSWE	Amahara Design and Supervision Enterprises
AET	Actual Evapotranspiration
AHP	Analytical Hierarchy Process
ASCII	American Standard Code for Information Exchange
Ave	Average
CMB	Combolcha
CROPWAT	Crop Water Requirement Software program
CSA	Central Statistics Agency
Cu	Consumptive Use
CWR	Crop Water Requirement
DEM	Digital Elevation Model
ERDAS	Earth Resources Data Analysis System
ET	Evapo Transpiration
ETc	Crop Evapo-transpiration
ET_O	Reference Crop Evapo-transpiration
FAO	Food and Agriculture Organization
Fig	Figure
GDP	Gross Domestic Product
GIS	Geographical Information System
GIWR	Gross Irrigation Water Requirement
GPS	Geographic Positioning System
GWIP	Groundwater Irrigation Potential
Ha	Hectares
HRM	Haramaya
HRR	Harar
IIDS	International Irrigation & Development Institute
IR	Irrigation Requirements
IWMI	International Water Management Institute
KC	Crop Coefficient

KM^2	Square kilometer
KRS	Karsa
L/c/d	Liter per Capita per Demand
LULC	Land use Land cover
m.s.l	Mean Sea Level
M^3	Cubic Meter
MCE	Multi-Criteria Evaluation
Mha	Million hectares
mm	millimeter
MOA	Ministry Of Agriculture
MoA	Ministry of Agriculture
MoARD	Ministry of Agriculture and Rural Development
MoWR	Ministry of Water Resources
N	Permanently not suitable
NASA	National Aeronautics and Space Administration
NIWR	Net Irrigation Water Requirement
NMA	National Meteorological Agency
PASDEP	Sustainable Development to End Poverty
PCP	Precipitation
PET	Potential Evapotranspiration
RWH	Rain Water Harvesting
S	Suitable class
SRTM	Shuttle Radar Topography Mission
SWAT	Soil and Water Assessment Tool Standard for Water Works
TBL	Table of Values
USDA	United States Department of Agriculture
USGS	United State Geological Survey
UTM	Universal Transfer Mercator
WetSpass	Water and energy transfer between Soil, plant, and atmosphere at quasi-steady state

TABLE OF CONTENTS

Contents **Page**

LIST OF TABLES

LIST OF FIGURES

LIST OF TABLES IN APPENDICES

LIST OF FIGURES IN APPENDICES

ABSTRACT

There is growing concerned about food security in Africa and especially in sub-Saharan Africa, Ethiopia. Even in good years, Ethiopia cannot meet its large food-deficit through rain-fed production. Irrigation in Ethiopia is considered a basic strategy to alleviate poverty and hence food security. Most of the traditional irrigated lands in Ethiopia are dominantly supplied by surface water sources; while groundwater is smaller, this means that there is significant potential to increase irrigation sources from the groundwater. This paper focuses on further developing groundwater irrigation potential in the Lake Haramaya watershed. The concept of the approach is to identify the irrigation potential of the groundwater by comparing monthly and annual groundwater availability and crop irrigation requirements after satisfying the human and environmental groundwater needs. A GIS-based MCE technique was used to identify potential land suitable for surface irrigation using groundwater. Key factors that significantly affect irrigation suitability evaluated in this study include the slope, land use, soil depth, soil texture, soil drainage, and road proximity and town proximity factors. The suitability of individual factors was analyzed separately and assigning the weight to each factor then overlaid using the weighted overlay tool in Arc GIS to get the overall suitability based on the criteria set by FAO for surface irrigation using groundwater. The available groundwater potential for irrigation was quantified by allocating some fraction of groundwater recharge that is in excess after satisfying other human needs and environmental requirements. The groundwater recharge was estimated using spatially distributed physical-based models called WetSpass. WetSpass-M model has been simulated the monthly and annual water balance components of Lake Haramaya watershed successfully. The key components WetSpass-M model analyzing include rainfall, groundwater depth, wind, temperature, PET, land use, soil, slope, topography, soil look up table, and land use lookup table data. The human water demand was estimated by multiplying the total projected population of three towns (Harar, Haramaya, and Bate) with 20l per capita per day. Due to the high uncertainty of groundwater environmental needs, three scenarios, leaving 30, 50, and 70 % of recharge for the environment, were implemented. And finally, crop irrigation water requirements were computed using the CROPWAT model. The key components of the CROPWAT model input include climate data, crop data, and soil data. The irrigation potential of the groundwater was identified by comparing groundwater availability and crop irrigation demand after satisfying the human and environmental groundwater needs. The result of the suitability analysis revealed that around 56.33% (7031ha) of the total watershed area (12,481.3 ha) was in the range of high to marginally suitable for surface irrigation development using groundwater. Results of the analysis show that average annual renewable groundwater availability for irrigation ranges from 174165268.8 to 321036480m3depending on the scenario. The CROPWAT8.0 model result revealed that crop irrigation requirements vary due to climatic station and type of major crops selected. The total crop irrigation requirements irrigable with groundwater ranges from 15531349.6 to 2274841.40 m3/year over the watershed. By comparing monthly groundwater available in m3/s at all scenarios with monthly crop gross irrigation demand in m3/s, the obtained total irrigation potential of the study area was 12,012.57ha. To conclude, this indicates that there is significant potential to increase irrigation sources from the groundwater.

Keywords: Groundwater irrigation, Land suitability, Groundwater availability, Crop irrigation requirements, Groundwater recharge.

1. INTRODUCTION

1.1. Background

Agriculture in Ethiopia is crucial for the country's food security and the sector is the largest contributor to overall economic growth and poverty reduction. The national strategy for "agricultural development-led industrialization" (ADLI) puts agriculture at the forefront of Ethiopia's development process. This strategy is reflected in the Plan for Accelerated and Sustainable Development to End Poverty (PASDEP). A central theme of the PASDEP is a call for accelerated market-based agriculture development with a focus on Ethiopia's 13 million smallholder farm households producing around 98 percent of the country's agricultural output (MoA, 2004).

Ethiopian Agriculture was characterized largely by rain-fed dependence that causes severe damage in agriculture due to shortage of rainfall and others. Over 85% of the population's livelihood base is agriculture-dependent, and thus development and technical support for the sector are of paramount importance. Thus technical support for the development of the available water resources and irrigation is inevitable and necessary to bring sustainable food production and agricultural development to achieve increased livelihood bases, income improvement, and generally to promote socio-economic development of the country. (Gamachu et al ., 2018).

Irrigation in Ethiopia is considered a basic strategy to alleviate poverty and hence food security. Irrigation expansion is seen as significant leverage to food security, livelihoods, rural development, and agricultural and broader economic development. It is useful to transform the rain-fed agricultural system which depends on rainfall into the combined rain-fed and irrigation agricultural system (MoA, 2004). (Makombe et al., 2011), Noted that irrigation development is a key for sustainable and reliable agricultural development which leads to overall development in Ethiopia.

Rainfall is available in multiple forms that can be used for agriculture and irrigation. These forms include surface water (perennial and seasonal rivers), groundwater, wetlands, soil moisture, and rainwater (captured or lost through evapotranspiration). However, these water sources are severely underdeveloped and under-utilized in Ethiopia, which implies that there is significant potential to increase water usage from these and other sources (Seleshi et al., 2010). Most of the traditional irrigated lands in Ethiopia are dominantly supplied by surface water sources, while groundwater uses has just been started on a pilot basis in the East Amhara region (MoA, 2004) . The Ethiopian Ministry of Water Resources (MoFD, 1999) , and Awulachew et al. (2007) reported that the country has significant surface water potential from its twelve major river basins, but there high spatial and temporal variability (Worqlul et al., 2015). Although there is no detailed study on groundwater resource potential in Ethiopia, a recent study by (MacDonald, et al., 2001) indicates that Africa has substantial groundwater storage. They estimate that the annual ground water storage in Africa has 100 times more than the annual renewable freshwater resources.

As Ethiopia is described as the water-tower" of Africa (Birkett et al., 1999); (Hammond et al, 2013); (Swain and A., 1997)), it may be fair to assume that Ethiopia may have the lion's share of this groundwater potential. Ethiopia is endowed with water resources, which could be easily tapped and used for irrigation. Water resources are the central element for the development of Ethiopia (MoFD, 1999) However; these water sources are severely underdeveloped and under-utilized in Ethiopia due to a lack of knowledge of the resource and the best options for sustainable development (Seleshi et al., 2010).

Groundwater will remain the ultimate source of freshwater while surface water sources have been depleted. Groundwater is more suitable for irrigation than surface water since it has a slow response to climate variability and requires less treatment (Sieber et al., 2010).

The total irrigable land potential in Ethiopia is 5.3Mha assuming the use of existing technologies, including 1.6Mha through RWH and groundwater. This means that there are potential opportunities to vastly increase the amount of irrigated land (Seleshi et al., 2010). Qualitative, relative groundwater potential was mapped for Ethiopia by (MacDonald, et al., 2001), however, with no specific focus on the irrigation potential. Much progress is achieved in using groundwater for cultivation in Asia (Sieber et al., 2010). The use of groundwater for irrigation has significantly affected agricultural growth in Asia, for example, especially after the green revolution. Groundwater played a critical role to support the agriculture industry (

(Altchenko et al., 2015). However, in Africa groundwater less utilized resource. For example, in Ethiopia, groundwater is not adequately used due to higher development and operational cost and a lack of understanding of the resource dynamics (Seleshi et al., 2010). The groundwater in Ethiopia is mainly used for domestic water use. There may be limited cases where the groundwater is used for irrigation and their purposes.

Estimates suggest that groundwater irrigation potential is 1.1 Mha irrigable potential by zone as with surface water potential, this total means that there is significant potential to increase irrigation sources from the groundwater. Despite some gross estimates (MoFD, 1999)and large-scale assessments of groundwater irrigation potential (MacDonald, et al., 2001), there is a little quantitative study on the groundwater resource potential for irrigation and other none domestic water uses. Since recent information indicates that Ethiopia's groundwater potential could be significantly higher than currently estimated, this 1.1Mha estimate can be refined in the future when more relevant information can be generated through further research and study (Seleshi et al., 2010). As a result, it's important to consider further developing groundwater irrigation potential in Ethiopia particularly the Lake Haramaya watershed. The objective of the present study is, to assess groundwater irrigation potential for the Lake Haramaya watershed in the GIS environment.

1.2. Statement of the Problem

A combination of population growth, land degradation, and more frequent droughts will result in more frequent food-related crises. Irrigation development is therefore perceived as one of the strategies with the potential for solving the problem related to food. (Makombe et al, 2007). (Tadesse, 2002), Argued that food shortage can be minimized if farmers have access to irrigation water.

The Ethiopian Ministry of Water Resources (MoWR, 2002)and (Seleshi et al., 2010) reported that the country has significant surface water potential from its twelve major river basins, but there high spatial and temporal variability (Worqlul et al., 2015). A recent study by MacDonald, Bonsor Dochartaigh, and Taylor (2012) indicates that Africa has substantial groundwater storage. (Seleshi et al., 2010) Suggest that groundwater irrigation potential is 1.1

Mha irrigable potential by zone as with surface water potential, this total means that there is significant potential to increase irrigation sources from groundwater.

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The Lake Haramaya watershed has no surface water; groundwater is the sole source for irrigation and domestic purposes. There is no detailed study on groundwater resource potential in the watershed in terms of irrigation potential after satisfying other groundwater needs such as human and environmental water needs. The challenges of expansion of groundwater-based irrigation in the watershed include a lack of knowledge of the resource and best options for renewable groundwater irrigation development.

The combination of the available land resources suitability for irrigation which expressed in hectares, available groundwater resources expressed in m3 per year that is in excess after satisfying the human water needs and environmental water requirements, and knowledge of the irrigation water requirements, expressed in m3 per year or mm per year, for assessing the groundwater irrigation potential is necessary. This paper focuses on the assessment of the groundwater irrigation potential in the Lake Haramaya watershed. The concept of the approach is to identify the irrigation potential of the groundwater by comparing groundwater availability and crop irrigation demand after satisfying the human and environmental water requirements.

1.3. Objective

1.3.1. General Objective

The general objective of this study was to assess the groundwater irrigation potential in the Lake Haramaya watershed.

1.3.2. Specific objective

The specific objectives of the study include:

- ✓ To identify available land resources suitability for irrigation in the study area;
- ✓ To quantify the groundwater resources of the study area;

- ✓ To determine crop irrigation demand for major crops;
- ✓ To compare groundwater availability and crop irrigation requirements at the study area.

1.4. Research Questions

1. What is the suitability of land for irrigation in the study area?
2. How much groundwater resources at the study area?
3. What is the crop irrigation demand of the study area?
4. How much crop can groundwater potentially irrigate in the watershed?
5. How much crop water demand can available groundwater irrigate?

1.5. Scope of approach

The methods following in the present study assumes that groundwater is the sole source of irrigation water and provides an estimate of the crop irrigation demand that could potentially irrigate by available groundwater for irrigation. The groundwater irrigation potential is the cropland area that can be irrigated with the available groundwater resources (as the excess of the groundwater recharge after satisfying other demands from humans and the environment), and crop irrigation requirements base on crop distribution and cropping calendar. The water balance approach considers water availability as the major controlling parameter for GWIP and assumes spatial characteristics.

1.6. Significance of the study

Irrigation technology is one means by which agricultural production can be increased to meet the growing demand for food. This implies that irrigation is one of the ranges of technologies available to increase agricultural production and maximize household income to improve rural livelihood. Spatial information on irrigation is highly important for policy and decision-makers, who are facing the transition towards more efficient sustainable agriculture (Jonas et al., 2018) to understanding trends in food production and their associated drivers (Meha et al., 2020) . This study provides an assessment of the groundwater irrigation potential of the Lake Haramaya watershed by synthesizing the latest information sources.

It confirms the availability of reliable and adequate groundwater resources, identification of potentially irrigable land, an irrigation potential of available groundwater, and knowledge of crop water requirements which could be informed policy and decision-makers about the groundwater irrigation potential of the study watershed that can be utilized as a foundation to support the advancement of economic and human development in the study area.

2. LITERATURE REVIEW

2.1. Irrigation Potential in Ethiopia and future development

2.1.1. Irrigation Potential in Ethiopia

Ethiopia has vast cultivable land (30 to 70 Mha), but only about a third of that is currently cultivated (approximately 15 Mha), with current irrigation schemes covering about 640,000 ha across the country. However, the study estimates that the total irrigable land potential in Ethiopia is 5.3 Mha assuming the use of existing technologies, including 1.6 Mha through RWH and groundwater. Despite significant efforts by the Government of Ethiopia (GOE) and other stakeholders, improving agricultural water management is hampered by constraints in policy, institutions, technologies, capacity, infrastructure, and markets. Addressing these constraints is vital to achieving sustainable growth and accelerated development of the sector in Ethiopia (Seleshi et al., 2010).

The estimates of the irrigation potential of Ethiopia vary from one source to the other, due to the lack of standard or agreed criteria for estimating irrigation potential in the country. The earlier reports for example according to World Bank (1973) as cited in (Rahmato, 1999), show the irrigation potential at the lowest 1.0 and 1.5 million hectares, and the highest according to (Tilahun et al., 2004) on the order of 4.3 million hectares. Thus, the above variation in estimates calls for an accurate review of the irrigation potential of the country.

2.1.2. Groundwater irrigation potential in Ethiopia

In Ethiopia, despite the high groundwater potential and opportunity to overcome dry spells and drought through supplementary irrigation leading to the possibility of increased production and productivity in high potential areas, no significant attention has been given to using the groundwater resource for agriculture (Merrey et al., 2005). A few places in Ethiopia though, have demonstrated the comparative advantages of groundwater irrigation over rain-fed agriculture and surface water irrigation. In Amhara and Tigray for instance, groundwater from shallow aquifers is found to be more productive than ponds.

In high technology groundwater irrigation farms around Addis Ababa (flower farms), and Debrezeit,(e.g. Gneiss farm), phenomenal success has been noted (Ayitenfsu M and Zemeagegnehu E., 2004), Estimated that there could be less than 200 ha of land irrigated with groundwater for horticulture and flower farms, more so in the Oromia region.

Given the hydro-geological complexity and costs, Ethiopia has barely exploited its groundwater resources, especially for agriculture. Research in this area is relatively new and initial estimates of groundwater potential vary from 2.6 to 13.5 billion m^3 per year. Local experts' advice and test drillings for pioneering projects suggest that the potential could be much higher (Seleshi et al., 2010).

2.1.3. The need for Irrigation expansion in Ethiopia

Ethiopia has a population of close to 91 million growing at 3.2 percent annually (Central Intelligence Agency, CIA, July 2011 estimate). About 83 percent of this population lives in rural areas. Ethiopia's GDP in 2008 was estimated at USD 318.7 per capita, growing at about 7 percent per year, of which agriculture and services contribute 43 percent each and the remaining 14 percent from industries (UN Data). The agricultural sector plays a central role in the socio-economy of Ethiopia. About 80-85 percent of the people are employed in agriculture, especially farming. The sector contributes about 40 percent of the total GDP with livestock and their products accounting for about 20 percent of total GDP. Smallholders, the backbone of the sector, cultivate 95 percent of the cropped area and produce 90-95 percent of cereals, pulses, and oilseeds. Subsistence agriculture is almost entirely rain-fed and yields are generally low. Irrigation is limited, and though the potential irrigation area is over 4 million ha, only about 6 percent is irrigated, and most of it is under unimproved traditional systems (Tilahun et al., 2004)

The development of irrigation and agricultural water management holds significant potential to improve productivity and reduce vulnerability to climatic volatility in any country. Although Ethiopia has abundant rainfall and water resources, its agricultural system does not yet fully benefit from the technologies of water management and irrigation (MoWR, 2007).

The majority of rural dwellers in Ethiopia are among the poorest in the country, with limited access to agricultural technology, limited possibilities to diversify agricultural production given underdeveloped rural infrastructure, and little to no access to agricultural markets and technological innovations (Wubneshe et al., 2019). These issues, combined with the increasing degradation of the natural resource base, especially in the highlands, aggravate the incidence of poverty and food insecurity in rural areas. Improved water management for agriculture has many potential benefits in efforts to reduce vulnerability and improve productivity. Specifically, primary rationales for developing the irrigation sector in Ethiopia include: Increased productivity of land and labor, which is especially pertinent given future constraints from population growth, Reduced reliance on rainfall, thereby mitigating vulnerability to variability in rainfall, Reduced degradation of natural resources, Increased exports and Increased job opportunities, and promotion of a dynamic economy with rural entrepreneurship (Seleshi et al., 2010).

2.2. Land suitability evaluation for irrigation

Land evaluation is formally defined as 'the assessment of land performance when used for a specified purpose, involving the execution and interpretation of surveys and studies of landforms, soils, vegetation, climate and other aspects of land to identify and make a comparison of promising kinds of land use in terms applicable to the objectives of the evaluation' (FAO, 1976). Land evaluation is a process of predicting land performance over time according to the specific types of use ((Martin et al., 2009); (Sonneveld et al., 2010).

Land suitability evaluation and agricultural land use planning are very necessary and are the basic information for the right decision-making afterward (FAO, 1993-a) The principal purpose of agriculture land suitability evaluation is to predict the potential and limitation of the land for crop production (Pan, G.and Pan, J., 2012). The basic physical factors in determining the suitability of land for irrigation are soil, topography, drainage, water quality and quantity, and climate. Water and climate differ from the others in that they are usually uniform throughout the specific area to be investigated (FAO, 2005).

Land suitability classification is the appraisal and grouping of specific areas of land in terms of the fitness of a given type of land for defined uses (FAO, 1985) based on the evaluation of the biophysical resources, the land may be classified in its present condition or after improvements for its specified use (FAO, 2007). In addition to these factors, land cover/land use types are considered as limiting factors in evaluating the suitability of land for irrigation (Haile et al., 2007)

The process of land suitability classification is the appraisal and grouping of specific areas of land in terms of their suitability for defined uses (FAO, 1976). Parametric evaluation approach (Sys et al., 1991) Multi-Criteria Evaluation (Malczewski and Jacek., 2004), and Analytical Hierarchy Process (AHP) (Saaty and Thomas L. , 2008) are the common approaches for land suitability analysis.

Several studies have applied multi-criteria evaluation method for various applications including; potential land suitability mapping for irrigation using groundwater ((Adhikary et al., 2015); (Jha et al., 2010); (Latinopoulos et al., 2011) , irrigation area suitability mapping using surface water ((Akinci et al., 2013); (Worqlul et al., 2015), to identify solid waste disposal site (Ceballos et al., 2003); (S¸ ener et al., 2010), mapping of erosion-prone areas (Assefa et al., 2015) and for financial decision-making (Steuer et al., 2003). The multi-criteria evaluation approach combines several factors to form a single indexed output. There are several methods of combining factors which includes a weighted linear combination (Miller et al., 1998), analytical network process (ANP) (Gencer, C., & Gürpinar, D. , 2007), multi-attribute utility theory (MAUT), weighted sum model (WSM) and analytical hierarchy process (AHP) (Saaty, T. L., & Erdener, E. , 1979); (Saaty, T. L. , 2008). This study applied the AHP method, which is widely used in the area of water resource management (Chen et al., 2010); (Mendas et al., 2012); (Steuer et al., 2003).

2.3. Groundwater recharge estimation

Water by nature is a sustainable natural resource found in three phases as liquid, solid, and vapor which are mostly explained by the hydrologic cycle.

The hydrologic cycle is a circulation of water in the lithosphere, hydrosphere, biosphere, cry-sphere and atmosphere. The hydrological cycle also defined as a water transfer cycle occurs continuously in nature; at which the phenomena of evaporative the land which exists in pores between sedimentary particles and in fissures and aquifers of solid rocks. Groundwater recharge is a movement of any water that enters into the groundwater system from any direction i.e. up, down, or laterally (Lerner DN., 1997) (Adem G. and Batelaan O., 2006); (Russell S et al., 2010). Recharge begins from rainfall infiltrates through diffuse and preferential soil pathways passes through the root zone and soil matrix, and then reaches the plane of the water table. (Batelaan et al., 2007) and (Russell S et al., 2010) described recharge as is often the smallest component of the water balance and is calculated as the residual after subtracting evapotranspiration and runoff from precipitation. Hence, it is part of a water balance system that can be computed with the help of the continuity equation.

For efficient and sustainable management of the groundwater resource, understanding and quantification of groundwater recharge have paramount importance (Obuobie Emmanuel et al., 2008).

The accurate estimation and quantification of groundwater recharge involve the identification of hydrological and biophysical characteristics in the hydrological cycle. Factors that affect groundwater recharge include rate and duration of precipitation, application of irrigation water, soil moisture content, geological formation, soil properties, depth of water table and aquifer properties, vegetation, land use, topography, and land slope (Obuobie Emmanuel et al., 2008). Consideration of these characteristics is a prerequisite in groundwater recharge estimation.

For estimating groundwater recharge a variety of methods exist. Different scientists (Nakashima et al., 2001); (Scanlon BR et al., 2002); (Christoph et al., 2011),: (Ahmadi T et al., 2013) have used different methods to estimate groundwater recharge. (Scanlon BR et al., 2002) Classified groundwater recharge methods based on hydrological zones from which the recharge data is obtained. These zones are surface water, unsaturated zone, and saturated zone. The groundwater recharge estimation methods are further classified into physical.

(Christoph et al., 2011), Introduced a new approach for the investigation of the unsaturated zone through the combined use of laboratory and field techniques in arid environments. This technique uses direct push techniques to get undisturbed soil samples, extraction of pore water for isotope analyses, and application of Time Domain Reflectometry (TDR) to determine soil moisture.

Similarly, (Ahmadi T et al., 2013) used the water balance principle (rainfall-groundwater level relationship) based approach to estimate groundwater recharge. These methods are WTF (Water Table Fluctuation), DHB (Distributed Hydrological Budget), and HB (Hydrological Budget). These methods were useful, easy to use, cost-effective, simple, requiring few data such as groundwater level measurements, rainfall, aquifer properties, and groundwater extraction datasets. The use of these methods helps to provide irrigation return flow percentage and contribution of precipitation to natural groundwater recharge.

The groundwater estimation techniques have their characteristics during recharge estimation. There must be factors that can help to choose which method should be selected in the course of the study. Hence, several factors such as the goal of the recharge study, the required accuracy, and reliability, space and time scale, the range of the expected recharge estimates, the time to be spent on the study, and the financial resources available should be considered, for accurate estimation of groundwater recharge (Lerner et al., 1990) and (Scanlon BR et al., 2002).

Hydrologic models are among those methods which are frequently used for groundwater estimation. Groundwater recharge modeling techniques can be used to estimate recharge based on time series data from hours to years. The application of groundwater recharge modeling techniques is important for forecasting recharge in the future time horizon (Obuobie Emmanuel et al., 2008).

There are several hydrological models available today for the estimation of groundwater recharge. These models are designed to work based on spatial and temporal distributions of the complex systems of groundwater recharge. Models can be categorized as conceptual, distributed, undistributed or stochastic, etc. based on their physical parameterization and model structure. Most of the models are rainfall-runoff models and or hydrological models. Most of the time, the terms rainfall-runoff models and or hydrological models are used interchangeably in the literature.

2.4. Irrigation water requirements

Crop water requirement was determined from the interrelationships of the ET, soil type, bulk density of the soil, field capacity and permanent wilting point of the soil, and the effective root zone of the crop grown at the project site. The crop ET (ETC) was estimated by FAO Penman-Monteith equation (FAO, 1998).

The CROPWAT program (version 8.0) developed for the FAO Penman-Monteith method (FAO, 1984) was utilized for estimating the crop water requirement of each of the seven crops studied. To ensure the integrity of computations, the weather measurements were made at 2m (or converted to that height) above an extensive surface of green grass, shading the ground.
By dividing the available water by the gross irrigation water requirement (GIWR) the maximum irrigated depth was calculated. Because of the scale, assumptions had to be made to the definition of areas to be considered homogeneous in terms of rainfall, potential evapotranspiration, cropping pattern, cropping intensity, and irrigation efficiency. First, the major irrigation cropping patterns were delineated. Second, the climatic zones were defined, based on climate stations. The combination of the cropping zones with the climate zones resulted in the study areas, homogeneous in irrigation cropping characteristics and climate. The model to calculate the Net irrigation water requirement (NIWR) was run for three scenarios and divided by the efficiency to calculate the GIWR. The influence of selecting, cropping pattern zones, and the estimations used for cropping intensity and irrigation efficiencies is of prime importance for the final results (J. Doorenbos et al., 1992). To grow a certain crop on a plot of land has to be supplied with water from time to time. The land is expected to receive water from rainfall on the land surface to grow a certain crop or a combination of crops. But, the distribution of rainfall is rather uncertain both in time and space. Hence, for proper crop growth, the uncertain rainfall has to be supplemented by artificially applying water to the field by irrigation. After knowing of irrigation is important to supplement the rainfall variability, the water resource engineer has to design enough water sources for irrigation and find out the methods by which estimation may be made for crop and irrigation water demand. The most important of crop and irrigation water demand computation is that knowing the total quantity of water required from its sowing time up to harvest. Under the same condition, different crops require a different amount of water and the quantities of water used by a particular crop are different in the entire life span (initial, development, mid-season, late-season stage) of the crop period. Initially during seeding, sprouting and early growth a crop uses water at a relatively slow rate. The rate will increase with the growth of

crop reaching the maximum in most crops as it approaches flowering and then declines towards maturity (MoA, 2004).

2.4.1. Estimation of ETO using the Hargreaves Method

The Hargreaves method is recommended to be adapted for areas where measured data on daily maximum and minimum temperature and rainfall data are available. These methods are important especially when there are no full climatic data of meteorological stations. The reference crop ET (ETO) is usually calculated by using CROPWAT8.0 software implementing through (FAO, 1998).

2.4.2. Irrigation efficiencies

The amount of water needed during a growing season depends on the crop, yield goal, soil, Temperature, solar radiation, and other biophysical factors. In general, long-season crops (FAO, 1993-a)

2.5. Irrigation potential by groundwater availability

Definition of irrigation potential in (FAO, 1984), area of land (ha) which is potentially irrigable. Country/regional studies assess this value according to different methods – for example, some consider only land resource suitable for irrigation, others consider land resources plus water availability, and others include in their assessment economic aspects (such as distance and/or difference in elevation between the suitable land and the available water) or environmental regional plans, groundwater is increasingly included as a viable and suitable supplementary or sole source to develop for irrigation along with traditional surface water resources (MoA, 2004); (MoFD, 1999) and (GIDA 2, 1998) According to (Albaji et al., 2015), available water resources will not be able to meet various demands shortly and inevitably result in the seeking of newer lands for irrigation to achieve sustainable global food security.

A key question is whether there will be sufficient freshwater to satisfy the growing needs of agricultural and non-agricultural users (Alexandratos et al., 2012) The truth is water has always been the main factor limiting crop production in much of the world where rainfall is insufficient to meet crop demand (Steduto et al, 2012). Thus, the assessment of irrigation potential should take into account water limitations.

(Pavelic et al., 2013) Afforded a relatively simple water balance approach to provide country or catchment scale estimates of gross GWIP in terms of irrigable cropland, taking into consideration the crop irrigation water needs and disregarding existing irrigation development. Water available for irrigation was constrained by sustainable groundwater resources, priority demands from domestic, livestock, industrial uses as well as environmental requirements.

(Altchenko et al., 2015) applied a methodology that assumes groundwater as the sole source of irrigation water and hence gives an estimate of the area that could potentially be irrigated by groundwater disregarding any existing irrigation, whether from groundwater or surface water. Irrigation potential is calculated as a ratio of groundwater available to maximum irrigation water demand; where groundwater availability is calculated as an excess of groundwater recharge, considering other demands from humans and the environment. The necessary crop data related to the crop distribution across the continent, the crop calendar over the year, encompassing one or a maximum of two crops per year for any area collected to calculate annually monthly crop water demand.

Similarly, (Worqlul et al., 2015) studied the country-level irrigation potential of the groundwater as the quotient of the potential average borehole yield and the total crop water requirement of the dominant crop in the area for the growing season.

2.6. Hydrological modeling

2.6.1. WetSpas Model

WetSpass is an acronym for Water and Energy Transfer between Soil, Plants, and Atmosphere. It is a physical-based and distributed hydrological model for predicting the Water and Energy Transfer between Soil, It Groundwater recharge models is a physically based and distributed hydrological model for predicting the Water and Energy Transfer between Soil, Plants, and Atmosphere on a regional or basin-scale and daily time step, developed in the Vrije Universities Brussels, Belgium (Batelaan et al., 2007) and (Wan, Zhengming. , 1997). The model is physically based and simulates hydrological processes of precipitation, interception, depression, surface runoff, evapotranspiration, infiltration, percolation, interflow, groundwater flow (Li, Qingting, Cuizhen Wang, Bing Zhang, and Linlin Lu., 2015). It simulates continuously both in time and space, for which the water and energy balance, is maintained on each raster cell.

2.6.2. CROPWAT model

CropWat is a decision support system developed by the Land and Water Development Division of the Food and Agriculture Organization (FAO) for the planning and management of irrigation (FAO, 1995-a) CropWat is a practical tool to carry out standard calculations for reference evapotranspiration, crop water requirements, and crop irrigation requirements, and more specifically the design and management of irrigation schemes. For this study, CropWat 8.0 was used. CropWat 8.0 is a computer program for the calculation of crop water requirements and irrigation requirements from existing or new climatic and crop data. Furthermore, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. In CropWat8.0, the calculation of crop water requirements is carried out per decade.

My computer model, CROPWAT8.0, unfortunately, difficult to predict as rainfall varies greatly from season to season. To estimate the rainfall deficit for irrigation water requirements, a statistical analysis needs to be made from long-term rainfall records (FAO, 1998).

2.6.3. GIS and groundwater

A Geographic Information System (GIS) is computer software used for capturing, storing, querying, analyzing, and displaying geographically referenced data ((Akıncı et al., 2013).

The aim of a Geographical Information System (GIS) is to store geographically referenced data as different layers. These different data layers may be manipulated and visually accessed as output data. The usefulness of the output data, however, is determined by the quality of the input data. Using a GIS in the modeling of small watersheds is not a new concept.

Mapping

The main application in GIS is mapping where things are and editing tasks as well as for map-based queries and analysis. A map is the most common view for users to work with geographic information. It's the primary application in any GIS to work with geographic information. The map represents geographic information as a collection of layers and other elements in a map view. Common map elements include the data frame containing map layers for a given extent plus a scale bar, north arrow, title, descriptive text, and a symbol legend. They state that both dynamic and static conditions must be considered and therefore proposed that depth to the water table, recharge, aquifer media, soil media, and topography, the impact of the vadose zone, and conductivity of the aquifer should all be included in a GIS. (Suwanwerakarntron , 1994), Stated that the use of hydrological models makes it possible to predict hydrological processes and watershed behavior. He also concluded that a GIS can provide essential input data for a hydrological model, in both time and space.

(S Coetzee, B Wolff-Piggott, 1995), as (Suwanwerakarntron , 1994) investigated the integration of GIS into a hydrological model. According to Wolff-Piggott, a GIS should rather be used as a pre-or post-processor for hydrological mode1ling for it cannot handle time-varying data structures, lineage, and product quality information. GIS should, therefore, be used as an enduring spatial database that can be used over and over again.

(S Coetzee, B Wolff-Piggott, 1995), also praised GIS for its map capabilities and for the assessment it gives in detecting configuration errors. GIS can be used in a weighted map overlay procedure for mapping groundwater pollution potential, providing a statistical snapshot rather than a dynamic model. GIS, therefore, has a weakness with data that varies in time and space, ego seasonal fluctuations in groundwater levels. GIS, however, is an excellent tool for water resource management, addressing management issues rather than scientific and technical questions.

(Donker N , 1992) Used a digital terrain model (DTM) to explain the main principles applied in the automatic extraction of catchment properties. Calculations were done from four data categories, *viz:*

• Elevation • Flow directions groundwater

• Ranked elevation • Flow accumulation

(Yaser A et al., 1995) Recognized that several previous attempts to evaluate hydrological systems with the aid of a GIS used the following data:

• Relief • Hydrology • Climate base data

• Soil • Land cover • Socio-economic constraints.

3. MATERIALS, AND METHODS

3.1. Description of the study area

3.1.1. Location of the study area

The Lake Haramaya watershed is located in the upper Wabishebele river basin of the Eastern part of Ethiopia, about 505 km east of Addis Ababa. The Lake Haramaya watershed covering a total area of 12481290ha. The watershed touches three administrative towns which are Haramaya, Adele, and Bati towns. The watershed is situated (Easting: 42^{0}0’0” to 42^{o}12’0” E and Northing: 9^{o}24’0” to 9^{o}30’0”) in the upper Wabishebele River basin. Lake Haramaya is the major Lake in the watershed. The monthly air temperature of the watershed varies from season to season. The maximum mean and minimum mean temperatures of the watershed are 30.2 and 12.3 respectively.

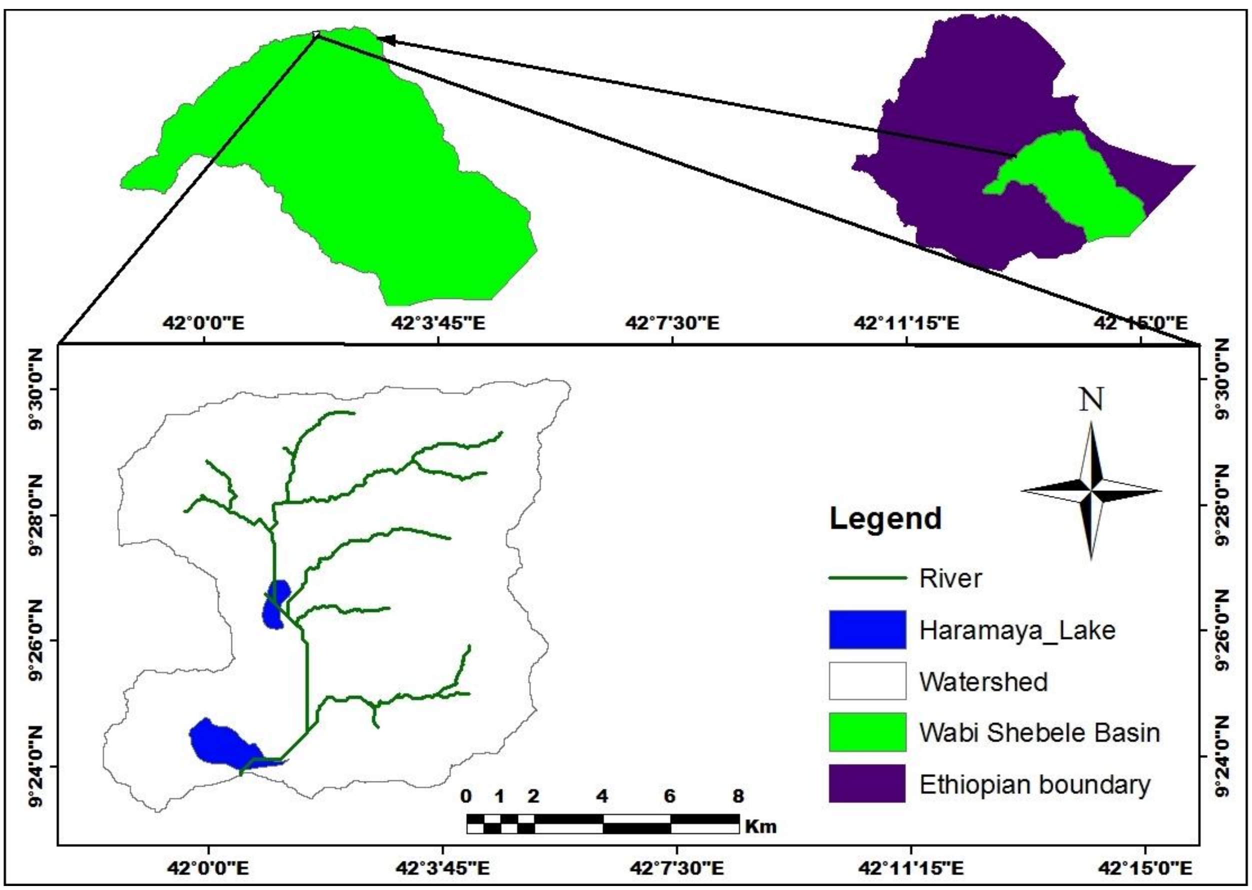

Fig.3. 1. Location map of the study area

3.1.2. Topography

The altitude of the Lake Haramaya watershed ranges from 2005 to 2430 meters above sea level. Both Kombolcha and Haromaya are major producers of vegetables for Djibouti.

It is characterized by steep to very steep slopes, hilly and mountainous area, which covers 18% of the total area of the watershed; characterize the eastern and northeastern parts of the watershed. Flat to gentle slopes, which cover 82% of the total area of the watershed and have a slope ranging from 0-15%, characterize the remaining parts of the watershed. This physiographic unit includes a water body area that lies in the southwestern part of the watershed. The slope of the watershed rises slowly in all directions away from the water body area. The slope, landform, and the configuration of the hills and peaks surrounding the study area have created a drainage network, which takes the surface flow towards the water bodies area.

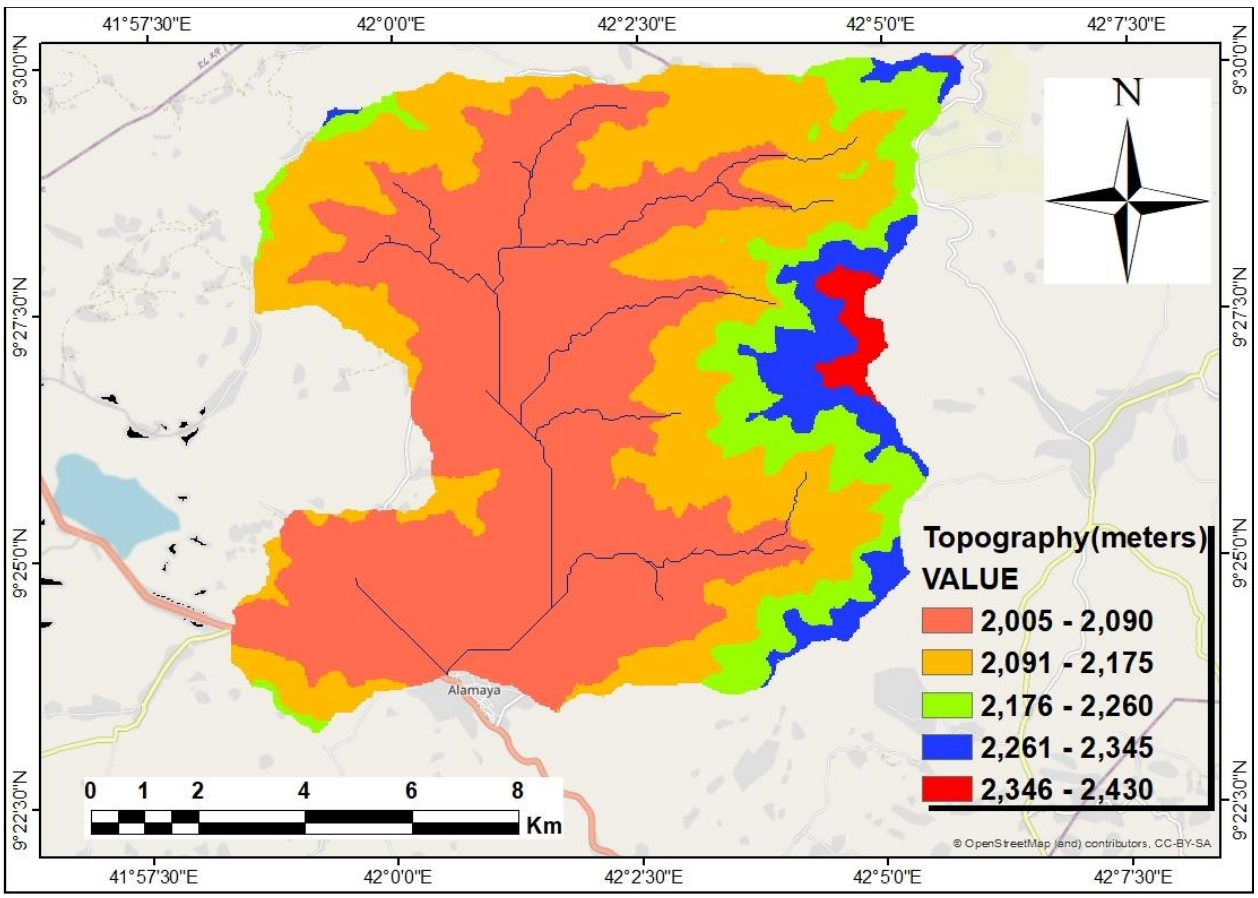

Fig.3. 2.Topographic map of the lake Haramaya watershed

3.1.3. Geology

The geology of the watershed is constituted by the rocks ranging in age from Precambrian to Recent. Strati graphically, from bottom to top, are granite (Precambrian), sandstone and limestone (Mesozoic sedimentary rocks), and recent sediments (Quaternary).

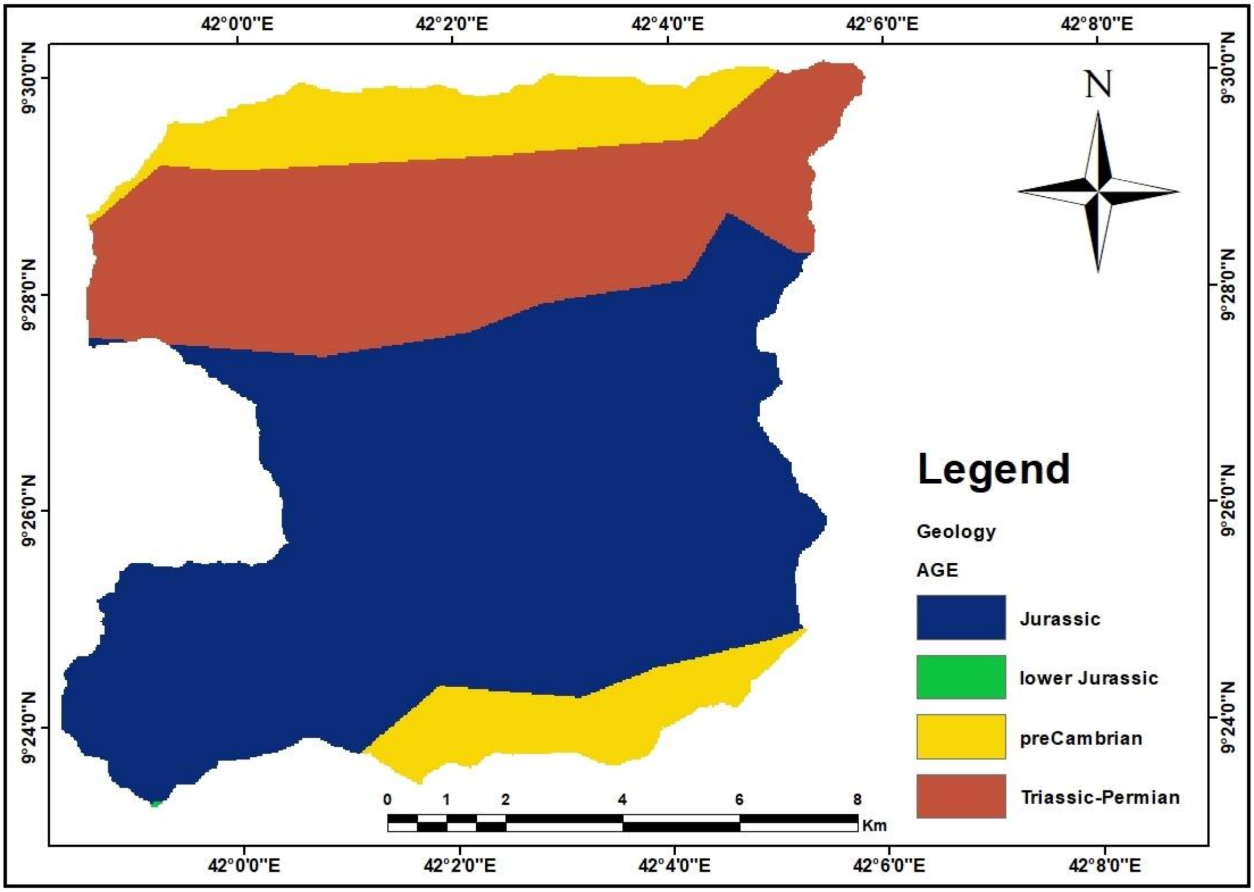

Fig.3. 3.Geology of the study area

3.2. Type, source, and purpose of the data

3.2.1. Climate

The daily precipitation, Wind speed, Maximum temperature, minimum temperature Relative humidity, and solar radiation of four stations were collected from the Ethiopian metrological Agency (EMA).In estimating groundwater recharge, the amount of rainfall over the basin is very crucial for the WetSpass models; the daily long-term precipitation was available from 1986 to 2019 for four stations. For calculating potential evapotranspiration by using the cropwat8.0 model, average monthly precipitation, Wind speed, Maximum temperature, minimum temperature Relative humidity, and solar radiation were used which were collected from four synoptic stations at Haramaya, Harar, Combolcha, and Karsa.

3.2.2. Soil data

The soil data were used for suitability analysis by using GIS-based multi-criteria evaluation, recharge estimation by using the WetSpass model, and crop water requirement calculation by using CROPWAT8.0 models. The soil data (physical property, texture, and drainage class, and soil depth) that the same with shape file of the study area was accessed from the FAO website Harmonized world soil Database, in Environmental System Institute (ESSRI) shape.

3.2.3. Land use/Land cover

Land cover and land use of the watershed is of the factor that used as input for suitability evaluation, recharge estimation. Seasonal land cover and land-use change of the watershed were derived from satellite imageries at 30mx30m grid cell resolution ERDAS.
Landsat8 image was obtained from landsat8 data sets USGS (www.earthexplorer.usgs.gov) and ground truth data are equally important as RS data which used for accuracy assessment of land cover and land use or classified image were collected from field observation.

3.2.4. Population data

Human activities (domestic, livestock, industrial) based on ''present'' human water demand derived from the density of population and livestock, and unit requirement, the total population data require to derive domestic groundwater demand in the study area were collected from, national census report of Central Statistical Agency in 2007.

3.2.5. Topographic data

Since the WetSpass model is a distributed hydrological model, it uses DEM, slope, and topography as inputs. The DEM was used to derive the slope, and contour pattern of the study area. Watershed networks were digitized from the DEM and GPS using ArcSWAT integration with ARC GIS. Shuttle Radar Topographic Mission Digital Elevation Model (SRTM DEM) was obtained from the digital elevation data sets of USGS (www.earthexplorer.usgs.gov).

3.2.6. Crop data

The necessary crop data to calculate potential evapotranspiration and irrigation water requirements related to the crop distribution, pattern and dominant crop, crop calendar over the year as well as a structural plan of woreda were obtained from the FAO and East Hararghe Zone agricultural development department.

3.2.7. Groundwater depth data

Groundwater depth plays a crucial role in providing drinking water supply and sustaining important native terrestrial ecosystems. The groundwater depth data is input parameters of WetSpass models which are used to estimate groundwater recharge. Average groundwater depth and location of the good station were collected both at field level and from the Haramaya water supply bureau using appropriate data collection methods.

Table 3. 1: Summary of type, purpose, and source of the data

No	Data type	Purpose	Source
1	Climate	✓ To estimate potential evapotranspiration ✓ To estimate groundwater recharge	Ethiopian metrological Agency (EMA)
2	Soil	✓ To estimate potential evapotranspiration ✓ To estimate groundwater recharge ✓ To assess land suitability for irrigation	(hhh:/www.africover.org./index.htm)
3	Landsat image	✓ To drive land cover and ✓ land-use image	(www.earthexplorer.usgs.gov)
4	Population	✓ To derive domestic groundwater demand	Central Statistical Agency in 2007
5	Topography	✓ to derive slope, ✓ contour pattern of the study area ✓ to derive watershed network ✓ to estimate groundwater recharge	(www.earthexplorer.usgs.gov)
6	Crop	✓ to calculate irrigation water demand	FAO and East Hararghe Zone Agricultural Development Department
7	Groundwater depth	✓ to estimate ground water recharge	Haramaya water supply bureau

3.3. Data management and analysis

Based on the approach of (Pavelic et al., 2013) the methodology assumes groundwater as the sole source of irrigation water and hence it gives an estimate of crop irrigation water demand that could potentially be irrigated by groundwater.

This study consist of three sections, first I have identified potential land areas suitable for surface irrigation using groundwater, and then quantified available groundwater for irrigation, and finally computed crop irrigation requirements. Land suitability was evaluated using the GIS-based Multi-Criteria Evaluation (MCE) technique by analyzing the suitability factors such as the slope, land use, soil depth, soil texture, soil drainage, road proximity, and town proximity. The amount of available groundwater for irrigation was evaluated by analyzing climate data, land use, soil, topography, Population data, and different scenarios of environmental water requirements based on (Pavelic et al., 2013) approach. The crop irrigation water requirements were computed based on climate data, crop data, and soil data.

3.3.1. Data preprocessing and checking

3.3.1.1. Estimation of missed rainfall data

Before using the rainfall record of a station, it is necessary to first check the data for continuity and consistency. The continuity of a record may be broken with missing data due to several reasons. In such cases, the missing data can be estimated by using the data of the neighboring stations. Missing records of the rainfall stations were estimated by using a normal ratio method which is recommended to estimate missing data in regions where annual average rainfall among stations differs by more than 10% (Stanley Lawrence Dingman, 2002).According to (Subramanya, 2004) the estimation of missing rainfall data by weighting the observation at N gauges of their respective annual average rainfall values were conducted using the following equation:-

$$Px = \frac{Nx}{M}\left[\frac{p1}{N1} + \frac{P2}{N2} + \frac{P3}{N3} + \cdots + \frac{Pm}{N\mathrm{m}}\right] \quad \text{......3.1}$$

Where

P1, P2, P3 ...Pm = annual precipitation at neighboring stations 1, 2, 3,...... M, respectively

Px = missing annual precipitation at station X (not included in M stations)

M = number of neighboring stations

N1, N2, N3, Nm = normal annual precipitations at each of the above (M+1) stations including neighboring station X

The daily maximum and minimum temperature values at the Haramaya, Harar, and Combolcha, and Karsa stations were averaged into maximum and minimum long-term monthly values. These values were used as input data for Potential evapotranspiration computations in CROPWAT. Other climatic data such as sunshine duration, relative humidity, and wind speed data of the four stations were recorded daily (four times per day) were also averaged into long-term mean monthly values and used for potential evapotranspiration calculation.

3.3.1.2. Homogeneity test

Homogeneity is an important issue to detect the variability of the data and it is used to identify a change in the statistical properties of the time series. In general, when the data is homogeneous, it means that the measurements of the data are taken at a time with the same instruments and environments. Homogeneity tests become an important procedure in analyzing the rainfall series. The causes can be either natural or man-made. These include alterations to land use and relocation of the observation station. Therefore, to select the representative meteorological station for the analysis of areal rainfall estimation, checking the homogeneity of group stations is essential and the homogeneity of the selected gauging station's monthly rainfall records was carried out by non-dimensional parameterization.

$$Pi = \frac{Over\ year\ average\ monthly\ PCP\ for\ month\ i}{the\ over\ years\ average\ yearly\ PCP\ of\ station} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

Where Pi: non-dimensional values of precipitation for a month i.PCP: precipitation of the station

The selected stations were also plotted for comparison with each other in Figure 3.4. They showed the same model and pattern for the selected station. These assure that the selected stations were homogenous.

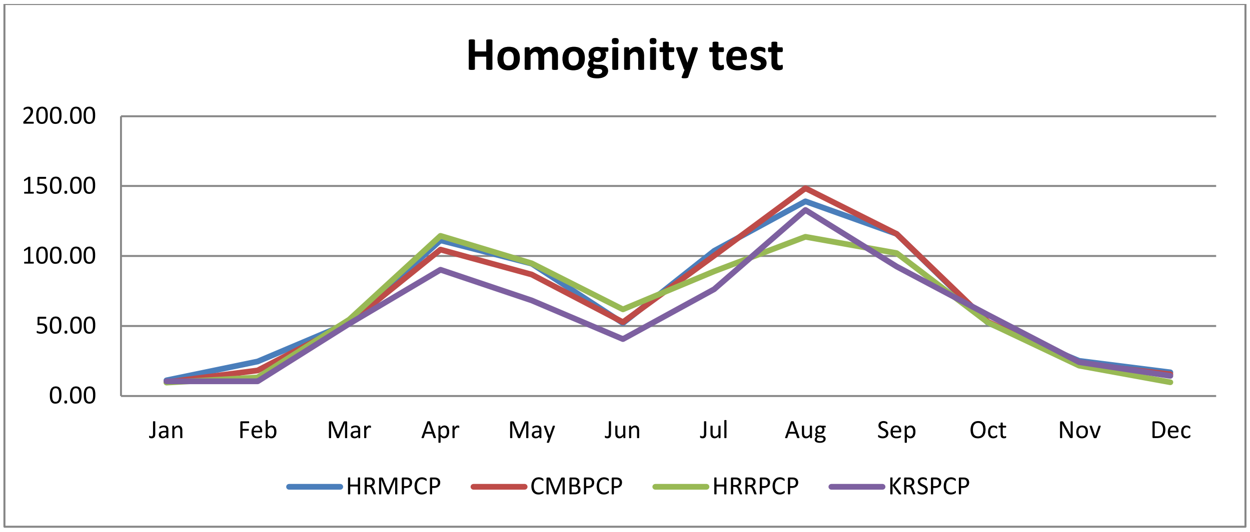

Fig.3. 4. Homogeneity test for the stations used

3.3.1.3. Consistency check by double mass curve analysis

If the conditions relevant to the recording of a rain gauge station have undergone a significant change during the period of record, inconsistency would arise in the rainfall data of that station. This inconsistency would be felt from the time the significant change took place. To prepare rainfall data for further application in this study, their consistency was checked using double mass curve analysis. The cumulative precipitation at station X (i.e.∑Px) and the average cumulative of the group of base stations (i.e. ∑Pave) are calculated starting from the oldest record. A plot of accumulated rainfall data at the site of interest (i.e.∑Px) against the accumulated average at the surrounding stations (i.e. ∑Pave) was generally used to check the consistency of rainfall data. A break in the slope of the resulting plot indicates a change in the precipitation regime of station X (Subramanya, 2004).

The precipitation values at station X beyond the period of change of regime thus have to be corrected by using the relations as follow:

$$\text{Correction factor} = \frac{M_c}{M_a} \quad \text{,...3.3}$$

$$P_{CX} = P_x \frac{M_c}{M_a} \quad \text{..3.4}$$

Where, P_{cx} = corrected precipitation at any time period t1 at station X

P_x = original recorded precipitation at time period t1 at station X

M_c = corrected slope of the double-mass curve.

Ma = original slope of the double-mass curve (

To check the degree of consistency, (Nemec, J. , 1973) provided the value of coefficient of correlation as follows:

r = 1: direct linear correlation

o.6 ≤ r <1: good direct correlation

-0.6 < r <0: insufficient – reciprocal correlation

If t-1 < r <0.6: good reciprocal correlation

r = -1: reciprocal linear correlation

If the recorded data is not accurate, the values of “r” might be <0.6 or >1. The consistency is checked using the double mass curve. For the grid interpolated rainfall data, no analysis was done and they were used in further analysis directly. The rainfall data are relatively consistent if the periodic data are proportional to an appropriate instantaneous period, and these inconsistent data can be adjusted by proportioning, using correlation coefficient, between the stations.

3.3.1.4. Accuracy assessment

Accuracy assessment or validation is a significant step in the processing of remote sensing data. It establishes the information value of the resulting data to a user. Productive utilization of geo data is only possible if the quality of the data is known. The overall accuracy of the classified image compares how each of the pixels is classified versus the definite land cover conditions obtained from their corresponding ground truth data (Sophia et al., 2017).

The accuracy of the obtained object-based classification was evaluated using user’s, producer’s, overall accuracies and kappa coefficient:

To validate and crosscheck the result of the SPOT classification with known ground truth data, accuracy assessment was checked for the signature values of the classified images by calculating the confusion matrix.

Table 3. 2: Confusion Matrix for 2019 land use/land cover classification

	Reference Data							
Classified data	Agriculture	Bare land	Forest	Grass land	Built-up	Shrub land	Water body	Total User
Agriculture	60	3	1	1	0	0	0	65
Bare land	2	43	1	2	0	0	0	48
Forest	1	0	49	0	0	5	0	55
Grass land	1	2	2	55	0	3	0	63
Built-up area	1	0	0	0	46	0	0	47
Shrub land	5	0	0	2	0	71	0	78
Water body	0	0	0	0	0	0	100	100
Total producer	70	48	53	60	46	79	100	456
Number of LULC correctly classified=424								
Overall Classification Accuracy% = ((60+43+49+55+46+71+100)/(456))*100 =92.98%								

As shown in Table 3.2, the confusion matrix indicates that the overall accuracy assessment is very strong i.e. 92.98% which is greater than the requirement for strongly acceptable classification, i.e. 84% (Caetano, 2005).The users and producer's accuracy assessment also calculated for each land class and indicated acceptable agreement.

Table 3. 3: Users and producers accuracy table

Class Name	Users Accuracy	Producers Accuracy
Agricultural	60/65*100=92.31	60/70*100=85.71
Bare land	43/48*100=89.58	43/48*100=89.58
Forest	49/55*100 =89.09%	49/53*100 =92.45%
Grass land	55/63*100 =87.3%	55/60*100 =91.67%
Built-up area	46/47*100 =97.87%	46/46*100 =100%
Shrub land	71/78*100 =97.87%	71/79*100 =89.87%
Water body	100/100*100 =100%	100/100*100 =100%

The kappa hat value of 0.9586 indicates a better accuracy that the classification has resulted from random sample class classification. Since the kappa hat value fell above 80%, it represents strong agreement.

User accuracy: User accuracy is a measure indicating the probability that a pixel is a Class of sample given that the classifier has labeled the pixel into sample class as shown in table 3.2.

Producer accuracy: The producer accuracy is a measure indicating the probability that the classifier has labeled an image pixel into the sample area given that the ground truth of the sample area.

Overall Accuracy: The overall accuracy is calculated by summing the number of pixels classified correctly and dividing by the total number of pixels sample. The ground truth image or ground truth training area defines the true class of the pixels. The pixels classified correctly are found along the diagonal of the confusion matrix table which lists the number of pixels that were classified into the correct ground truth class. The total number of pixels is the sum of all the pixels in all the ground truth classes. The kappa coefficient is calculated by multiplying the total number of pixels in all the ground truth classes by the sum of the confusion matrix diagonals, subtracting the sum of the ground truth pixels in a class times the sum of the classified pixels in that class summed over all classes, and dividing by the total number of pixels squared minus the sum of the ground truth pixels in that class times the sum of the classified pixels in that class summed over all classes as shown in table 3.4. In addition, it is a way to measure the actual agreement and chance agreement between the reference data and the classified data. The Kappa coefficient represents the proportion of agreement obtained after removing the proportion of agreement that could be expected to occur by chance (Foody, 2002). This would be expressed in terms of the percentage of strong, moderate and poor agreement i.e. a value >0.80 (80%) strong agreement; a value b/n 0.40 and 0.80 (40 to 80%) represents moderate agreement; and a value < 0.40 (40%) represents poor agreement.

Table 3. 4: Conditional kappa coefficient for each LULC

Class Name	Conditional kappa for each LULC class	Percentage (%)
Agricultural	$\frac{(436 * 456) - (75 * 65)}{(456 * 456) - (70 * 65} = 0.9551591$	95.5159155
Bare land	$\frac{(436 * 456) - (48 * 48)}{(456 * 456) - (48 * 48)} = 0.9556489$	95.5648926

Forest	$\frac{(436*456)-(55*53)}{(456*456)-(55*53)} = 0.95551675$	95.551675
Grassland	$\frac{(436*456)-(63*60)}{(456*456)-(63*60)} = 0.95085707$	95.085707
Built-up area	$\frac{(436*456)-(47*46)}{(456*456)-(47*46)} = 0.95567953$	95.567953
Shrubland	$\frac{(436*456)-(78*79)}{(456*456)-(78*79)} = 0.95480091$	95.48009
Waterbody	$\frac{(436*456)-(100*100)}{(456*456)-(100*100)} = 0.953924$	95.39245
Overall kappa statistics =95.45124083		95.4512

3.3.1.5. Watershed delineation

The Watershed Delineation carries out advanced GIS functions to aid the user in segmenting watersheds into several "hydrological" connected_sub-watersheds for use in watershed modeling with SWAT. The watershed was delineated by using the watershed delineator tool in Arc SWAT based on an automatic procedure using 30m x 30m DEM. The watershed of the study area was delineated by using the watershed delineator tool in ArcSWAT based on an automatic procedure using the watershed outlets created by using GPS reading through directly from the area.

3.3.2. Potential land suitability factors for surface irrigation using groundwater

Identification of suitable lands for irrigation was carried out based upon carefully determined and documented criteria or specifications of the Food and Agriculture Organization (FAO, 1976) guideline in terms of land suitability to achieve the objectives of land suitability classification.

Potential lands in the watershed suitable for irrigation using groundwater were identified using a GIS-based Multi-Criteria Evaluation (MCE) technique. The land suitable for irrigation was identified by developing and assigning weight to individual key factors. The key factors that affecting land suitability were identified from literature and experts in the region (Akıncı et al., 2013), (Chen et al., 2010), (Mendas et al., 2012), (Worqlul et al., 2015). Factors considered include land features such as soil types, soil texture, soil depth, soil drainage, slope, land cover, and land use and Proximity to the road, and proximity to town. The individual suitability of each factor was first analyzed and finally weighted to get potential irrigable sites. The factors were weighted using a pairwise comparison matrix reclassified and overlaid to identify the suitable areas then optimize the optimal areas using con and major filter tool in Arc GIS for groundwater irrigation. The factors that affect the suitability of land for surface irrigation were collected as gridded and vector data formats. Grid formats include: Soil, land use, slope, and vector data format include town shapefiles and road network.

3.3.2.1. Slope

The slope of the land is the major factor in the assessment of land suitability because the slope of the land affects the suitability of an area in terms of land preparation for irrigation and irrigation operation or irrigation practices. The slope of the land was estimated using 30 m resolution Digital Elevation Model (DEM) data from the Shuttle Radar Topography Mission. Source of DEM 30X30m is (SRTM, (www.earthexplorer.usgs.gov.htm).

3.3.2.2. Soil

Soil factor affects the suitability of an area for agriculture in general and irrigation in particular. The soil data (physical property, texture, and drainage class, and soil depth) that the same with shapefile of the study area was accessed from the FAO website Harmonized world soil Database, in Environmental System Institute (ESSRI) shape. The soil data contains several layers. Each soil layer contains soil texture, soil depth, and soil drainage, and soil group.

3.3.2.3. Market proximity

In the watershed, vegetables are produced and export to the other markets, so implementation of irrigation requires access to the market to purchase agricultural inputs and to sell agricultural outputs. Market access was represented by using town shapefiles and derived using distance to major paved roads. The shapefile of the towns was obtained from the Ethiopian urban authority.

3.3.2.4. Road proximity

To get market access the road is necessary for transportation of goods since cash crops are produced in the watershed so road proximity analysis is an important factor that represents market access. Vector data showing asphalt and gravel road network for the watershed was collected from the Ethiopian Road Authority (ERA) and derived by using Euclidian distance tool and classified into eight equal intervals using reclassify tools.

3.3.2.5. Land use

Land use data helps to identify the productivity of an area for irrigation. This study uses land use derived by using ERDAS IMAGINE based on the landsat8.0 image. Landsat8 image was obtained from landsat8 data sets USGS (www.earthexplorer.usgs.gov.htm).

3.3.3. Available groundwater resources

Assessment of groundwater available resources for irrigation purposes consists of obtaining information on the distribution of water availability along the year to be compared with irrigation water requirement (FAO, 1989). Based on the approach (Pavelic et al., 2013), the net annual groundwater availability for irrigation is calculated by deducting the allocation for domestic water demand and environmental water requirements from the estimated annual replenishable groundwater resource.

GWA = GWR-HGWD-EGWR: ………….……………………….…….…………………….... 3.5

Where:

GWA [mm] is Groundwater Available

GWR [mm] is groundwater Recharge

HGWD [mm] is Domestic Groundwater Demand

EGWR [mm] is the Environmental Groundwater Requirement

3.3.3.1. Groundwater recharges estimation in the watershed

The knowledge of total groundwater recharge is important to quantify the groundwater irrigation potential. The method proposes in this study to estimate groundwater recharge is spatially distributed and based on a water balance approach using spatially distributed hydrological model WetSpass with the integration of Arc GIS. Computation of long-term average spatial patterns of recharge was the main objective for the development of the WetSpass methodology (Batelaan et al., 2007). The original WetSpass model is a quasi-steady-state spatially distributed water balance model scripted in avenue and used to predict hydrological processes at a monthly and annual time step. In WetSpass M, monthly recharge [Rm (mm/month)] is calculated as the residual term of the Water Balance:

Rm=$Pm - SRm - ETm$…………………………………………………...………………………3.6

WetSpass model input data

The input data of the WetSpass model are the long-term average data which include: precipitation, wind speed, temperature, potential evapotranspiration, groundwater depth, slope, land use/land cover, elevation, and soil data. The magnitude and even the direction of change in recharge depend on the local soil, vegetation, and climatic region (Craig et al., 2010). WetSpass model input variables are monthly so all inputs were prepared on monthly basis.

Data required as inputs for the WetSpass model were prepared using ArcGIS in two different formats such as grid maps in ASCII and parameter tables in TBL formats. The input data prepared as grid maps in ASCII format include: groundwater depth, precipitation, wind speed, slope, elevation, land use /land cover, potential evapotranspiration, average temperature, and soil data as well as the input data prepared as parameter table in TBL format include: land use lookup table, soil lookup table and several rainy days. Since the WetSpass model requires all grid maps in the same row and column as well as the same cell size, all input grid maps should be prepared in the same row and column as well as cell size. The cell size, columns, and rows were 30mx30m, 457, and 425respectively.

Grid maps for all metrological data were prepared on a monthly and annual basis using the Kriging interpolation technique in ArcGIS and the other grid maps prepared from spatial data such as slope, land use/land cover, elevation, soil, and ground depth data were the same throughout the year.

3.3.3.2. Domestic groundwater demand

The average water demand is considered as the total of domestic, industrial, and livestock demands, as it is indicated in the water Sector development program 2002-2016) document for urban areas prepared by the Ministry of Water Resource (MoWR, 2002).

Human activities (domestic, livestock, industrial) based on ‘’present’’ human water demand derived from the density of population and livestock, and unit requirement (FAO, 1985).

Population projection

Based on this, the population of the town in each planning year throughout the economic life of the project was projected using a geometric growth rate method:

$PF=p_p(1+r)^n$ …………………….……………………………………………….…………….…….. 3.7

Where

PF=Future population at year n

PP=present population

R= growth rate

To estimate total human groundwater demand (domestic, livestock, industrial), average water consumption (unit requirement) of the study area is used that is 20l/c/d for a given year based on the ministry of water resources design criteria manual, 2006 for urban areas, then multiplying the total population of each block with the per capita water demand and several days in a year.

3.3.3.3. Environmental water requirement

Environmental groundwater requirements (mm) are the quantity of water coming from groundwater, which is directly linked to the environment for maintaining ecosystems. This includes river base flow and groundwater influx to wetlands. The environmental groundwater requirements remain highly uncertain.to account for this, three scenarios have been applied. The environmental groundwater requirements represents70 %(Scenario 1), 50 %(Scenario2), and 30 %(Scenario 3) of the recharge, respectively ((Pavelic et al., 2013).

3.3.4. Irrigation water requirements

Adequate knowledge of crop water use and irrigation requirements for the various crops in the given climatic conditions will be essential in the planning, implementation, and monitoring of the irrigation (FAO, 1985). The CROPWAT8.0 model is a computer program for crop water requirement calculations developed by FAO ((FAO, 1995-a)) was used to compute crop water requirements, effective rainfall, and crop irrigation requirements based on basic information of the major crops which should include: average planting date average harvesting date, standard information on crop coefficient, rooting depth, depletion level, and yield response factors are included for most crops in the CROPWAT8.0 program. Length of the individual growth stages needs, however, to be adapted to fit planting and harvest dates.

CROPWAT8.0 model inputs include climatic parameters such as rainfall and ETO, soil texture, and crop type.

Climatic data of station which obtained from Ethiopian metrological station was used to create the database and then based on crop pattern of the study area, obtained from East Hararghe agricultural office five major crops selected such as kchat, onion, potato, tomato and carrot to estimate the water demand monthly and total irrigation demand. Planting dates for each crop was chosen based on the planting dates coincided with the local cropping calendar in the region. Crop water requirements were estimated using the CROPWAT model based on climate, rainfall, soil, and crop data of the study area.Net irrigation requirements was estimated by deducting effective rainfall from crop water requirements.

The total irrigation water demand, which represents the groundwater abstraction needed to satisfy the deficit rainfall and the irrigation losses of the study watershed, is determined by.

Total irrigation water demand $(mm)]$ $= \frac{\sum_i^n NIR(mm)_i x[\%of\ Area]}{Irrig.Efficiency} i$……….……………..……..... 3.8

- Net irrigation water requirements (mm), which represent the monthly amount of irrigation water needed by the crop to grow optimally during the months of its growing period, independently of the water source and considering water as the only limiting factor for optimal growth (FAO, 1986).
- % of Area [–] is the areal fraction of a specific crop relative to the total crop area within a grid cell.
- n (mm) is the number of crops grown within the grid cell.

Irrigation efficiency [–] is the irrigation efficiency coefficient.

3.3.4. 1. Crop water requirements

The crop water requirement (CWR) was calculated as a product of the potential evapotranspiration (ET_O) and the crop coefficient (Kc) (Allen et al., 1998).

Crop Water Requirements ((mm)) =$Kc×ETo$ ……………………………………..……3.9

CWR$_i$=$\sum_{t=0}^{T}(kci * ETot)$ unit: mm……………………..…..……………….……...3.10

Kc [–] is the crop coefficient.

ET_O- potential evapotranspiration

3.3.4.2. Effective rainfall

Effective rainfall is the water available for plants naturally and indirectly from the rainfall through soil moisture. An assessment of the adequacy of rainfall and the effect of rainfall deficits on crop production can be made from actual rainfall data.

Effective rainfall is calculated according to the FAO/AGLW formula ((Allen et al., 1998)):

$Peff$=0.6∗P−10 for Pmonth <=70 mm……………………….……………………..….3.11

$Peff$=0.8∗P−24 for Pmonth>70 mm ……………………. ……………………………...3.12

P is precipitation (mm)

3.3.4.3. Net irrigation water requirements

The assessment of the irrigation potential, based on soil and water resources, can only be done by simultaneously assessing the irrigation water requirements (FAO, 1997).

Each crop has its water requirements. Net irrigation water requirements (NIWR) in a specific scheme for a given year are thus the sum of individual crop water requirements (CWRi) calculated for each irrigated crop, i. Multiple cropping (several cropping periods per year) is thus automatically taken into account by separately computing crop water requirements for each cropping period.

$NIWR$ (mm) = (mm)−$Peff$(mm) ………………………………………..…………...3.13

NIWR (mm) =$\sum_{i=1}^{n} NIWRi * ai$ unit: m3……………………………….……...….. 3.14

EE= ((CWR (mm) - Peff))/ (Vs.)………………………………..…………………..…. 3.15

Where:

CWR- is crop water requirement for the growing period

Peff is the effective rainfall, and.

Vs is the volume of water delivered to the command area

Where CWR is crop water requirement for the growing period, Kc is a crop coefficient for the crop, ETo is Potential evapotranspiration,

P_{eff} is effective rainfall (mm)

Where a_i is the area cultivated with the crop, i.

Dividing by the area of the scheme (a, in ha), a value of irrigation water requirements is obtained, expressed in m3/ha or mm (1 mm = 10 m3/ha).

$NIWR = \frac{\sum_{i=1}^{n} CWRi*ai}{A}$ Unit: m^3/ha…………………………………………..….…….….. 3.16

The cropping intensity of the scheme can be defined as: $\frac{\sum_{i=1}^{n} ai}{A}$……………………….…….3.17

3.3.4.4. Irrigation efficiency

Gross irrigation is the quantity of water diverted or extracted and net irrigation is the quantity of water consumed by the crop. Efficiency, therefore, is the share of gross irrigation that is used by the crop (Allen et al., 1998)

It is used to express the fraction of groundwater abstracted that is not lost along with the water transport from the abstraction point to the crop ((FAO, 1989). The extracted groundwater quantity does not reach fully the crops because of transport losses or losses in the field. Then, gross irrigation water requirements of the crops at the identified potential irrigable sites were estimated by considering field efficiency of 70% according to (FAO, 2001).

Finally, gross irrigation water requirements were estimated by:

$GIWR = \frac{NIWR}{na}$ unit: mm………………………………………………….……...…...…. 3.18

3.3.5. Irrigation potential by groundwater availability

Irrigation potential is calculated as a ratio of groundwater available to maximum irrigation water demand; where groundwater availability is calculated as an excess of groundwater recharge, considering other demands from humans and the environment (Altchenko et al., 2015). . The irrigation potential of the groundwater was estimated as the quotient of the groundwater available for the irrigation and the total crop water requirement (CWR) of the dominant crop in the area for the growing season (Allen et al., 1998). In this study, the irrigation potential was assessed based by comparing the monthly groundwater available with monthly crop irrigation requirements.

The GWIP [mm] is calculated as the potential cropland area that the available groundwater resource can irrigate

$$\text{GWIP}=\frac{\textbf{Groundwater (GW) available(mm)}}{\textbf{Total irrigation water demand(mm)}} \quad \ldots\ldots 3.19$$

Where:

- GWIP (mm) is groundwater irrigation potential
- Groundwater available [mm] is calculated as any excess of groundwater recharge, considering other groundwater demands from humans (domestic uses, livestock, industry) and the environment:
- Total irrigation water demand (mm) is the total irrigation water demand, which represents the groundwater abstraction needed to satisfy the deficit rainfall and the irrigation losses of the study watershed.

Table 3. 5: Summary of the required model, selection criteria, and their purpose

No	**Model type**	**Selection criteria**	**Purpose**
1	WetSpass	Its model bias, confidence, and efficiency	To estimate groundwater recharge
2	CROPWAT8.0	It's a climatic database	To estimate potential evapotranspiration
3	ARC GIS MAP	It's the sensitivity of defining land suitability for irrigation and in water allocation scenarios	To evaluate potentially suitable land
4	ERDAS EMAGINE 2014	Its accuracy and simplicity	For land sat image classification
5	SWAT	Its accuracy in delineating watershed	To delineate watershed by integrating with Arc GIS

3.3.6. Conceptual framework

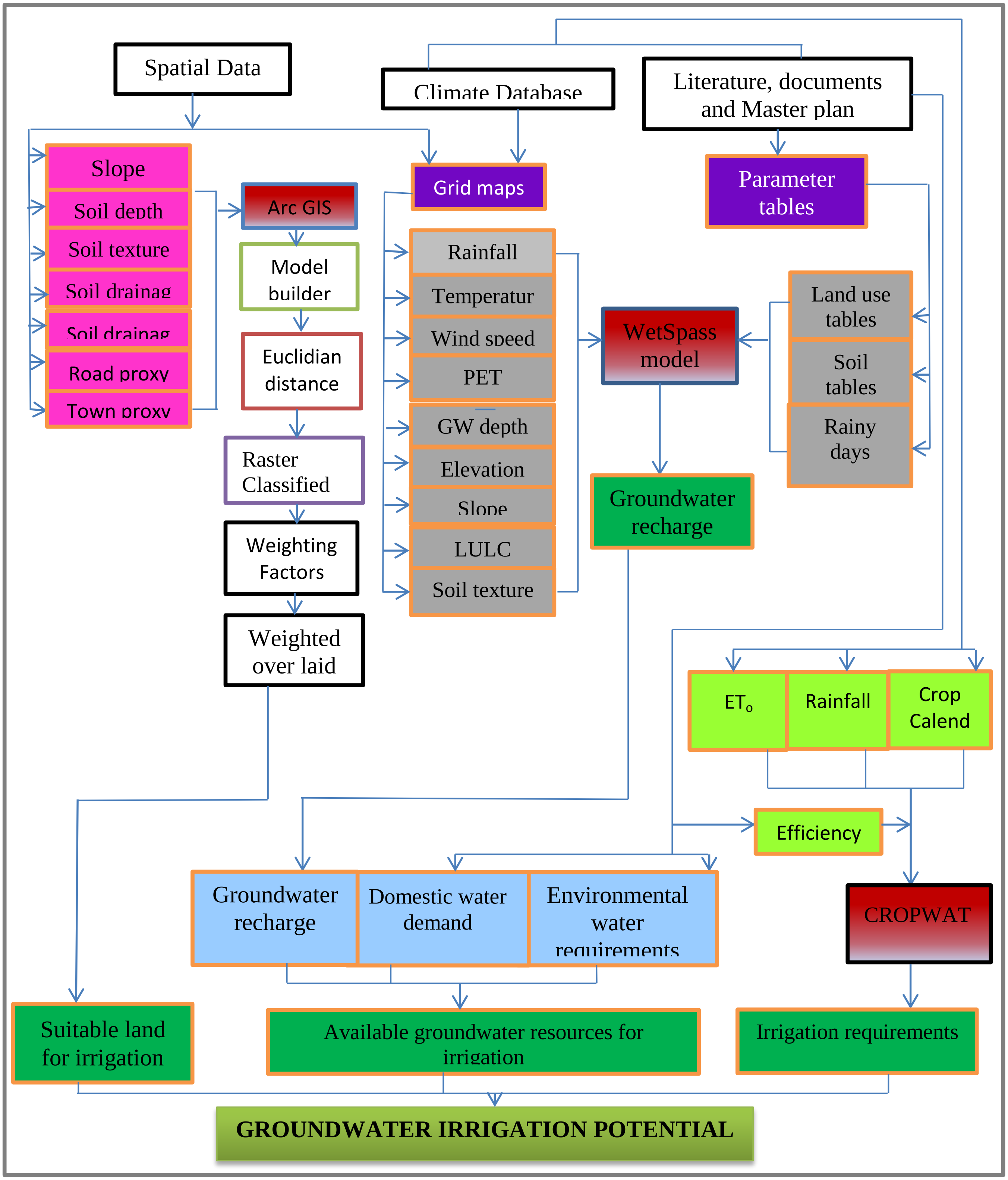

Fig.3. 5.Workflow diagram

4. RESULTS AND DISCUSSIONS

4.1 Data preprocessing

4.1.1. Estimation of missed rainfall data

The rainfall analysis result showed that there were missing rainfall records at Harar, Kombolcha, and Karsa stations. Therefore, to use these data for further application, missing values were filled by using the normal ratio method, and results are summarized in Appendix Tables. The rainfall data at Haramaya station, as presented in Appendix Table, this station has no missing records and with data of other stations, they were used to fill missing values for other rainfall stations.

4.1. 2. Consistency of rainfall

The results of the double-mass curve analysis of the rainfall data at stations (Haramya, Combolcha, Harar, and Karsa) revealed that there is a good direct correlation between the cumulative rainfall recorded at the station with the cumulative average of base stations at the four stations (r =0.9996). This indicates that the rainfall data at Haramaya gauging station is consistent with no significant change of slope on their respective. For the other three stations, the consistencies of the rainfall records were checked using a similar procedure and there was no significant change of slope observed on their respective plots. The correlation coefficients of the three stations indicated that there is a good direct correlation between the stations' records and their corresponding base stations. Therefore, it was concluded that the rainfall data recorded at these four stations can be used directly for further analysis.

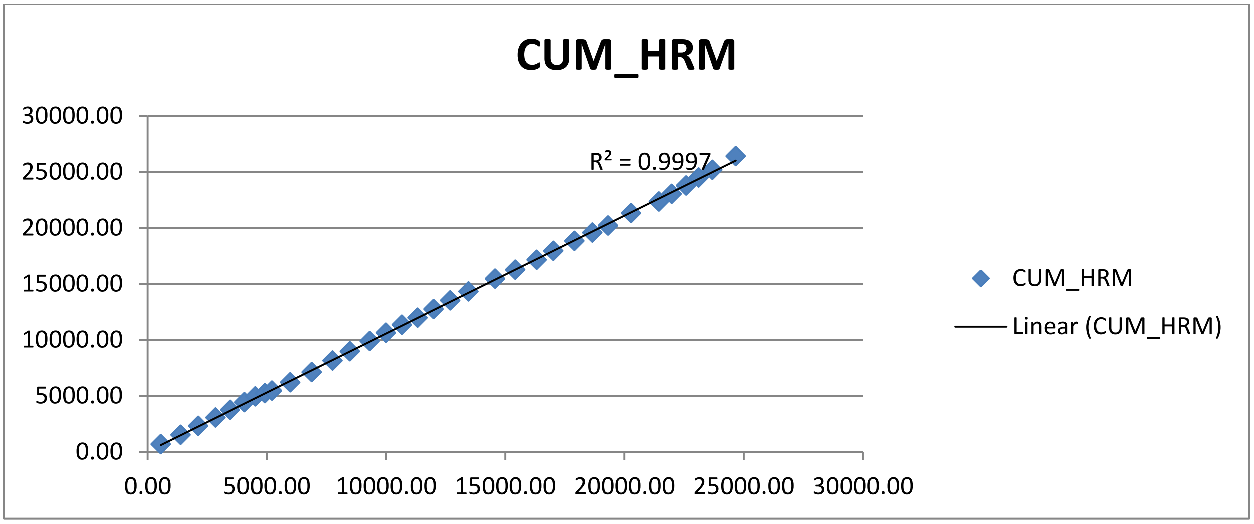

Fig.4. 1.Double mass curve of Haramaya rainfall station

4.1. 3. Watershed delineation

The watershed delineation results showed that there was one main watershed in the study area. The resulted watersheds are called Lake Haramaya watershed which contributed water for the Lake Haramaya. The lake Haramaya watershed covering a total area of 12481290 ha this is shown in the following figure.

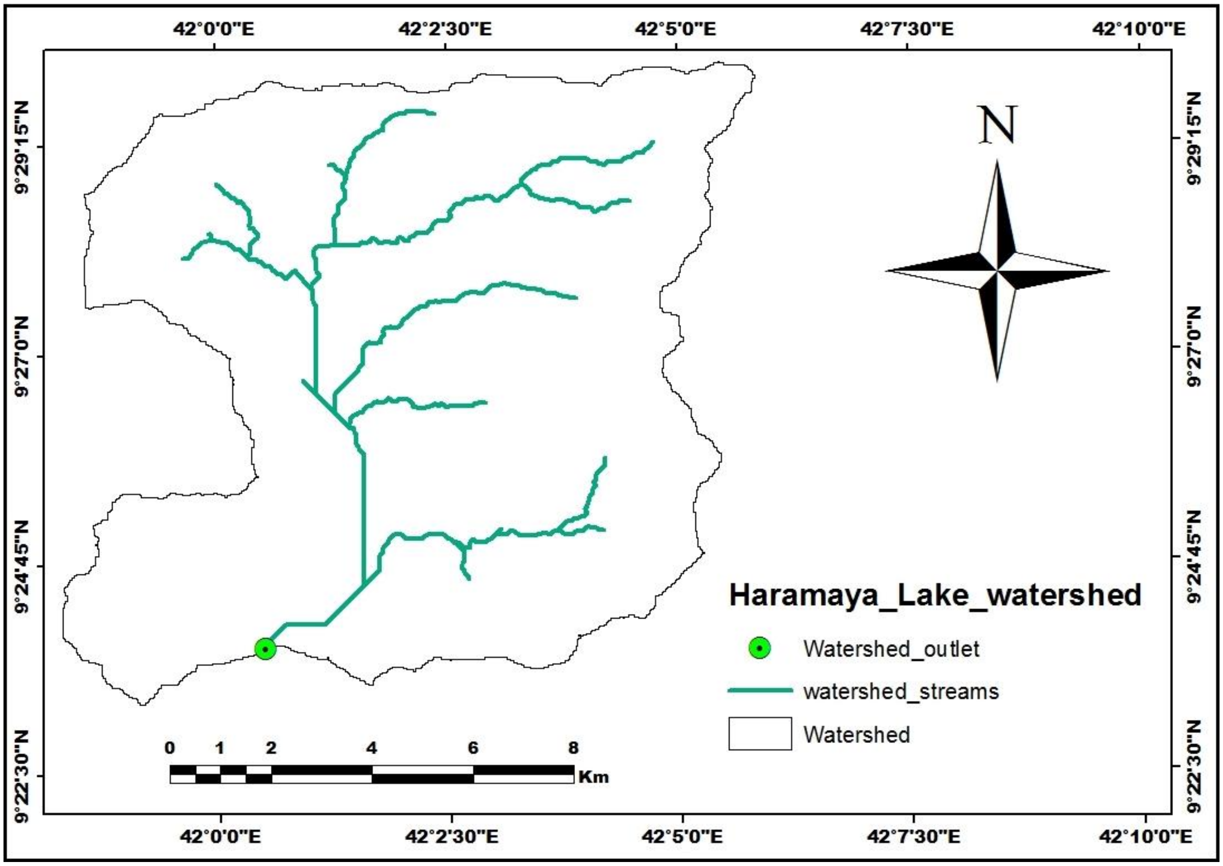

Fig.4. 2.The Lake Haramaya watershed and stream network

4.2. Potentially suitable land for irrigation

The potential land areas suitable for irrigation were identified using the GIS-based Multi-Criteria Evaluation (MCE) technique. Multi-Criteria Evaluation was implemented in a GIS environment to combine several criteria to make a single indexed output ((Chen et al., 2010); (Saaty, T. L. , 2008)). The suitable land for surface irrigation using groundwater was obtained first by deriving data sets, calculate distance using the Euclidian distance tool, reclassified using reclassify tools, then weighted using a pairwise comparison matrix, and finally overlaid using weighted overlay tools. The individual suitability of each factor was first analyzed and finally weighted to get potential irrigable sites. Since the spatial resolution of suitability analysis factors were vary, the nearest neighbor method was used to resampling all data to 30m resolution.

4.2.1. Slope suitability

Since the slope affects the water flow, fertility of soil profile, depth of irrigation, and drainage of the watershed it is considered as the main factor in suitability evaluation. The slope map computed from a 30m DEM was classified into four classes of land suitability, as indicated by (Worqlul et al., 2015) . The slopes from 0 to 2% were classified as highly suitable, 2 to 5% moderately suitable, 5 to 8% marginally suitable, and above 8% were classified as not suitable. The slope suitability map of the watershed area coverage of each suitability class was described in Figure 4.3. and table 4.1. The result shows that 73.92% of the total watershed area was in the range of highly suitable to moderately suitable for surface irrigation (Table 4.1), 20.23% was moderately suitable and 5.43% was not suitable for surface irrigation.

Table 4. 1: Summary of the slope of the study area

Slopes range (%)	area coverage (km^2)	% of the total area	suitability classes
0 – 2	43.37	34.75	S1 (Highly suitable)
2 – 5	49.42	39.59	S2 (moderately suitable)
5 – 8	25.25	20.23	S3 (marginally suitable)
>8	6.78	5.43	N (not suitable)

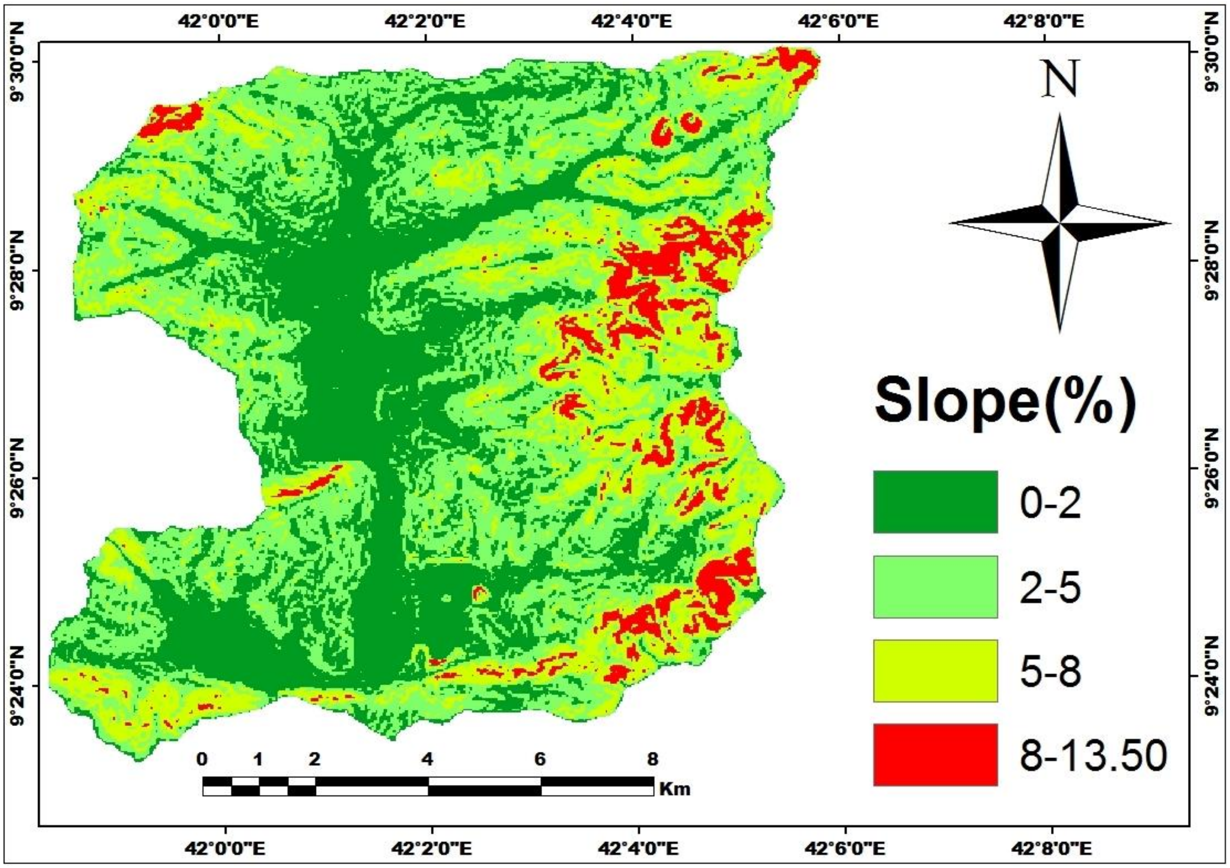

Fig.4. 3.Slope suitability of the Lake Haramaya watershed

4.2.2. Soil suitability

The soil is a major factor in the suitability of land for sustained irrigation. Its primary influence is on the productive capacity, but it may also influence production and development costs (FAO, 1984) several soil characteristics must be evaluated to determine soil suitability for irrigation. The primary factors are soil physical parameters to determine soil suitability analysis, but mainly there are three soil physical properties to evaluate soil suitability in the watershed. These are soil texture, soil depth, and soil drainage properties each data were taken accordingly from (FAO, 2006) to describe in detail as follows.

4.2.3. Major soil suitability

The major soil groups in the study area were identified based on (FAO, 1984) soil map. Identified soil groups were included Chromic Luvisols, Humic Nitosols, Lithic leptosols, and water bodies (Figure 4.4).

Chromic Luvisols: - The third dominant soils groups are Chromic Luvisols. This soil group covers 21.75km2 and has been characterized as a depth of moderately deep to deep and well-drained soil property having a soil texture group of Sandy clay loam. It is commonly dominant on flat to gently sloping topography. The result shows that this soil group is highly suitable for irrigation.

Humic Nitosols: - The second dominant soil groups are Humic Nitosols which cover an area of 48.91Km2 and are characterized as a depth of deep depth and well drainage property. This soil in the study area has been found in deep depth with limited profile development.

Lithic leptosols:-The first dominant soil group of the watershed is Lithic leptosols which covering an area of 49.71 km2 and was characterized as a depth of shallow deep and imperfect drainage. Lithic leptosols are extremely hard when dry and very sticky and plastic when wet which is reflected in their poor workability.

Water bodies: - the remaining area is occupied with the water bodies which cover the area of 4.43 Km2 and are limited by shallow soil depth which is unsuitable for crop growth and surface irrigation method. Therefore, areas Covered by water bodies were classified as N (not suitable class).

Table 4. 2: Suitability of soil characteristic

Soil type	Texture	Depth(cm)	Drainage	Suitability	Shape Area(Km^2)
Chromic Luvisols	Sandy Clay loam	>120	well	S2(highly suitable)	21.75
Humic Nitosols	clay	>120	well	S1(moderately suitable)	48.91
Lithic leptosols	Clay loam	<30	imperfect	N(not suitable)	49.71
Water bodies		<30	imperfect	N(Not suitable)	4.43

Generally, the soil texture suitability, soil drainage suitability, soil depth, and irrigation suitability of the given watershed soil are described in the following section within their area suitability from the total area of the watershed.

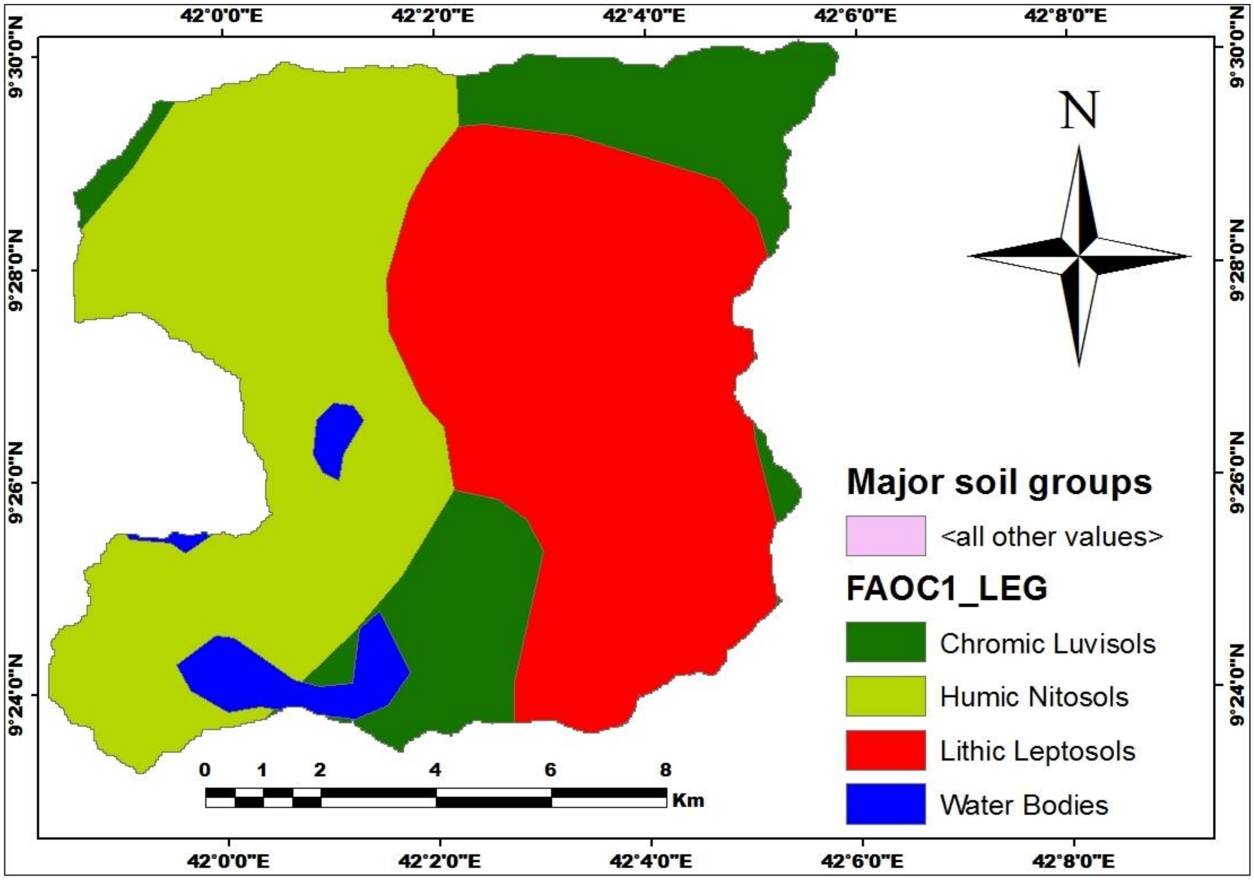

Fig.4. 4.Major soil suitability

4.2.4. Soil texture suitability

The most important soil physical characteristics are soil texture. The fine-textured soils were the dominant soil groups in the watershed area. The texture of a given soil affects infiltration capacity and water retention capacity. Fine-textured soils have high water holding capacity and low infiltration rate, whereas coarse-textured soils have low water holding capacity and a high infiltration rate. The soil texture was classified into four groups based on the soil water holding capacity, namely very high holding capacity (e.g. silt, silt loam, and silt clay loam), high capacity(e.g. silt clay, and clay), low capacity(e.g. loamy sands), and very low(e.g. sands, and loamy sands (Bell, J. C., 1992)).

As soil textural classes of investigating soils in the study area vary from fine to course, i.e. clay to sandy loam. The result of soil textural class suitability analysis for groundwater irrigation development of the watershed area revealed that 52.51% of the area cover by clay soils,47.55% cover by clay loam soils, and 24.76% cover by sandy clay loam. The summary of soil textural suitability of the watershed areas for groundwater irrigation development and geographical location of these textural classes and their area of coverages were given in table 4.3.

Table 4. 3: Soil texture suitability and their area of coverage

No	Soil texture	Suitability	Area(Km^2)	Area (%)
1	Clay Loam	S3(moderately suitable)	47.55	38.10
2	Clay(light)	S1(highly suitable)	52.51	42.07
3	Sandy Clay Loam	S2(marginally suitable)	24.76	19.84
4	Total		124.82	100

The soil textural suitability for groundwater irrigation as Clay loam, Clay and Sandy Clay Loam presented in figure 4.5 and each covers 38.1%, 42.07%, and 19.84% respectively.

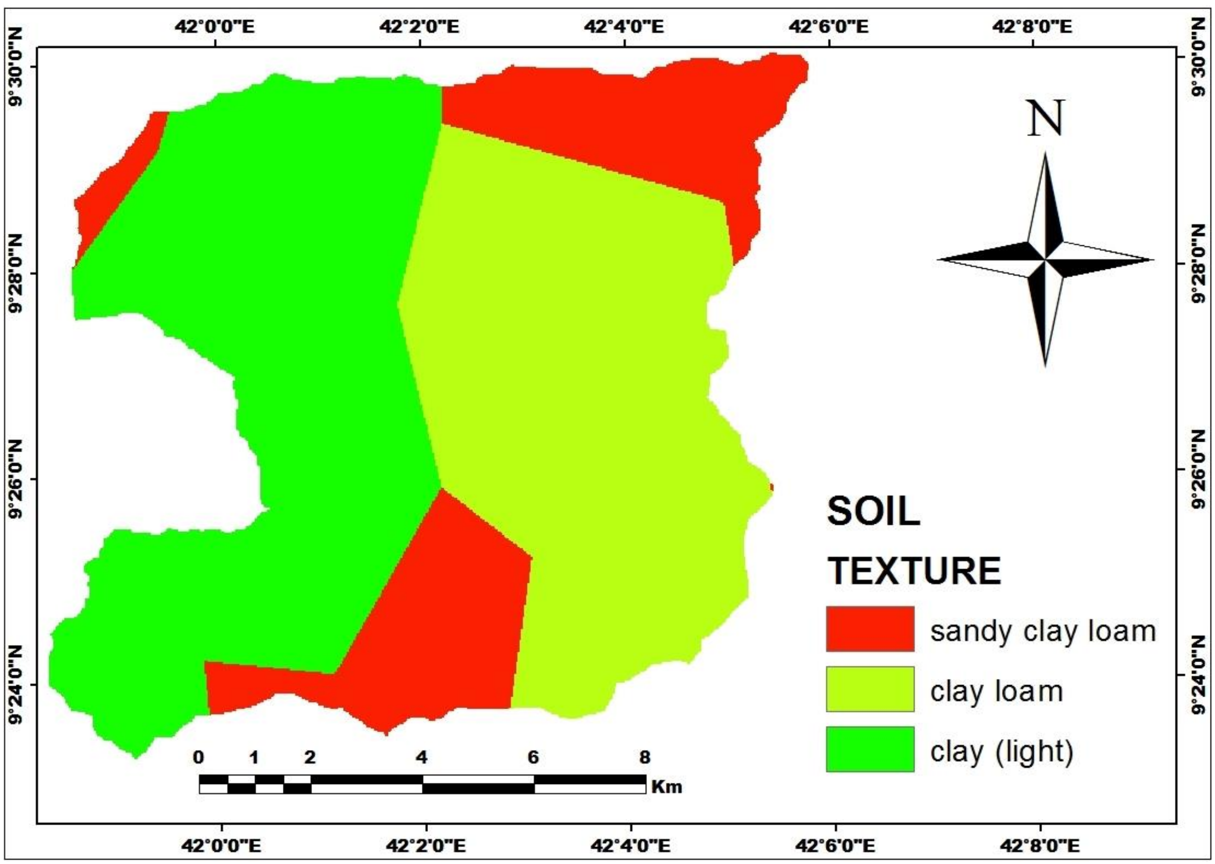

Fig.4. 5.Soil texture map of the Haramaya lake watershed.

4.2.5. Soil depth suitability

Soil depth is one of the important physical parameters that are used to evaluate the suitability of lands for irrigation development using groundwater. A soil depth of the watershed soils was interpreted from geomorphology and soil map legend of (FAO, 1984).

The soil depth map indicated a depth found in the watershed basin was <30cm and >120cm, accordingly, the soil depth was reclassified into two classes which are <30cm and >120cm as given in Table 4.4, and (Fig 4.6).

Soil depths of the watershed area were evaluated in terms of the degree of their suitability for irrigation and classified into two classes as highly suitable(>120cm) and not suitable(<30). The results show that 56.62% (70.67Km^2) of the basin soil was categorized as highly suitable, and 43.38% (54.15Km^2) of land was categorized under the not suitable class for the irrigation purpose. The suitability results of soil depth and geographic location of these soils in the basin were presented in table 4.4. From the total percentage cover of the watershed areas, 56.62% of the soil was highly suitable for groundwater irrigation in terms of soil depth suitability.

Table 4. 4: Soil depth, suitability and their area coverage in the watershed

S/N	Soil Depth	Soil Suitability	Area (km2)	%Area
1	>120	highly suitable	70.67	56.62
2	<30	Not suitable	54.15	43.38

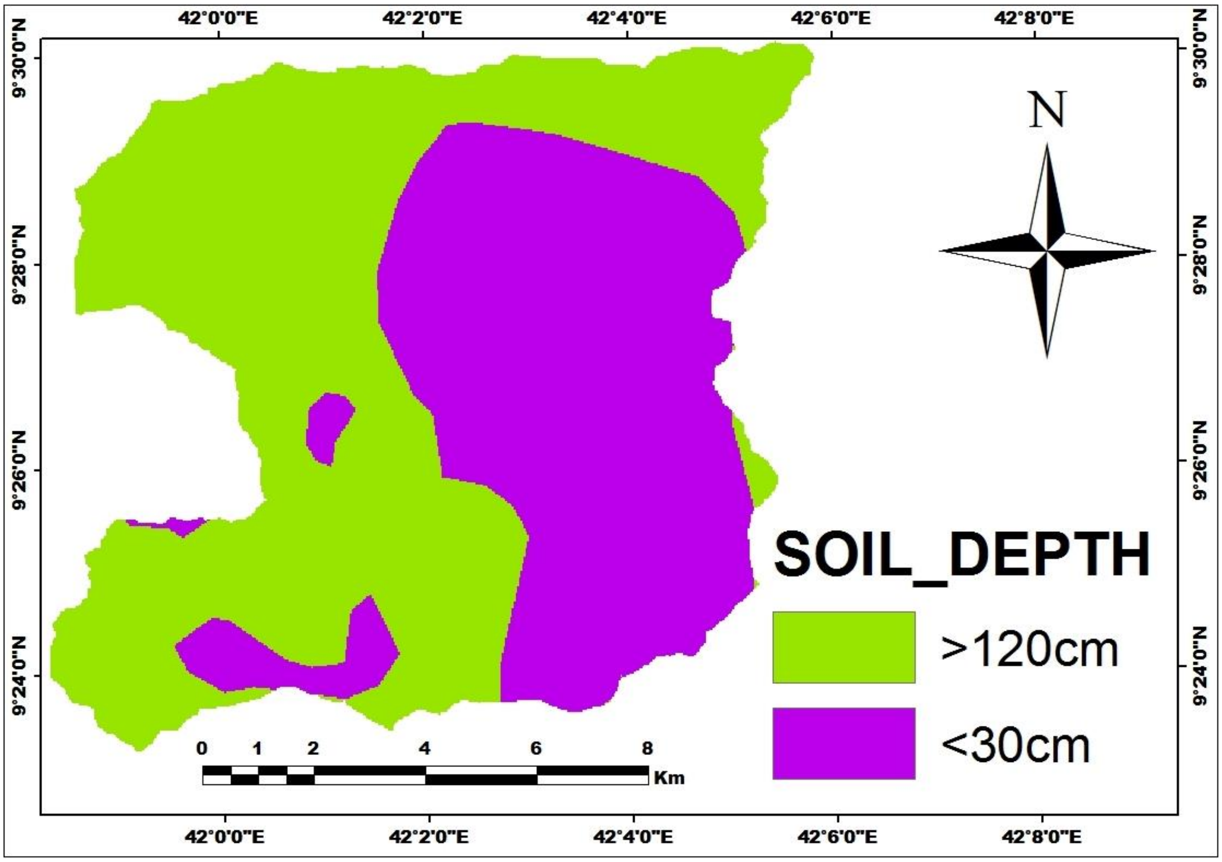

Fig.4. 6.Soil depth map of the watershed

4.2.6. Drainage suitability of the area

The soil drainage represents the rate at which water drains into the soil, lower drainages will pond water on the soil surface while in well-drained soils water is removed readily but not rapidly. So soil drainage is an important parameter for the evaluation of the area for surface irrigation. The soil drainage map collected from Africa, FAO over has two classes well-drained and imperfect drain.

The soil-based on the (FAO, 1984) guidelines, two soil drainage classes (well drained and imperfectly drained classes) were identified. Well-drained soils are good for agriculture in general. Well-drained soils are easy for cultivation easy for aeration, easy for crop nutrient and water sucking. The well-drained soils of the area were associated with areas with high slope percent (>8%) and slopes between 5–8%. The imperfectly drained soils are linked to lowlands of the sub-basin with a slope percentage of less than 8%. Imperfectly drain soils were mainly dominant between flat to 2% slope.

The result shows that there was no limitation from irrigation development due to drainage problems. From the total area of the basin (124.81Km2), the well-drained soil covers an area of 77.62Km2(62.19%), and the imperfectly drain soil covers an area of 47.19km2 (37.81%) which not suitable for irrigation. Generally, the soil drainage properties of the dominant soils in the watershed were summarized in table 4.5.

Table 4. 5: Drainage suitability and their area coverage

S/N	Drainage Class	Suitability Class	Area (Km2)	%Area
1	well drain	S1(highly suitable)	77.62	62.19
2	imperfect drain	S2(Not suitable)	47.19	37.81
3	Total		124.81	100

The well-drained soils are categorized under a high suitability rating class and the imperfectly drained soils are categorized as not suitable for surface irrigation development using groundwater (FAO, 1984) .

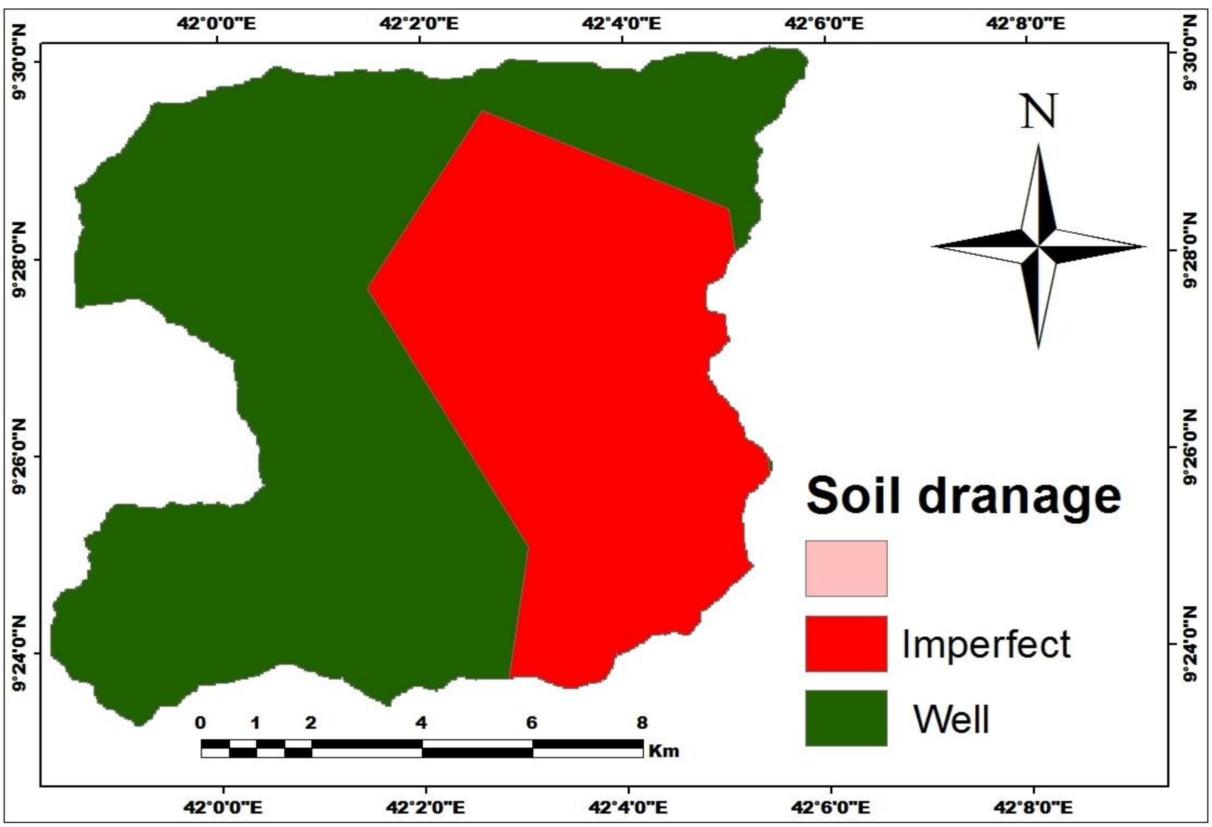

Fig.4. 7. Drainage map of the Lake Haramaya watershed

4.2.7. Land use /land cover evaluation

Land use/Land cover map was prepared from landsat8.0 image using supervised classification technique. The land use/cover information help in the evaluation of land suitability for groundwater irrigation development. The super classifications results show that seven land cover/use classes were identified these classes include agricultural land, bare land, forest, grassland, settlement, shrubland, and water body. The result of the classified image for land suitability analysis of the watershed area revealed that 57.39% of the area cover by agricultural land, 1.80% of the area cover by bare land, 3.11% of the area cover by forest, 3.99% of the area cover by grassland, 2.58% of the area cover by settlement, 29.20% of the area cover by shrubland, and 1.94% of the area cover by water body. The largest area is agricultural land (57.39%) and the lowest area is under the bare land category (1.8%).

Table 4. 6: Framework of land suitability classification of FAO

Class	Land Description
Class S1: Highly suitable	Land without significant limitations. This land is the best possible and does not reduce productivity or require increased Inputs.
Class S2: Moderately suitable	Land that is suitable but has limitations that either reduce productivity or require an increase of inputs to sustain Productivity compared with those needed on S1 land.
Class S3: Marginally suitable	Land with limitations so severe that benefits are reduced and/or the inputs required sustaining production need to be Increased so that this cost is only marginally justified.
Class S4 (N1): Currently not suitable	Land that cannot support the particular land use on a sustained basis or land on which benefits do not justify inputs

The land use was reclassified into four classes of agricultural land suitability for irrigation according to the FAO framework (FAO, 1976), (FAO, 1985), (FAO, 1989); (Walker, W. R., 1989) Based on the above justification, the land-use group was classified into four classes ranging from highly suitable (s1) to not suitable (s4). Table 4.7 presents the FAO framework of land suitability classification. Agricultural land use is classified as highly suitable (s1) and grassland, which requires land clearing, and leveling, is moderately suitable (s2). Shrub land and bare land, which require a higher initial investment for land preparation, were reclassified as marginally suitable (s3). Forest, water bodies, and urban types were reclassified as not suitable (s4).

Table 4. 7: Summary of the land cover and land use

Code	Class name	Area_Km2	%Area	class	Degree of suitability for irrigation
1	Agricultural Land	71.6255951	57.39382401	Class s1	Highly suitable
2	Bare Land	2.2400999	1.794999389	Class s3	Marginally suitable
3	Forest	3.8780999	3.107534155	Class s4	Not suitable
4	Grass Land	4.9734001	3.985201794	Class s2	Moderately suitable
5	Settlement	3.2156999	2.576750865	Class s4	Not suitable
6	Shrubland	36.4391995	29.19884994	Class s3	Marginally suitable
7	Water Body	2.4245999	1.942839843	Class s4	Not suitable
Total	7	124.8			

Table 4.7 presented, all land cover/use classes which were classified by supervised classification technique with high accuracy using ERDAS IMAGINE 2014. The land cover/use of the study area was classified with an overall accuracy of 92.98 % and a Kappa coefficient of 0.95. The Kappa coefficient of 0.95 of the land cover classification in the study area represents a strong agreement according to (Raghunath H.M., 2006).

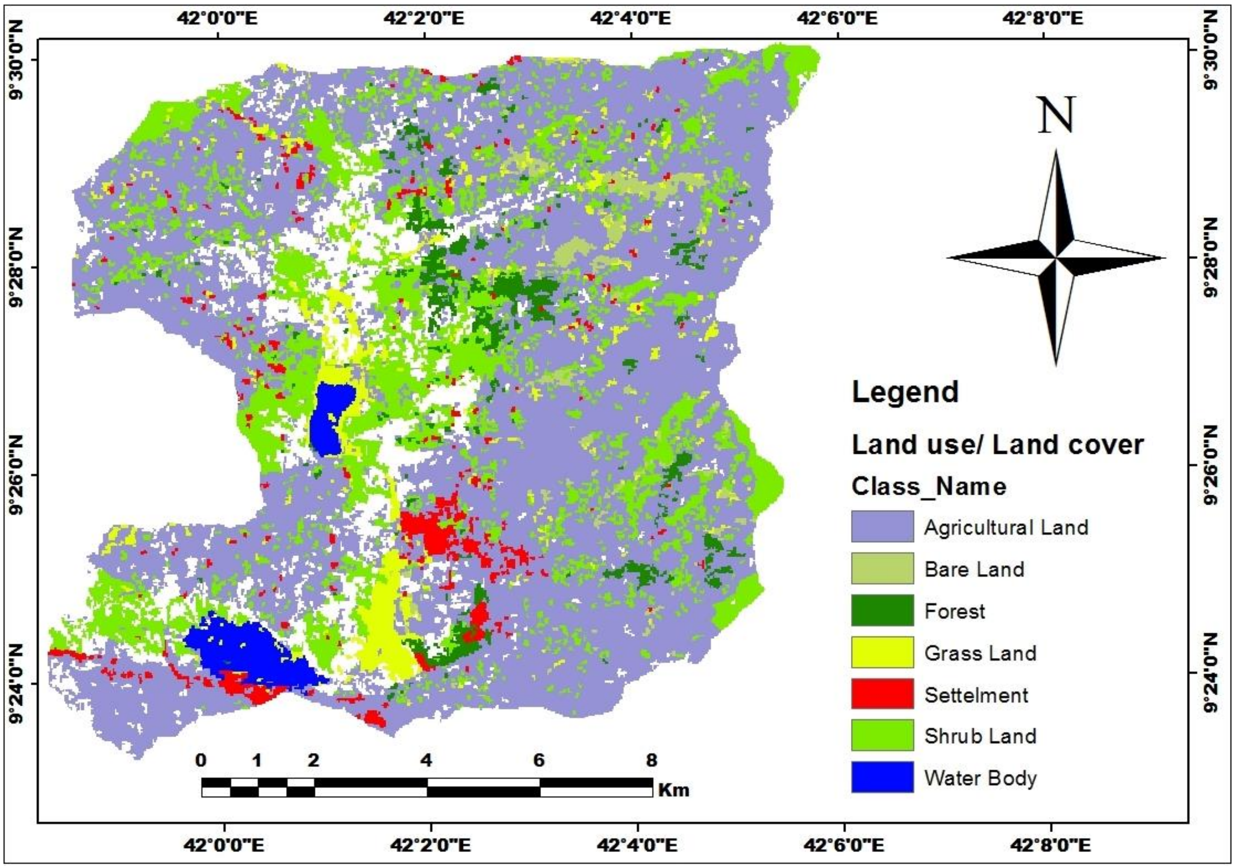

Fig.4. 8. Land cover and land use map of the watershed

4.2.8. Market access

The proxy for market access is ‘time taken to the market’, which was more appropriate than physical distances, due to differences in wealth and farm resources, and hence different means of transportation.

Market access was determined by using the town's shapefile and the GPS location of the three major towns with a population density of more than 223,000 identified using the 2007 Population and Housing Census of Ethiopia. The result of market access shows that there are three available markets in the watershed which included Haramaya, Adele, and Bate towns. For feature data, the tools found in the distance toolset were used to discover proximity relationships between the market and the feature data in the watershed. The proximity of market class suitability analysis for groundwater irrigation development of the watershed area revealed that nearly 35.21% (43.94km2) of the area is most suitable in terms of nearness to market access and hence is considered as S1. Nearly 22.53% (28.12km2) and 21.42% (26.74km2) land of the area are found to be moderately (S2) and marginally (S3) suitable for market access respectively. Whereas, (26.01km2) 20.85% is not recommended (N) for the implementation of surface irrigation practice in the present situation. The summary of market access suitability of the watershed areas for groundwater irrigation development and geographical location of market proxy classes and their area of coverages were given in table 4.8 and figure 4.9.

Table 4. 8: Summary of the market proximity and their area of coverage

No	Distances(m)	Area_km^2	%Area	Suitability
1	2425.95	43.9425011	35.21	S1(Highly suitable)
2	3653.19	28.1177998	22.53	S2(Moderately suitable)
3	5784.22	26.7353992	21.42	S3(Marginally suitable)
4	9703.78	26.0172005	20.85	N(Not suitable)
5		124.81	100	

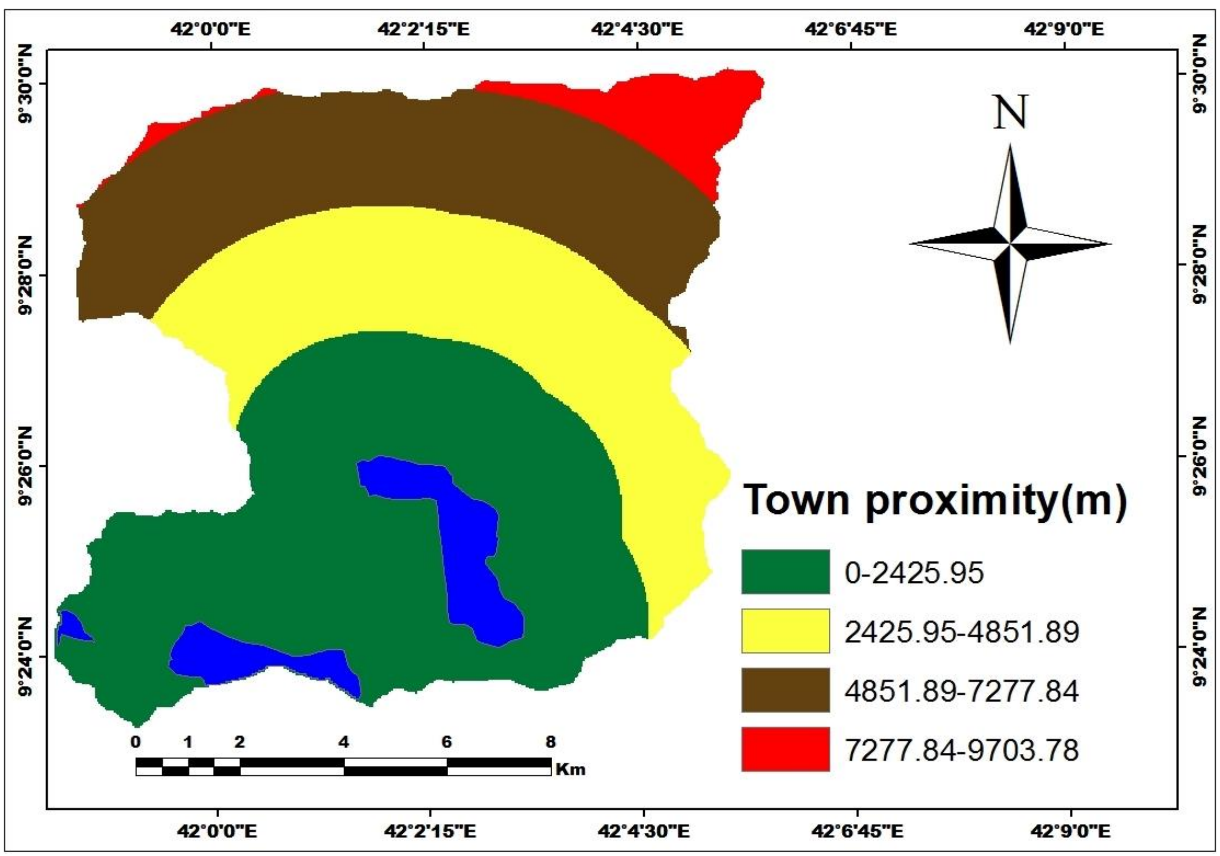

Fig.4. 9.Market access of the watershed

4.2.9. Road Proximity

Distance tools in ARC GIS calculate the distance from each point in one feature class to all the points within a given search radius in another feature class (Ceballos et al., 2003). The major road networks are used to determine market access by estimating the distance between each pixel and the nearby network. Due to higher variability, the road proximity map was reclassified into four classes of suitability using an equal interval ranging technique and the nearest point is S1 and the farthest distance is S4 (Abeyou et al., 2015). The road proximity map indicates that the farthest point is located at 5215.61m away from the paved road, and the smallest distance from the paved road was 748.54m.

The major paved road networks in the watershed were obtained from the Ethiopian road authority. The proximity of road class suitability analysis for groundwater irrigation development of the watershed area was derived using Euclidian distance tool in Arc GIS toolset and the result revealed that 51.04% of the areas cover by 748.54m distances, 28.42% of the areas cover by 1810.97m distances and 13.48% of the areas cover by 3308.046m distances, and 7.05% of the areas cover by 5215.61m distances. The summary of market access suitability of the watershed areas for groundwater irrigation development and geographical location of market proxy classes and their area of coverages were given in table 4.8 and figure 4.10.

Table 4. 8: Summary of the road proximity, their area of coverage, and suitability

No	Distances(m)	Area(km2)	Area (%)	Suitability class
1	1307	63.7082977	51.04	S1(highly suitable)
2	2614	35.4824982	28.42	S2(moderately suitable)
3	3921	16.8281994	13.48	S3(marginally suitable)
4	5228	8.7938995	7.05	S4(not suitable)

This table can be used for statistical analyses, or it can be joined to one of the feature classes to show the distance to points in the other feature class.

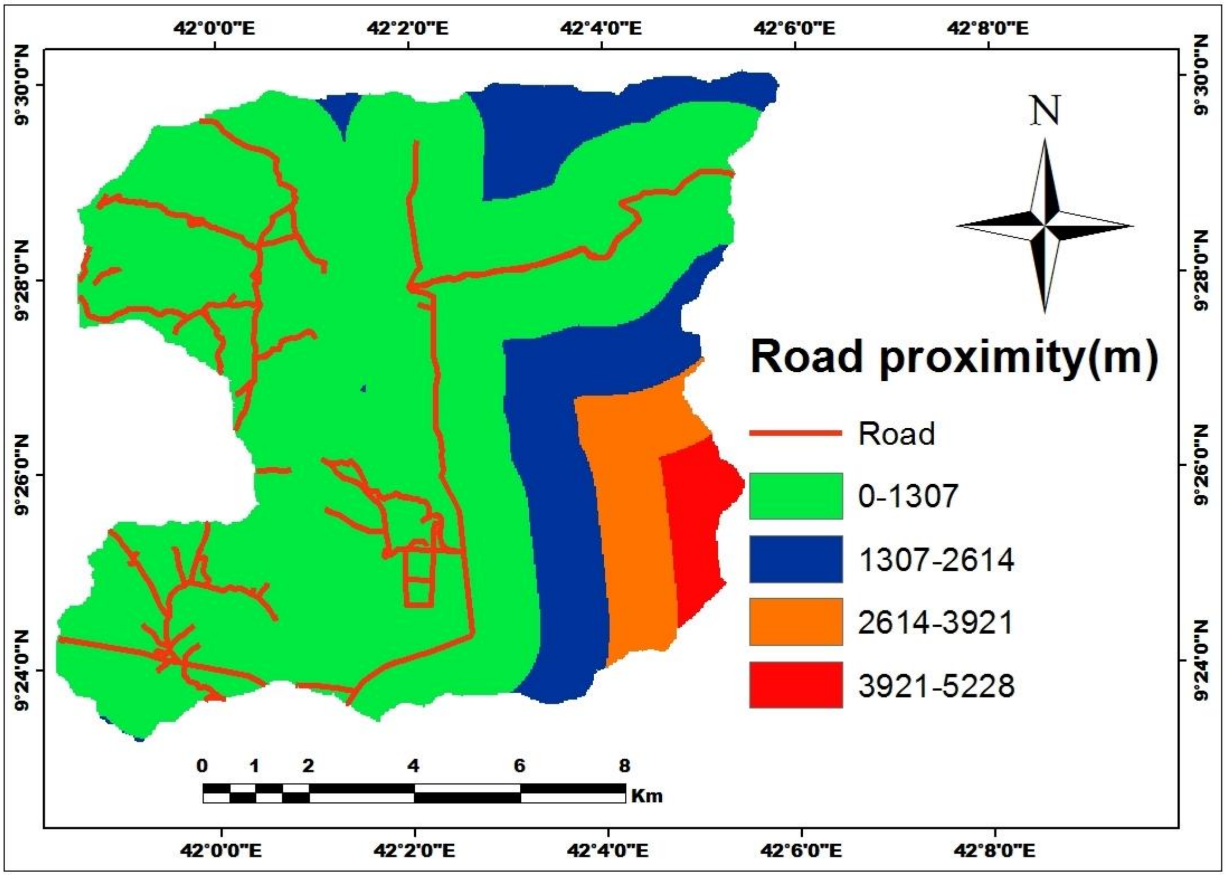

Fig.4. 10. Road proximity of the Lake Haramaya watershed

4.2.10. The weighting of factors for suitability analysis

The analytical hierarchy process (AHP) developed by (Saaty, T. L. , 2008) is a multi-criteria decision (MCD) approach. For GIS-based land suitability evaluation, a multi-criteria decision approach is frequently applied for weighting criteria. The AHP is a method for deriving a priority scale through pairwise comparison of attributes based on the factors.

Table 4. 9: pair wise comparison scale and definition (Saaty, T. L., & Erdener, E. , 1979)

Intensity of importance	Definition	Description
1	Equal importance	Two factors contribute equally to the suitability of surface irrigation
3	Somewhat more important	Experience and judgment slightly favor one over the other
5	Much more important	Experience and judgments strongly favor one over the other.
7	Very much more important	Experience and judgments very strongly favor one over the other.
9	More important	The evidence favoring one over the other is of the highest possible validity.
2,4,6,8	Intermediate values	When compromise is needed

Based on a pair-wise weighting approach, each factor was compared to each other's, and then a comparison matrix was prepared using the Saaty table indicating the relative importance of one factor over the other. The level of importance of each factor was scaled from values of 1 to 9.

The Pair-wise comparison matrix of the factors table 4.10 (using table 4.9) was constructed first. The seven factors ranging from slope to river proximity are added in the first eight columns and first eight rows in table 4.10. The column factors were compared with the factors in the rows for their significance to groundwater irrigation, and then using the scoring of Saaty (1977) in table 10.10, the pair-wise matrix table 10.11 was prepared.

Table 4. 10: Pair-wise comparison matrix

NO	Slope	Soil depth	Soil Texture	Soil_ drainage	Land use	Roads proxy	town proxy
Slope	1	5	3	5	7	8	6
Soil depth	1/5	1	1/3	1/2	2	4	7
Soil Texture	1/3	3	1	7	7	8	8
Soil drainage	1/5	2	1/7	1	3	4	7
Land use	1/7	1/2	1/7	1/3	1	2	2
Road proxy	1/8	1/4	1/8	1/4	1/7	1	2
town proxy	1/6	1/7	1/8	1/7	1/2	1/2	1

4.2.11. Weighting of factors

Table 4. 11: Standardized pair wise comparison matrix

NO	Slope	Soil depth	Soil Texture	Soil drainage	Land use	Roads proxy	town proxy	Weight average	%Weight
Slope	0.4613	0.4204	0.6161	0.3515	0.3391	0.2909	0.1818	0.3802	38
Soil depth	0.0923	0.0841	0.0685	0.0351	0.0969	0.1455	0.2121	0.1049	11
Soil Texture	0.1538	0.2523	0.2054	0.4921	0.3391	0.2909	0.2424	0.2823	28
Soil drainage	0.0923	0.1682	0.0293	0.0703	0.1453	0.1455	0.2121	0.1233	12
Land use	0.0659	0.0420	0.0293	0.0234	0.0484	0.0727	0.0606	0.0489	5
Road proxy	0.0577	0.0210	0.0257	0.0176	0.0069	0.0364	0.0606	0.0323	3
town proxy	0.0769	0.0120	0.0257	0.0100	0.0242	0.0182	0.0303	0.0282	3

Based on the Saaty (1977), the pair-wise comparison matrix was used to weight the factors and seven major factors (slope, soil depth, soil texture, soil drainage, land use, road proxy, and town proxy) compared to each other using a scale from 1 to 9 according to Saaty (1977). The Eigen vector was calculated as the product of the row matrix and the weights of each factor were calculated by normalizing the respective eigenvector by the cumulative vector.

The result of multi-criteria approach analysis in the above table 4.11 shows that the factor “slope” is the most important factor and weighted 38.02% values, the factor “soil texture “ was the second most important factor and weighted 28.23% values, the factor “soil drainage” was the third important factor and weighted 12.33%, the factor “soil depth” was the fourth important factor and weighted 10.49% values, the factor “land use” is the fifth important factor and weighted 4.89% values, the factor “Road proximity” is the sixth important factor and weighted 3.23% values, the factor “Town” is the least important and weighted 2.82% values. From the above table's result, I concluded that the most important factor was a slope and the least important factor was town proximity in considering surface irrigation development using groundwater.

Consistency of pair-wise comparison matrix

The credibility of the pairwise matrix consistency was evaluated using the consistency ratio. The result was found to be trustworthy with a consistency ratio of 0.071 (Byun, D.-H., 2001) (Chen et al., 2010): (Koczkodaj et al., 2016).

Table 4. 12: Pairwise matrix consistency summary

	Slope	Soil depth	Soil Texture	Soil drainage	Land use	Roads proximity	town proximity
Weight Sum	3.136	0.760	2.4128	0.9226	0.358	0.2355	0.2000
Weight average	0.380	0.104	0.2823	0.1233	0.048	0.0323	0.0282
Weight sum/weight aver	8.253	7.252	8.5478	7.4838	7.317	7.2994	7.0962
ʎmax	7.607						
CONFIDENTIALITY-INDEX(CI)	0.1012						
Random Index(RI)	1.410						
INDEX_RATIO	0.071	<0.1					

4.3.12. Weighted overlay analysis of suitability factors

The total area of the watershed, which is suitable for surface irrigation development using groundwater without hesitating crop production, was computed using weighted overlay toolset in ArcGIS and overlaid suitability analysis factors such as slope, soil texture, soil depth, soil drainage, land use, Road proximity and Market access as shown in the following diagram Figure 4.15.

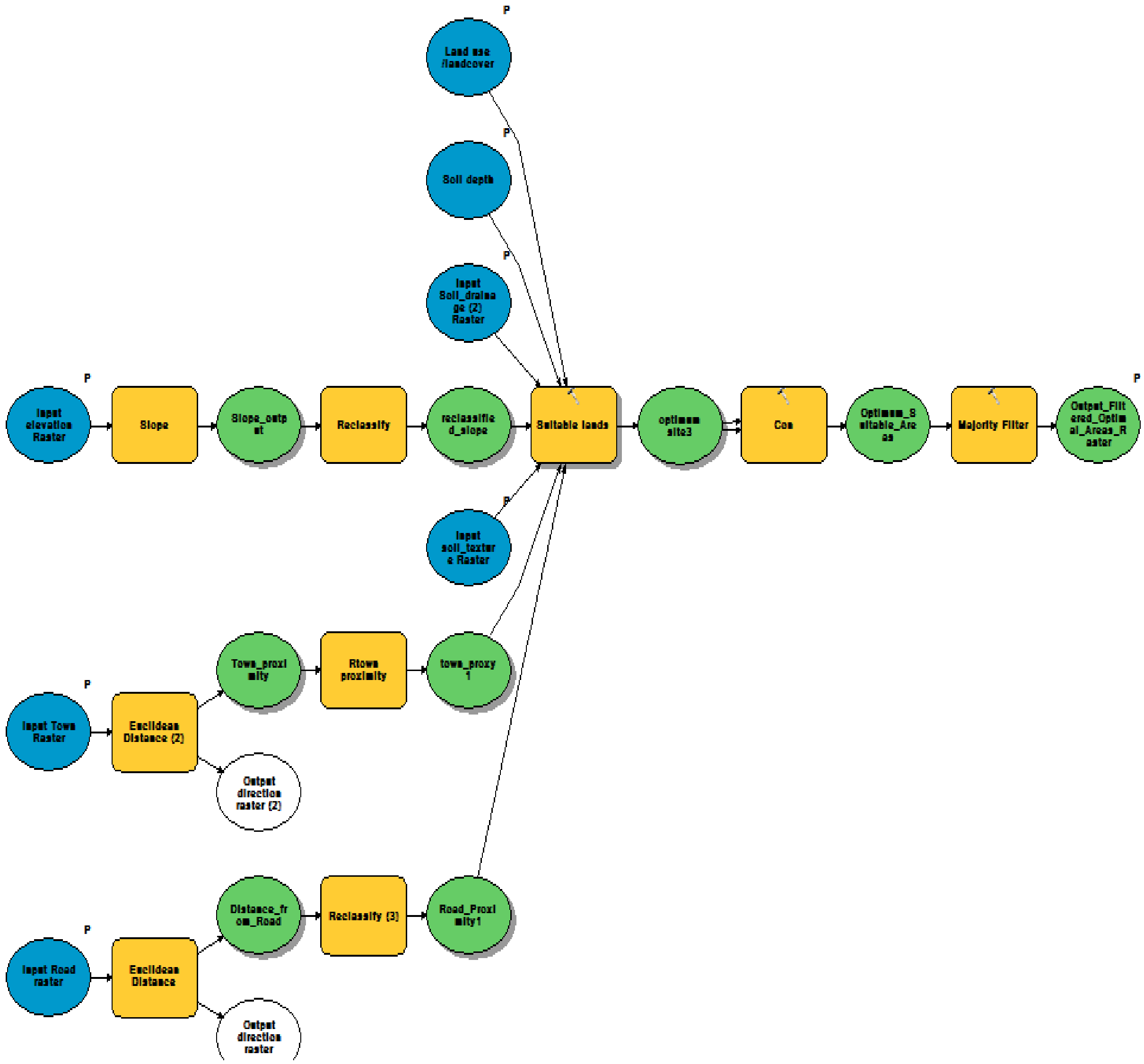

Fig.4. 11. Weighted overlaid of the suitability analysis factors

4.2.13. Potentially irrigable land

Potentially irrigable land was evaluated and obtained by developing an irrigation suitability analysis model based on a multi-criteria decision(MCD) approach that was weighting values of all factor such as slope, soil (dominant soil group, depth, drainage, and texture), land cover and land use, proximity(road, and town). The details of the result of the analysis were presented in table 4.13 and figure 4.12.

Table 4. 13: Summery of the potentially suitable land for groundwater irrigation

No	Area(Km2)	Area (%)	Suitability
1	36.38	33.19	S1(Highly suitable)
2	33.93	31.00	S2(Marginally suitable)
3	35.14	32.02	S3(Moderately suitable)
4	1.73	1.58	S4(Not suitable)
5	2.43	2.22	Water Bodies

The identified potential irrigable land area that suitable for surface irrigation using groundwater was found to be 36.38(33.19%), 33.93(31.00%), 35.14(32.02%), and 1.73(1.58%) Km^2 Highly suitable, marginally suitable, moderately suitable and not suitability while 2.43km2(2.22%) are water bodies which were restricted.

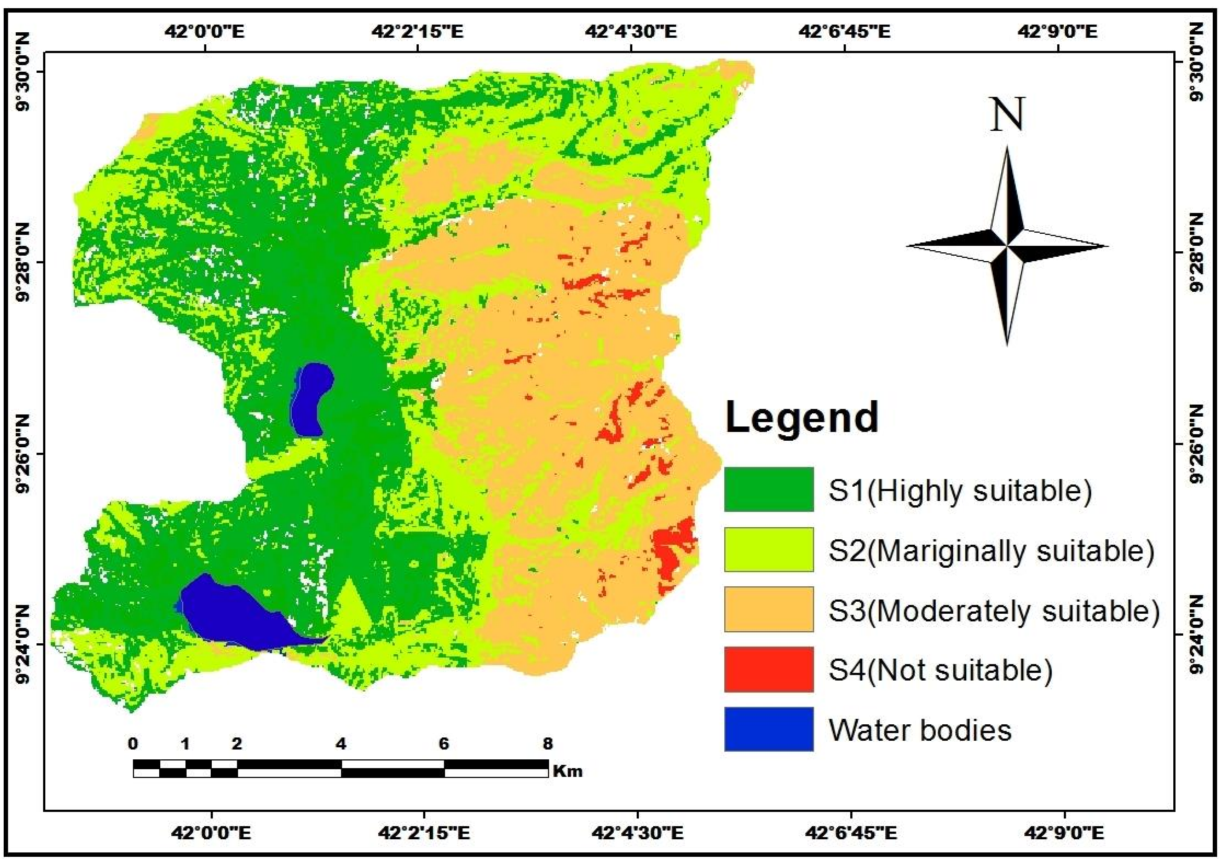

Fig.4. 12. Suitable sites for surface irrigation development using groundwater

4.3. Available groundwater resources potential for irrigation

Assessment of groundwater available resources for irrigation purposes consists of obtaining information on the distribution of water availability along the year to be compared with irrigation water requirement (Collier-F.w.Collier & Wallington, 2010). Following the approach of Pavelic et al. (2013), the net annual groundwater availability for irrigation was calculated by deducting the allocation for domestic water demand and environmental water requirements from the estimated annual replenishable groundwater resource.

Groundwater Available (GWA) = GWR - DGWD - EGWR…………………….………….4.1

Where:
GWA [mm] is groundwater available

GWR [mm] is groundwater recharge

DGWD (L/yr.) - Domestic Groundwater Demand

EGWR (mm)-Environmental Groundwater requirement ((Pavelic et al., 2013).

4.3.1. Estimation of groundwater recharges

The method proposes in this study to evaluate groundwater recharge was spatially distributed in the study watershed and based on a water balance approach using spatially distributed hydrological models WetSpass model with the integration of GIS.

WetSpass model is a quasi-steady-state long-term spatially distributed model for simulating groundwater recharge, soil water storage, evapotranspiration (soil evaporation and transpiration as separate outputs) runoff, and interception using climate input on a monthly, seasonal and annual scale. The output was on the same temporal scale as for the input and was required to give input maps in as ESRI-asci grid files through a graphical user interface (UGUI). The land use and soil parameter were modified within the interface and demonstrate the model features.

Model parameters were derived in grid format from topography, slope, land cover and land use, soil maps, rainfall, temperature, groundwater depth, potential evapotranspiration, and wind data of the Lake Haramaya watershed. The land use and soil grid maps are supported by attribute lookup tables of land use and soil data prepared in pdf format.

To use the model efficiently, all model parameters data were prepared on a monthly and annual basis and the model grid maps and parameter tables were required as inputs for the WetSpass model in integration with arc GIS and it was prepared using Arc GIS software tools.

4.3.1.1. Elevation

Topography is the dominant factor controlling groundwater recharge and the topographic map of the Lake Haramaya watershed area was obtained from the Shuttle Radar Topographic Mission (SRTM) data set of USGS. The Digital Elevation Model (DEM) processed from SRTM provides with 30*30m resolution.

The most elevated point in the watershed is located on the top of the watershed upstream and the elevation of the watershed ranges from 2005 to 2430m.a.s.l while the mean elevation is 1951m.a.s.l. the highest elevation of the watershed is 2430m which is located in the Eastern part of the watershed and the lowest point 2005m is located in the Western part of the area. While the mean elevation of the watershed is 2217.5m and 55% of the total area of the watershed is between 1109 and 1500m elevation which is highly suitable for agriculture. The longest flow path along the watershed outlet was 18.154km in length. Finally, the elevation raster grid map of the watershed was converted to ASCII format for suitability of model processing with 30m*30m resolution.

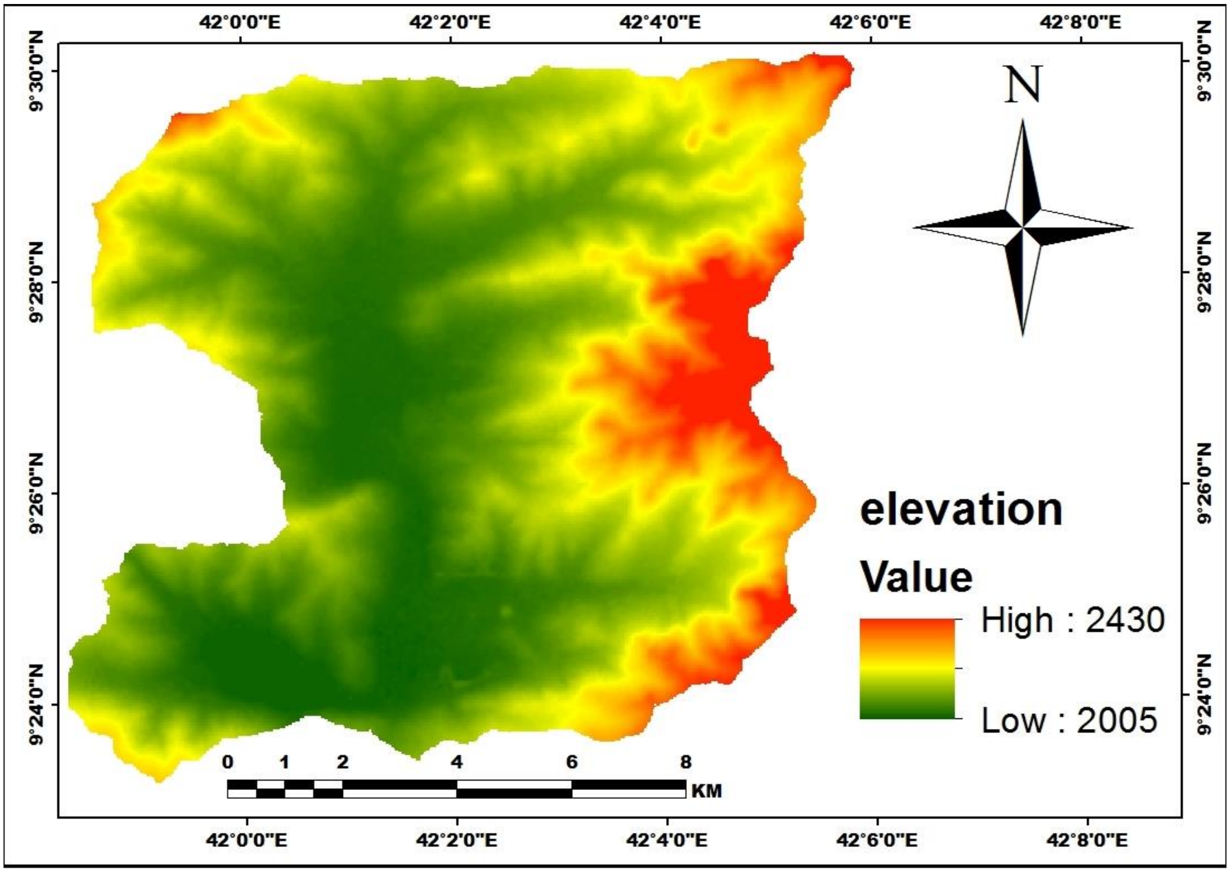

Fig.4. 13. The elevation map of Lake Haramaya watershed

4.3.1.2. Slope

The slope of the watershed is an important model parameter used to identify the hydrological characteristics of the watershed and it has a direct relationship with the topography of the watershed. The steep slope part of the watershed is considered to be recharge areas whereas the gentle slope is considered to be discharge areas.

The slope map of the study area was derived from 30*30m DEM using spatial analyst tool, slope in ArcGIS software toolset. It is classified by the degree of steepness ranging from 0 to13. The value 0 indicates the gentlest slope /lowland and 13.5 was represented the steepest slope/edge of the watershed. The Lake Haramaya watershed included a wide area of gentlest slope which is suitable for agricultural activities and small area coverage with the steepest slope which not suitable for agricultural activities. About70% of the study area is below 8 of slope which is highly suitable for recharge/discharge hydrological process. Finally, a slope raster grid map of the watershed was converted to ASCII format for suitability of model processing with 30m*30m resolution.

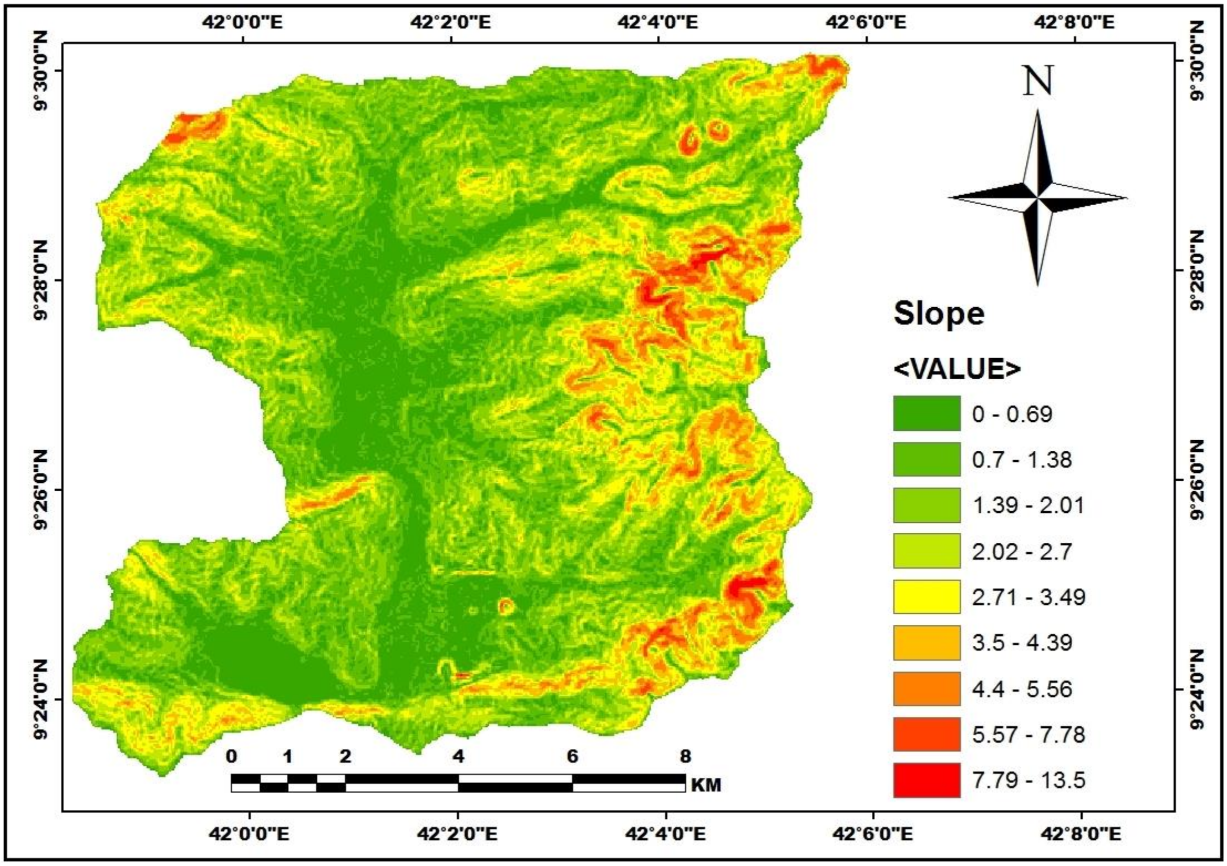

Fig.4. 14. Slope map of Lake Haramaya watershed

4.3.1.3. Soil texture

The soil texture is an important and sensitive parameter for the recharge estimation process using WetSpass. A soil texture map of the Lake Haramaya watershed was obtained from Africa over the map.

Three classes of soil texture were identified from the study area map such as sandy clay loam, clay, and clay loam as described in figure 4.4.3, and clay soil is the dominant soil with an area coverage of 51.66Km^2(42.13%), clay loam is the second dominant soil of the watershed with area coverage of 47.05Km^2(34.30%) and sand clay loam Km^2 is the third dominant soil in the watershed with area coverage of 23.91Km^2(19.45%). The soil grid maps supported by attribute lookup tables of soil data prepared by the WetSpass model for recognition of soil and the soil texture class identified in the watershed were prepared concerning the model code in TBL format. Finally, the soil texture raster grid map of the watershed was converted to ASCII format for suitability of model processing with 30m*30m resolution.

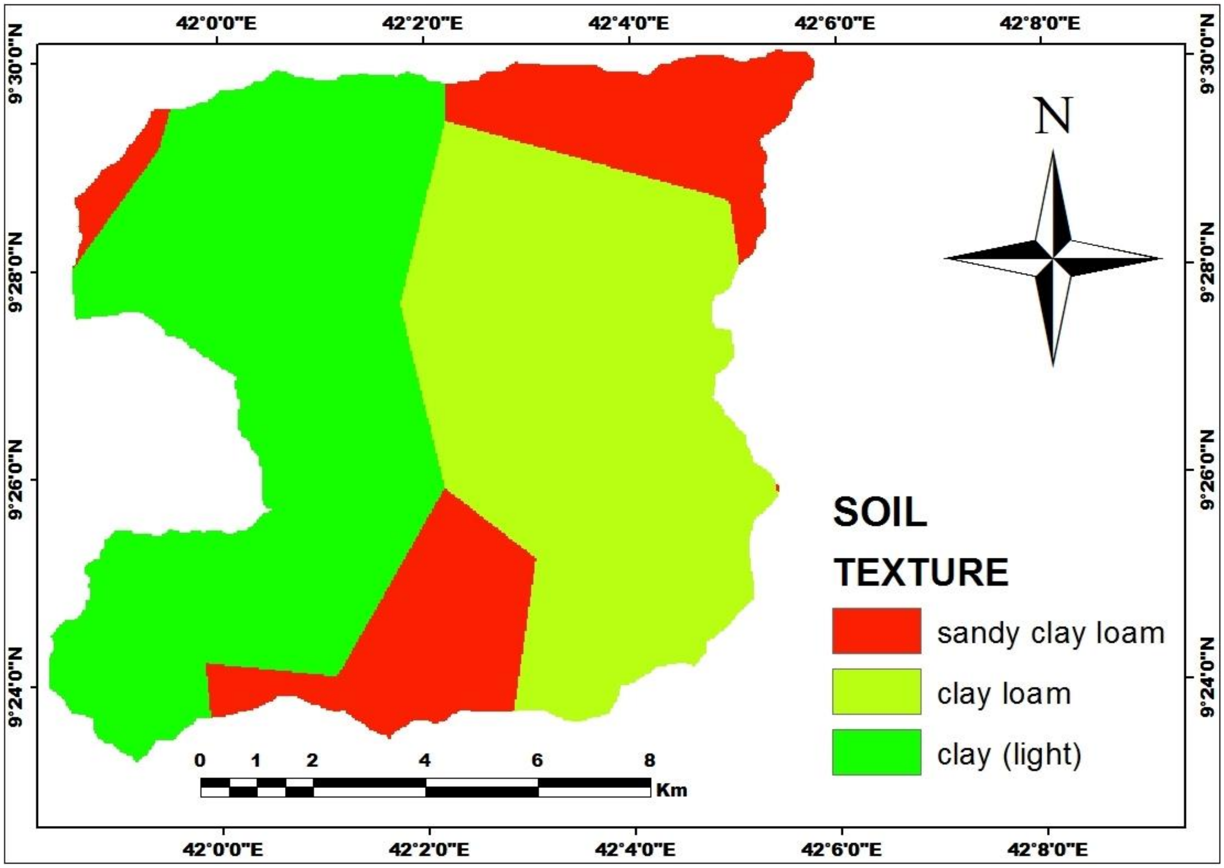

Fig.4.15. Soil texture map of Lake Haramaya watershed

4.3.1.4. Land cover and land use

The effects of land use and land cover (LULC) on groundwater recharge and surface runoff and how these are affected by LULC changes are of interest for groundwater recharges estimation.

Land use is an important characteristic to govern the surface runoff process that affects infiltration (recharge), evapotranspiration, and erosion. Different land-use types have different influencing capacities on recharge, runoff process, and evapotranspiration rates, due to their different leaf area indices, root depth, and size (Batelaan et al., 2007)

Land cover and land use are some of the important WetSpass model parameters and it’s a highly sensitive parameter for recharge estimation.

The land use maps of the Lake Haramaya watershed was derived from landstat8.0 image using ERDAS IMAGINE 2014.Landsat8.0 image was obtained from USGS. The result of the classified image indicated, Lake Haramaya watershed was covered by different land cover and land use which described in terms of areal coverage, the important land covers of the watershed area revealed that 57.39% of the area cover by agricultural land, 1.80% of the area cover by bare land, 3.11% of the area cover by forest, 3.99% of the area cover by grassland, 10.56% of the area cover by Kchat land, 2.58% of the area cover by settlement, 18.64% of the area cover by shrub land, and 1.94% of the area cover by water body.

There is no significant change throughout the year and thus it was not taken into account in the respective parameter tables for WetSpass modeling. Land-use/land-cover fractions are used as weighting factors for the calculation of the water balance at the grid-cell level. The total coverage of the watershed is presented in figure 4.4.5and in the attribute table with all areal coverage.

Finally, the land use raster grid map of the watershed was converted to ASCII format for suitability of model processing with 30m*30m resolution.

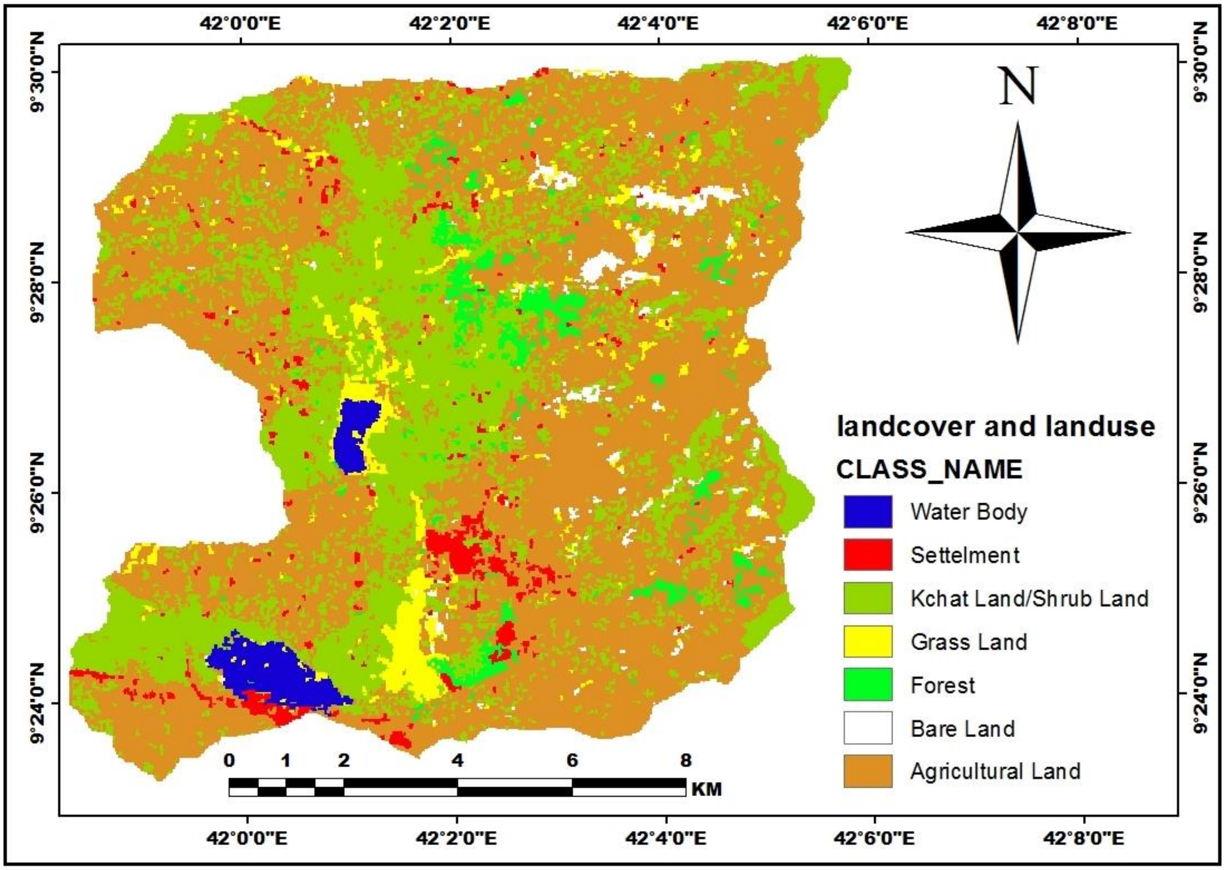

Fig.4. 16. Land use map of Lake Haramaya watershed

4.3.1.5. Precipitation

Precipitation is one of the hydrologic cycle components. Groundwater recharge of a given watershed is highly dependent on precipitation and it is a major source of recharge. The spatial distribution of rainfall characteristics in the watershed is a very important factor in the recharge and runoff generation of the watershed (Subramanya, 2004)

The precipitation characteristics of the Lake Haramaya watershed are spatially varied throughout the year. Temporal variability and rainfall distribution analysis of the Lake Haramaya watershed were done using daily recorded point rainfall data obtained from four synoptic meteorological stations in the study area. The thirty-four (34) years precipitation data were used in the analysis which starting from 1986 to 2019 and the analysis was done based on the monthly and annual basis to work efficiently in WetSpass model processing. The Haramaya station which is located in the watershed was received a minimum rainfall of 11.1mm in January month and maximum rainfall of 138.4mm in August month and the normal annual precipitation of the station is 788.34mm. The Combolcha station which is outside the watershed was received a minimum rainfall of 9.5mm in January month and maximum rainfall of 148.8mm in August month plan normal annual precipitation of 788.34mm. The Harar station which is located neighbor to the watershed was received a minimum rainfall of 9.5mm in January month and maximum rainfall of 113.8mm in august month plan normal annual precipitation of 788.34mm. The Haramaya station which is located in the watershed was received a minimum rainfall of 11.1mm in January month and maximum rainfall of 138.4mm in an August month plan normal annual precipitation of 731.8mm. The Karsa station which is located in the Karsa woreda was received a minimum rainfall of 9.7mm in February month and maximum rainfall of 132.9mm in August month plan normal annual precipitation of 665.0mm. Generally, the normal annual rainfall value of the study area ranges between 665mm and 788.34mm.

The spatial rainfall distribution analyses over the Lake Haramaya watershed were done after interpolating the available point data using Kriging spatial analysis tools in Arc GIS10.4.1 and topographically low elevated areas (gentle slope) have received maximum rainfall and highland an area of the watershed was received relatively low rainfall amounts. Table 4.14 and figure 4.17 show the monthly and annual precipitation of the watershed.

Table 4. 14: Monthly and annual precipitation of lake Haramaya watershed

No	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average_ Annual_ PCP
1	Haramaya	11.1	22.8	52.3	108.1	94.5	50.7	103.7	138.4	113.4	52.3	24.3	16.8	788.3
2	Kombolch	9.7	16.3	52.0	101.8	86.9	51.7	100.2	148.5	113.5	52.8	21.9	15.3	770.8
3	Harar	9.5	12.4	54.6	112.6	94.9	61.1	89.1	113.8	100.8	52.4	20.9	9.8	731.8
4	KARSA	9.4	10.4	51.5	88.8	68.2	40.0	76.2	132.9	91.3	58.0	23.7	14.4	665.0

Finally, the precipitation raster grid map of the watershed was converted to ASCII format for suitability of model processing with 30m*30m resolution.

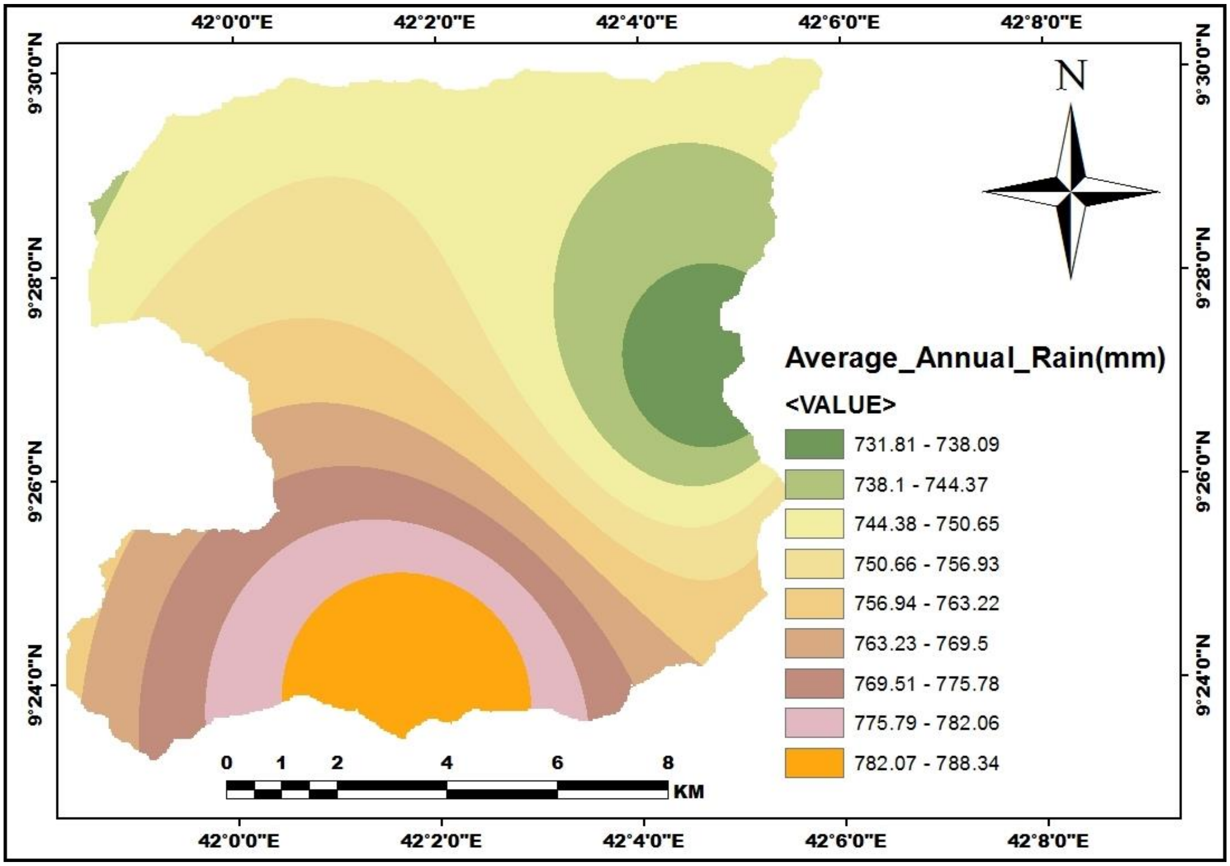

Fig.4. 17. Average annual precipitation of Lake Haramaya watershed

4.3.1.6. Temperature

Temperature is the main controlling factor in the water balance analysis. Temperature is used to understanding and modeling the hydrologic system of a given watershed. It is a governing factor in the occurrence of precipitation and responsible for the amount of evapotranspiration. Higher temperatures are often associated with increased evapotranspiration (ET) because temperature affects both evaporations from open water bodies and transpiration through plants depending on the available increases water while fewer temperature results in the decreased amount of evapotranspiration (Lidija et al., 2014).

The temperature analyses over the Lake Haramaya watershed were done after interpolating the available point data using Kriging spatial analysis tools in Arc GIS.

After the interpolation analysis using Kriging, the average monthly temperature value ranges between 14.99oc^{o} and 19.64c^{o}for Haramaya station with the mean is 12.57c^{o}, the average monthly temperature value ranges between 16.4oco and 19.84co for Combolcha station with the mean is 12.57co, the average monthly temperature value ranges between 18.63co and 20.49co for Harar station with the mean is 12.57c^{o} and the average monthly temperature value ranges between 17.16Co and 20.28co for Karsa station with the mean is 18.72c^{o} and the annual average ranges between 17.7$\dot{c}$ and 19.53 $\dot{c}$ and the mean is 18.62C^{o}.

Finally, the temperature raster grid map of the watershed was converted to ASCII format for suitability of model processing with 30m*30m resolution. Table 4.15: and figure 4.18 shows the monthly and annual temperature of the Lake Haramaya watershed.

Table 4. 15: Average monthly and annual temperature of Lake Haramaya watershed

No	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1	Haramaya	15.46	16.66	18.58	19.20	19.54	19.64	18.90	18.84	18.72	16.98	15.48	14.99	17.75
2	Comblcha	16.71	17.73	19.14	19.42	19.72	19.84	19.09	19.05	19.07	17.89	16.90	16.40	18.41
3	Harar	19.03	19.90	20.49	20.19	20.00	19.84	19.27	19.38	19.49	19.23	18.96	18.63	19.53
4	Karsa	17.57	18.62	19.79	20.04	20.17	20.28	19.64	19.71	19.68	18.53	17.55	17.16	19.06

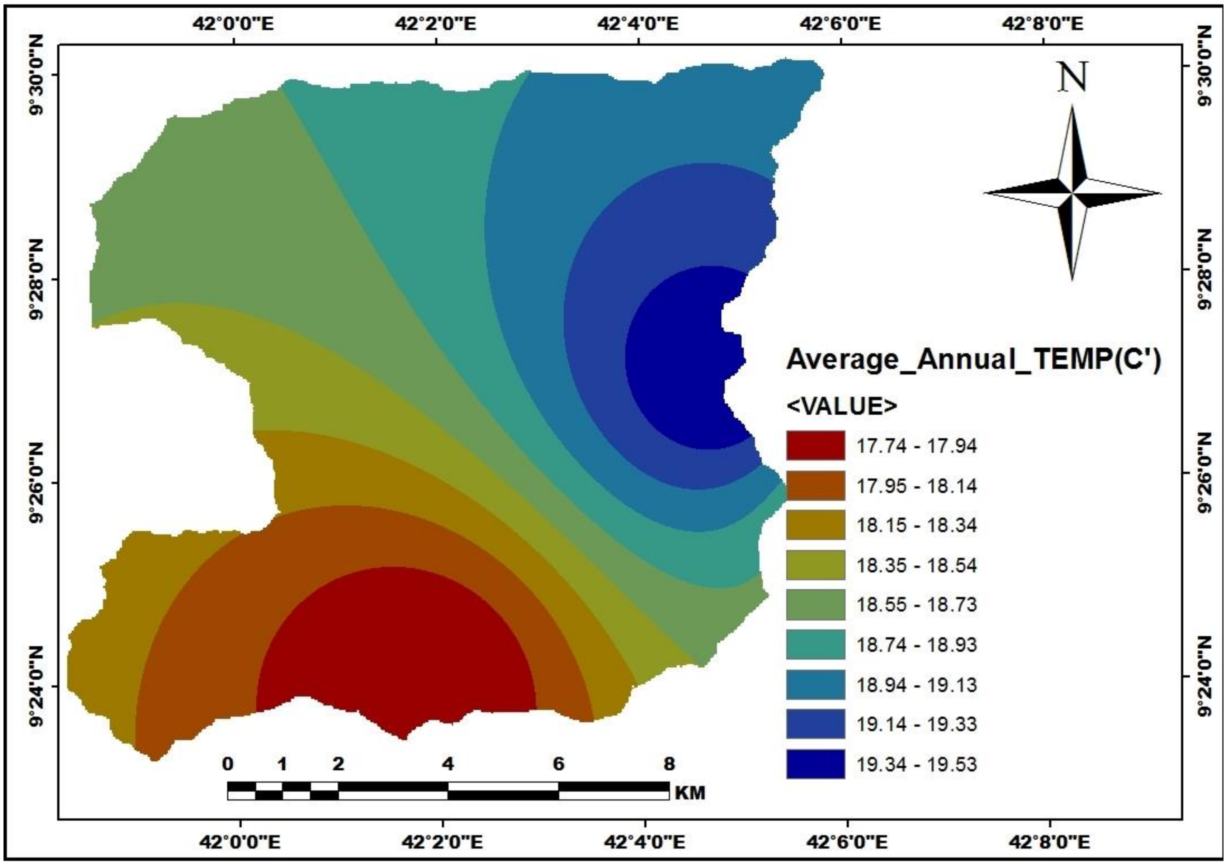

Fig.4. 18. Average annual Temperature map of Lake Haramaya watershed

4.3.1.7. Wind map

Wind speed is the governing factor of evapotranspiration and other water balance components of a given watershed. The existence of statistically significant trends in wind speed from observation of datasets, measured in four synoptic stations over the Lake Haramaya watershed recorded during the period ranges from 1986-2019 was investigated. The monthly minimum and maximum wind speed for each station was 1.04 m/s in October and about 1.65 m/s in June for Haramaya, 1.00 m/s in October and about 1.43 m/s in June for Combolcha, 0.88 m/s, in September and about 1.37 m/s in January for Harar, 1.33 m/s, in October and about 1.91 m/s in June for Karsa respectively and the average annual wind speed of the watershed ranges from 1.07 to 1.34m/s. The analysis of the wind speed distribution over the area was conducted through interpolation using the Kriging spatial interpolation tool in Arc GIS 4.4.1. The summary of average monthly wind speed over the Lake Haramaya watershed for each station was presented in table 4.16 and Figure 4.19.

Finally, the wind raster grid map of the watershed was converted to ASCII format for suitability of model processing with 30m*30m resolution.

Table 4. 16: Average monthly and annual wind speed of Lake Haramaya watershed

No	Station name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
1	Haramaya	1.37	1.39	1.45	1.38	1.33	1.65	1.54	1.42	1.15	1.04	1.10	1.32	1.3
2	Comblcha	1.40	1.31	1.27	1.21	1.17	1.43	1.37	1.28	1.06	1.00	1.10	1.28	1.2
3	Harar	1.37	1.27	1.12	1.01	0.97	1.11	1.02	0.98	0.88	0.92	1.06	1.22	1.1
4	Karsa	1.87	1.75	1.69	1.61	1.56	1.91	1.82	1.71	1.41	1.33	1.46	1.70	1.7

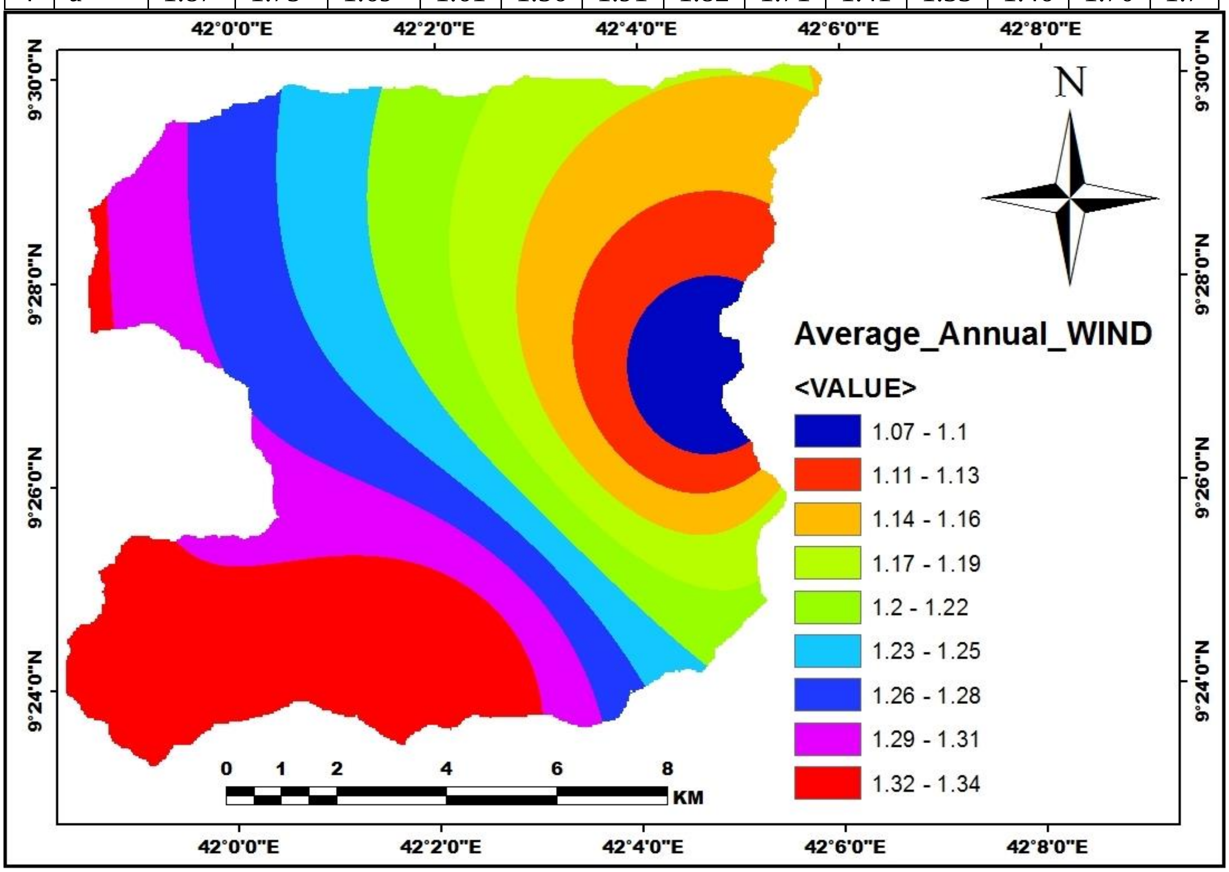

Fig.4. 19. Average annual wind map of Lake Haramaya watershed

4.3.1.8. Groundwater depth

The groundwater depth map is an important model parameter to estimate groundwater recharge using the WetSpass model in integration with Arc GIS. The mean annual evapotranspiration (ET) estimated in combination with precipitation rates were correlated with depth to groundwater values in the Lake Haramaya watershed were used to obtain net groundwater recharge.

The groundwater depth in the Lake Haramaya watershed is spatially varied in the watershed and twelve (12) borehole data were collected for analysis from the Haramaya water supply bureau. The groundwater depth was calculated by deducting static water level from ground surface level and the map was produced. The analyses of obtained groundwater depths were done by interpolation using the Kriging spatial analyst tool in Arc GIS4.4.1 to represent the groundwater depth, entire area of the watershed. The results show that most of the borehole data indicated static water level is shallow and artesian wells have recorded and low elevated areas have shallow groundwater level because a mostly water table in unconfined aquifers follows topography and high elevated areas have high groundwater level. In the Lake Haramaya watershed, the groundwater level varies from 5 to 54m below the surface of the ground which represents the low elevated area of the watershed.

Table 4. 17: Groundwater depth of the Lake Haramaya watershed

No	Station name	Latitude	Longitude	Groundwater depth(m)
1	HRU	9.42	42.04	5
2	Finkille	9.45	42.08	45
3	HRU	9.41	42.04	13
4	HRU	9.42	42.04	54
5	Harar	9.43	42.12	83.53
6	S2	9.4	42.03	54
7	A3	9.41	42.04	36
8	M1	9.41	42.04	44
11	hrm3	9.45	41.92	53
12	hrm4	9.72	42.1	39

Source: Haramaya water supply office, 2019

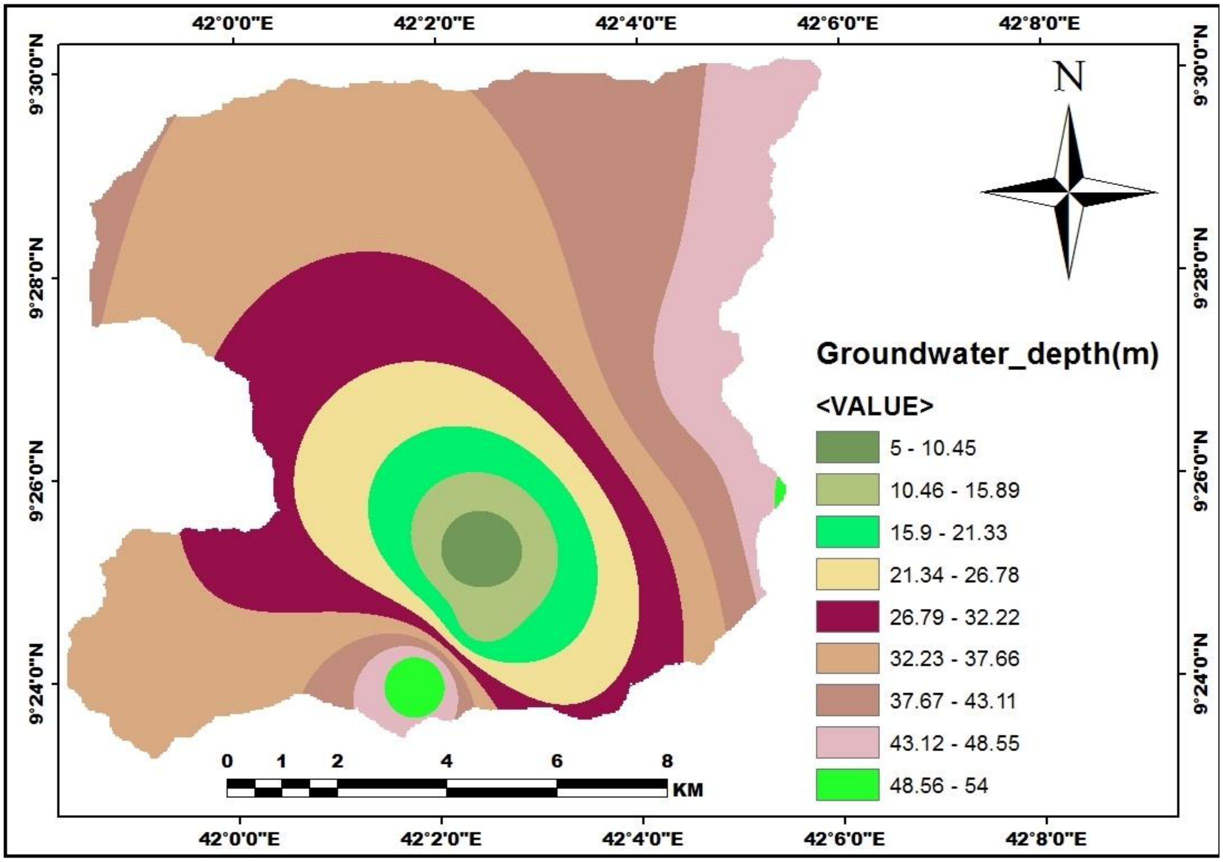

Fig.4. 20.Groundwater depth map of Lake Haramaya watershed

4.3.1.9. Potential evapotranspiration

Potential evapotranspiration is the process that describes the water loss from an open water body by evaporation and plant by transpiration under a given climatic condition with no deficiency of water in the given soil for vegetation while the actual evapotranspiration accounts for the field condition; it depends on the availability of water. Potential evapotranspiration is an important input and component of water balance in hydrologic cycle simulation to determine groundwater recharge of a watershed using the WetSpass model in integration with Arc GIS.

For efficient processing of the WetSpass model, potential evapotranspiration was estimated on a monthly and annual basis using CROPWAT 8.0 for Windows is a computer program for the calculation of potential evapotranspiration based on soil, climate, and crop data.After the potential evapotranspiration (PET) of the watershed was obtained using CROPWAT 8.0 model, to get the spatial distribution of PET over the watershed, the Kriging spatial interpolation technique was used for both hydrological seasons to get the distribution value over an area.

The average annual potential evapotranspiration for stations Haramaya, Combolcha, Harar, and Karsa were 284mm, 262mm, 300mm, and 295mm respectively.

After interpolation, the raster map was converted into ASCII format and the resulting grid map was incorporated with other input parameters of the WetSpass model to calculate recharge.

Table 4. 18: Summery of average monthly and annual potential evapotranspiration

No	Station Name	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average PET
1	Haramaya	176	280	520	580	783	187	180	216	88	75	163	165	284
2	Combolcha	175	285	537	595	446	194	186	226	93	74	163	165	262
3	Harar	180	291	535	586	777	187	172	191	181	173	162	167	300
4	Karsa	197	307	579	632	472	204	190	216	188	191	179	184	295

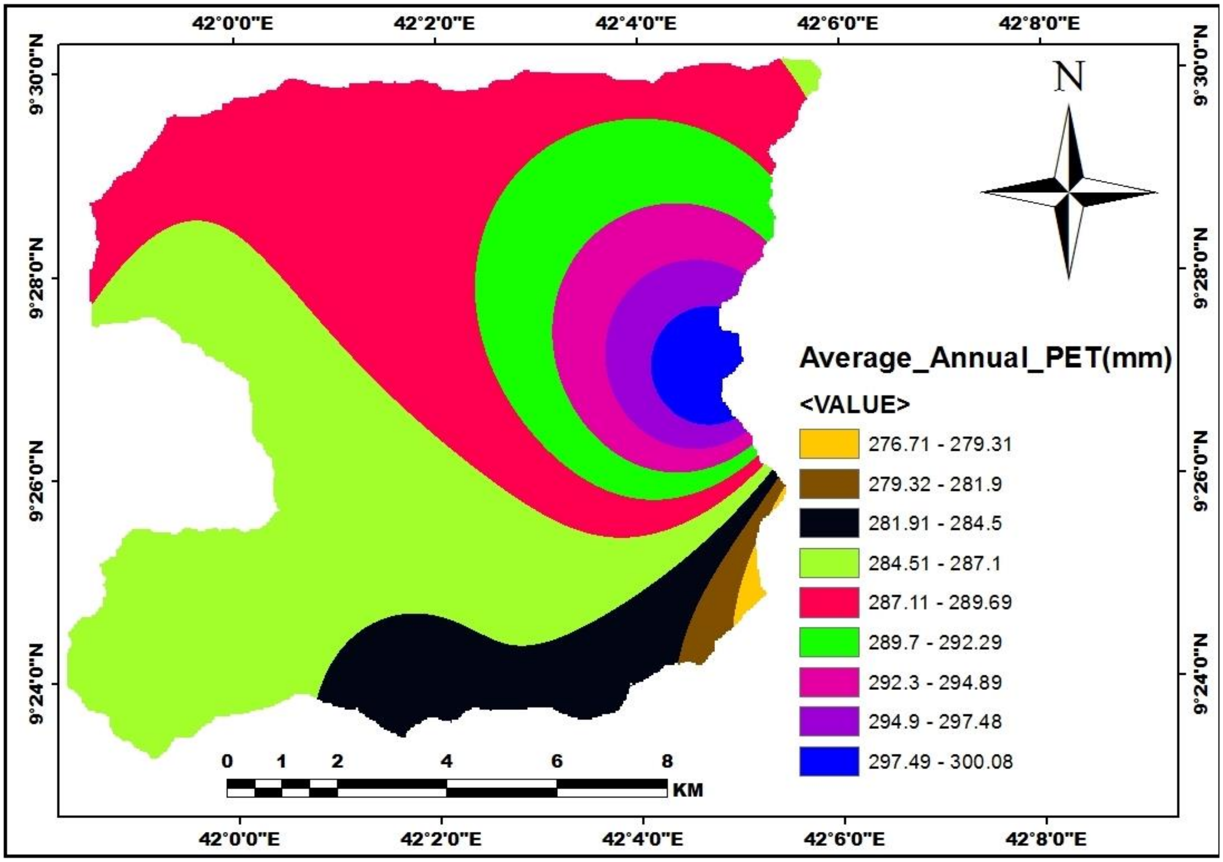

Fig.4. 21. Average annual potential evapotranspiration map of Lake Haramaya watershed

4.3.1.10. Soil lookup table

The soil lookup table was prepared in the appropriate format concerning the model code in TBL format for the effective model running process because the soil grid maps supported by attribute lookup tables of soil data prepared by WetSpass model for recognition of soil and the soil texture class identified in the watershed.

Code	Soil	Fied capac	Wilting pnt	Paw	Residualwc	A1	Evapo depth	Tensionhht	P_frac sum	P_frak_win	Teta
7	sandy clay l	0.26	0.16	0.1	0.068	0	0.05	0.28	0.54	0.3	0.35
9	Clay loam	0.33	0.19	0.14	0.075	0	0.05	0.26	0.62	0.41	0.49
12	Clay	0.46	0.33	0.13	0.09	0	0.05	0.37	0.95	0.85	0.85

Table 4. 19: Summary of soil lookup table of the watershed

Code = Soil type code; Soil = Soil type (texture); Fieldcapac = Field capacity; Wiltingpnt = Wilting Point; PAW = Plant available water content; Residualwc = Residual water content; A1 = Calibration parameter dependent on the sand content of the soil; Evapo depth = Bare soil evaporation depth; Tension hht = Tension saturated height; P_frac_sum = Fraction of summer precipitation contributing to Hortonian runoff; P_frac_win = Fraction of winter precipitation contributing to Hortonian runoff.

4.3.1.11. Landuse and cover lookup table

The monthly land-use lookup table's parameter values are readjusted using the WetSpass database because the soil grid maps supported by attribute lookup tables of land cover and land use data prepared by the WetSpass model for recognition of land cover and land use class identified in the watershed. The developed land use grid maps and the lookup table of identified parameter data in the watershed together make the required interaction among each other as a result the appropriate average values produced during the simulation process using WetSpass in integration with Arc GIS4.4.1.

Table 4. 20: Summary of land cover and land use lookup table of the watershed

No	luse_ type	runoff_ veg	veg_ area	bare_ area	imp_ area	Open w area	root_ depth	lai	min_stom	Veg_height	nmanning	land factor
2	settlement	grass	0.5	0	0.5	0	0.3	2	100	0.12	0.04	0.5
7	bare land	bare soil	0	1	0	0	0.05	0	110	0.001	0.09	0.222
21	agriculture	crop	0.8	0.2	0	0	0.4	4	180	0.6	0.037	0.541
33	Forest	forest	1	0	0	0	2	5	375	16	0.1	0.2
36	shrub land	grass	1	0	0	0	0.6	6	110	2	0.05	0.4
52	water body	open water	0	0	0	1	0.05	0	110	0	0.02	1
307	grass land	grass	1	0	0	0	0.3	2	140	0.12	0.035	0.571

Luse_type = Land Use Type; Runoff_veg = Runoff Vegetation; Num_veg_Ro = Runoff class for vegetation type; Num_imp_Ro = Impervious Runoff class for impervious area types; Veg_area =Vegetated Area; Bare_area = Bare Area; Imp_area: Impervious Area; Openw_area: Open water Area; Root_depth = Root depth; Lai = Leaf Area Index; Min_stom= Minimum Stomatal Opening; Interc_per = Interception Percentage; Veg_height = Vegetation Height

4.3.1.12. Outputs of WetSpass-M model

Since the model is a distributed one, the water balance computation is performed at a raster cell level. Individual raster water balance is obtained by summing up independent water balances for the vegetated, bare soil, open-water, and impervious fraction of a raster cell. The total water balance of a given area is thus calculated as the summation of the water balance of each raster cell. There were three water balance components which are the outputs of the WetSpass model such as total evapotranspiration, surface runoff, and groundwater recharge. The water balance components of vegetated, bare-soil, open-water, and impervious surfaces are used to calculate the total water balance of a raster cell.

Precipitation is taken as the starting point for the computation of the water balance of each of the above-mentioned components of a raster cell, the rest of the processes (interception, runoff, Evapotranspiration, recharge) follow in an orderly manner. This order becomes a prerequisite for the monthly time scale with which the processes will be quantified. The water balance for the different components is treated hereafter.

4.3.1.13. Surface runoff

All input parameters were used by the WetSpass-M model to calculate monthly surface runoff (SV) and surface runoff is a function of elevation, slope, vegetation type, soil texture, and meteorological characteristics of the Lake Haramaya watershed. Due to the above input parameters variations in space and time, surface runoff (SV) quantity in the Lake Haramaya watershed was highly variable in space and time.

The WetSpass model simulated result shows that the minimum and maximum annual runoff values of the Lake Haramaya watershed were 426.2mm and 785.4mm respectively. The mean value of the watershed was 605.8mm which accounts for about 20.5% of the total annual precipitation of the Lake Haramaya watershed. The monthly distribution of the runoff shows that the minimum and maximum runoffs in the watershed were 0.0003mm occur in January and 137.6mm occur in August respectively.

The above results show that there was a variation of both monthly and annual runoff in space and time because the runoff is highly affecting by the runoff coefficient. The runoff coefficient is affecting by the soil moisture condition, soil infiltration condition, land cover/use, the intensity of rainfall, and topography which change in space and time, but the most governing factor is precipitation. During the dry season, the infiltration capacity of soil exceeds the rainfall which results in less surface runoff, but in the wet season, the rainfall exceeds the infiltration capacity of the soil which results in a high amount of surface runoff.

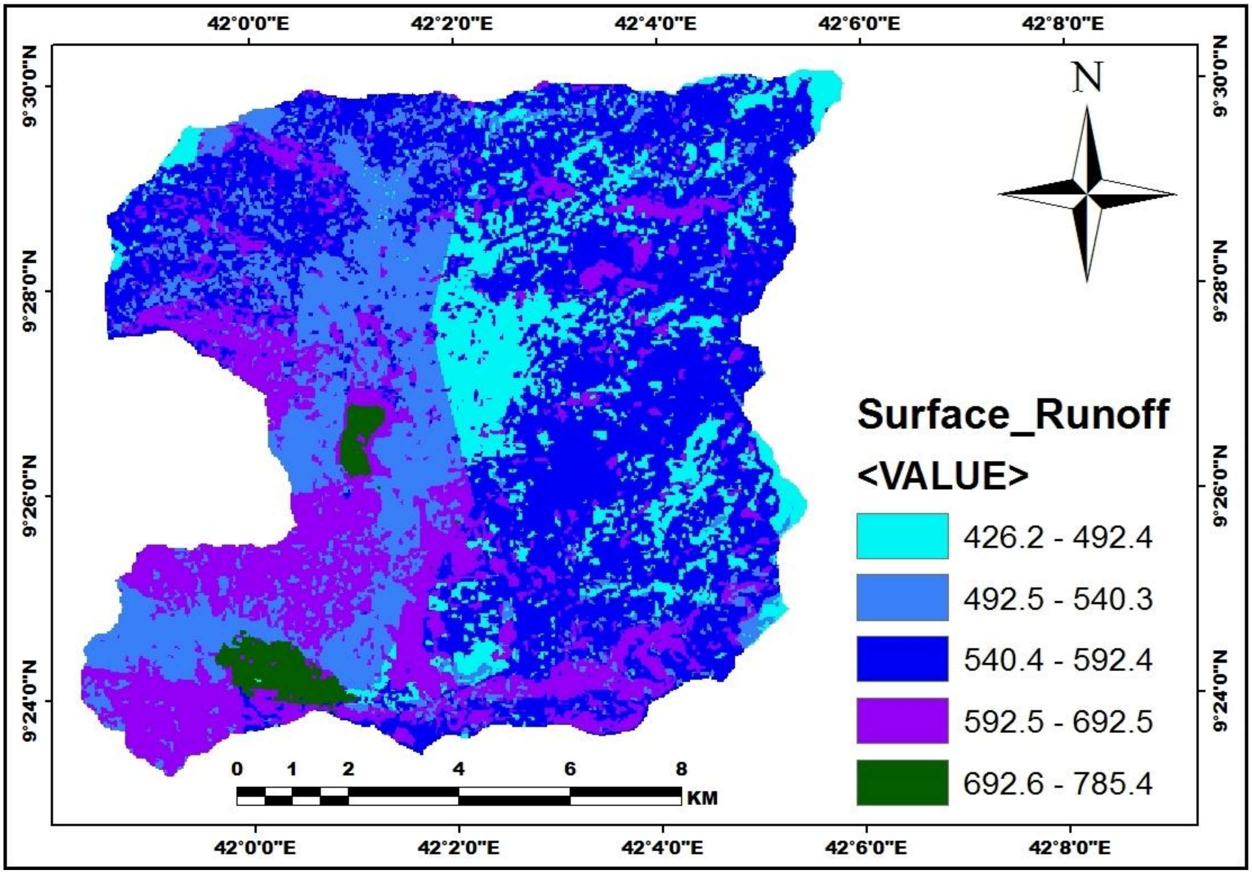

Fig.4. 22. Runoff maps of Lake Haramaya watershed

4.3.1.14. Total evapotranspiration

The WetSpass-M model has calculated the evapotranspiration as a sum of the water balance components of vegetated, bare-soil, open-water, and impervious surfaces are used to calculate the total evapotranspiration of a raster cell (Figure 4.5).

Evapotranspiration was a major component of water balance in the groundwater recharge estimation at the Lake Haramaya watershed. The WetSpass model simulated evapotranspiration monthly. To get the annual values for the water balance components of the watershed the monthly results were added from September to December. In the same manner, the average values for the different water balance components have been obtained from summing up the monthly results.

The simulated result of the watershed showed that minimum and maximum annual evapotranspiration values were 190.2mm and 573.3mm. From total rainfall, about 190.2 to 573.3mm was lost due to evapotranspiration throughout the year. The evapotranspiration rate was affected by radiation, wind, land cover and land use, water availability in the watershed as a result variation was occurred due to the difference in rainfall and others parameters concerning space and time.

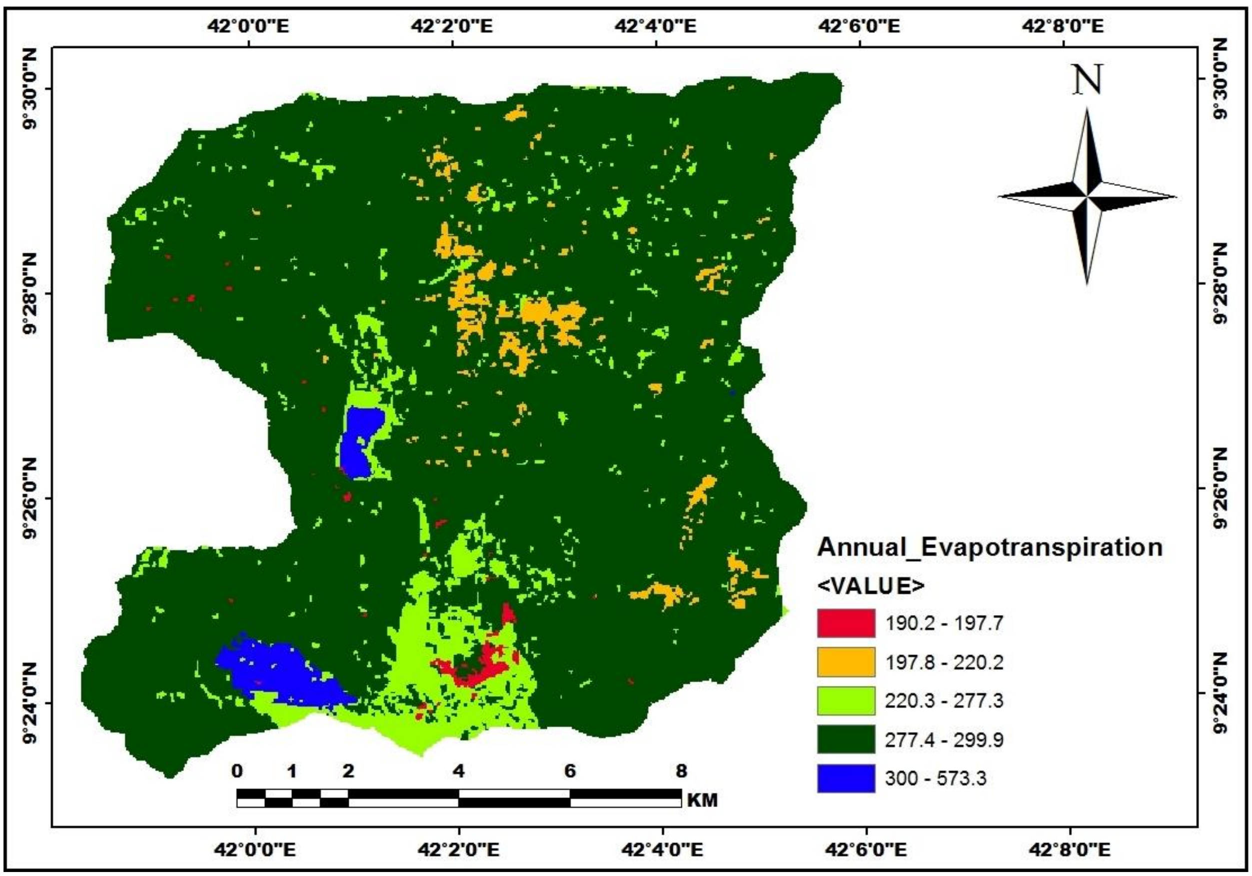

Fig.4. 23. Simulated evapotranspiration map of Lake Haramaya watershed

4.3.1.15. Sustainable groundwater recharges

Groundwater recharge or deep drainage or deep percolation is a hydrologic process, where water moves downward from surface water to groundwater which affecting by the topography, slope, land cover/land use, soil texture, and groundwater level (Lerner et al., 1990) WetSpass model was estimated monthly and annual long-term spatiotemporal distribution of groundwater recharge of Lake Haramaya watershed by deducting surface runoff and evapotranspiration from precipitation. The WetSpass model estimates the groundwater recharge on monthly basis as per input parameters then the annual groundwater recharge was obtained by summing up the monthly recharge per cell for each component.

P-ET-Sy-R=0…………………..4.2

Where P is precipitation (mm), ET evapotranspiration (mm), Sy surface runoff (mm), and R recharge (mm).

The simulated result of the WetSpass model shows that the minimum and maximum annual recharge value of the Lake Haramaya watershed was 0 and 429.8 mm respectively. The mean recharge of the study area was 128.2mm and the estimated mean annual groundwater recharge is proportional to 14,977,200m3. This covers about 15.22% of the total annual rainfall. The groundwater recharge of the watershed was varying in space and time because of the model input parameters fluctuation, mainly precipitation and soil moisture condition. The duration, intensity, and quantity of precipitation distribution and soil moisture content in the watershed were high in the wet season as a result; the rate of groundwater recharge was low.

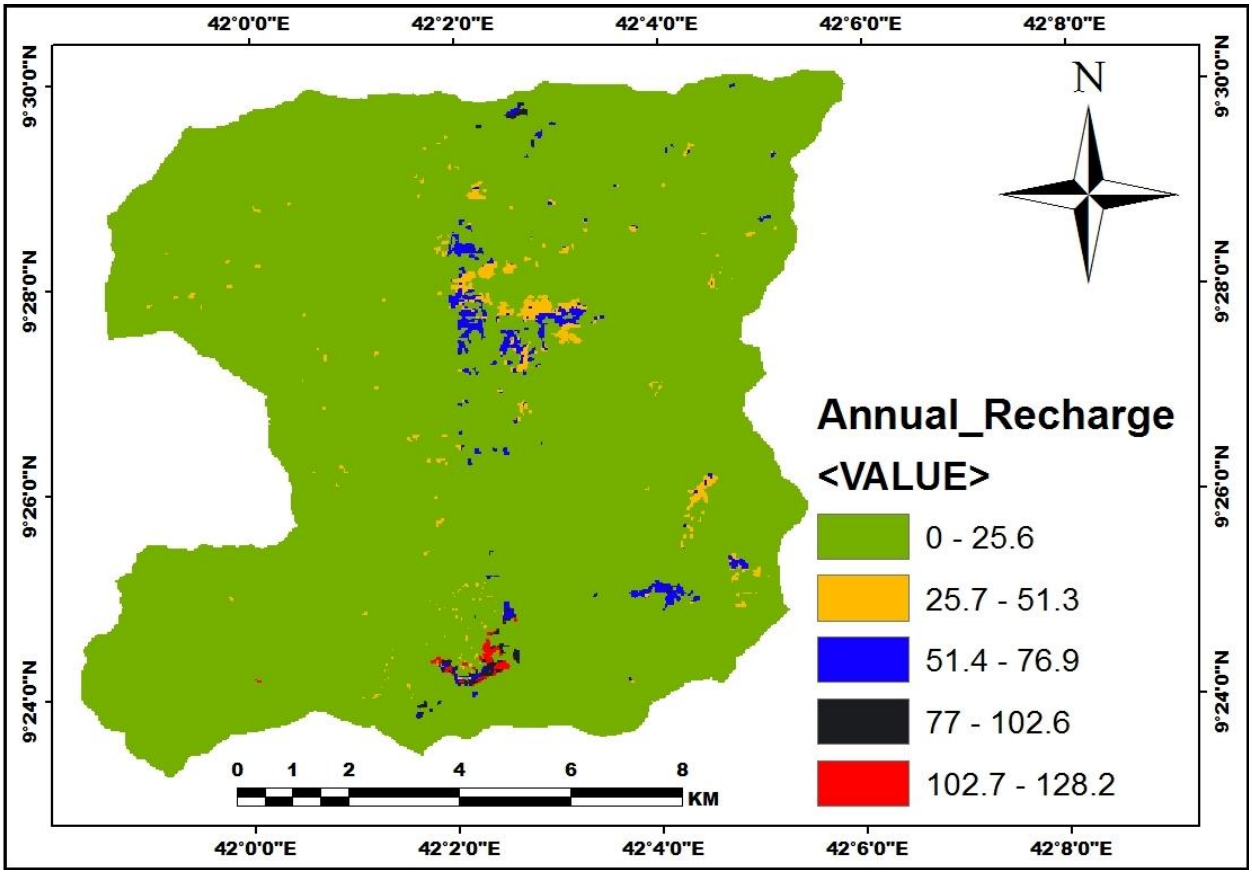

Fig.4. 24. Annual groundwater recharge of the Lake Haramaya watershed

Table 4. 21: Outputs of average monthly groundwater recharge

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Recharge(mm)	8.37	16.96	40.99	74.11	70.85	31.68	40.1	51.87	38.32	28.37	16.33	12.00

The outputs of average monthly groundwater recharge from the WetSpass model were summarized in Table 4.22 for January, February, March, April, May, June, July, August, September, October, November, and December.

4.3.2. Domestic groundwater demand

Water demand is the demand of water by the users for various purposes and estimating the water demand of a given town was important to identify or know the total quantity of the water consumed by the population to be served at a given area.

4.3.2.1. Population projection

The population of the given town affecting the water demands of the area, because the water demand of a particular town is proportionally related to the population to be served. The Lake Haramaya watershed was serving as the source of water supply for Haramaya, Bate, and Harar towns. As a result, population projection includes a population of Haramaya, Bate, and Harar towns as a base population. The population of Haramaya, Bate, and Harar towns from the Ethiopian CSA report, which was conducted in 2007, were 30,728, 6,762, and 99,368 respectively.

The Central Statistical Authority has established annual growth rates for population projection from 1995 up to the year 2030. Hence, in projecting the future population sizes of the kebele, the country level CSA's growth rates of Oromia regional state were taken and have been used. The projected populations using the base populations of the 3 towns and the growth rates presented below are shown in the table underneath.

According to CSA, the regional level annual growth rate for the urban population (2017-2022) were 3.59%, 3.59%, and 3.02% for Haramaya, Bate, and Harar towns respectively.

Based on the base population of the town in each five-year growth rate interval was projected using a geometric growth rate method.

Table 4. 22: summary of the projected population for Haramaya, Bate, and Harar towns

No	Years	Growth rate (%)			Projected population		
		Haramaya town	Bate town	Harar town	Haramaya town	Bate town	Harar town
1	2007	4.13	4.13	2.02	30,728	6,762	99,368
2	2008-2012	3.95	3.95	2.52	37,296	8,207	112,536
3	2013-2017	3.77	3.77	2.77	44,876	9,875	129,009
4	2018-2022	3.59	3.59	3.02	53,530	11,780	149,702

Source: CSA, 2007 national statistical census document, Oromia region, Ethiopia

From the above table, it is concluded that the total projected population of the given towns in 2019 is 215,012 which helps to estimate the total water demands from the Lake Haramaya watershed.

4.3.2.2. Average water demand

To estimate total human groundwater demand (domestic, livestock, industrial), average water consumption (unit requirement) of the per capita water demand per day was used that is 20l/c/d for a given year based on the WHO criteria manual, for urban areas, then multiplying the total population of each block with the per capita water demand and several days in a year.

Q= 215,012 * 20l/c/d = 4,300,240 l/d=4300.24m^3/d

=1,569,587.6m^3/year

4.3.3. Environmental water requirement

Environ. GW Req. (mm) is the quantity of water coming from groundwater, which is directly linked to the environment for maintaining ecosystems. This includes river base flow and groundwater influx to wetlands. Environmental water requirement was considered as scenario 1(30%), scenario2 (50%), and scenario 3(70%) of total groundwater available (Pavelic et al., 2013).

Table 4. 23: summery of environmental water requirements for all three scenarios

No	Parameters	Scenario1 (70%)	Scenario2 (50%)	Scenario3 (70%)
1	Groundwater recharge	14,977,200m3/y	14,977,200m3/y	14,977,200m3/y
2	Environmental requirements	4,493160m3/y	7,488,600m3/y	10,484,040m3/y

4.4. Irrigation water requirements

Standardized procedures with FAO software and an extensive climatic and crop database will allow routine calculations and ready information on crop water climate conditions in the SPFP pilot areas (W.P. Field - F.W. Collier H.R. Wallington Ldt. , 2006).

CROPWAT8.0 model inputs include climatic parameters such as rainfall and ETO, soil texture, and crop type. Based on the above inputs the water requirements of each crop were calculated using the model and the output from CROPWAT includes monthly water requirements, effective rainfall, net irrigation requirements, and gross irrigation requirements. The results of the CROPWAT model were presented in the following sections.

Table 4. 24: Soil and crop data for the selected major crops

No	Crop type	Planting date	Base Period(days)	KC				Root Depth(cm)	Soil water depletion (%)
				Initial	Dep't	Mid-stage	Late stage		
1	Chat	01/10	365	1		1	1	140	50
2	Onion	01/10	145	0.60		1.10	0.85	50	50
3	Tomato	01/10	130	0.50		1.15	0.75	60	50
4	Potato	01/10	145	0.60		1.15	0.8	100	50
5	Carrot	01/10	95	0.70		1.05	0.95	60	50

Table 4. 25: Total crop water and irrigation requirements

Major crops	$Et_{c.}$ (mm)	Eff. rain(mm)	Irr. Req. (mm)	Gross. Irr. Req(mm)
1. KCHAT(kata edulis)	1376	630.9	747.1	1067.3
2. Onion	507.5	28.1	480	685.7
3. Tomato	503.3	28.1	475.8	679.7
4. Potato	436.8	26.8	410	585.7
5. Carrot	464.9	27.1	437.7	625.3

Table 4. 26: Monthly net irrigation requirements for a major crop in mm/month

Major crops	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1. KCHAT	112	104.	103	57	69.3	92	53	27	43	97	106	109.3
2. Onion	121	79.3								53	103	122.1
3. Tomato	132	80.6								49	87.3	126.1
4. Potato	119	21.6								39	101	127.8
5. Carrot	127.	47.6								61.	85.1	115.5

Table 4. 27: Total volume of irrigation water requirements

No	Major crops	Base period(days)	The total depth of irrigation(mm)	Plot size(ha)	The total volume of irrigation water(m3)
1	Chat	365	1067.3	2812.4	30016745
2	Onion	145	685.7	1406.2	9642313
3	Tomato	130	679.7	1054.65	7168456
4	Potato	145	585.7	1054.65	6177085
5	Carrot	95	625.3	703.1	4396484

Using the CROPWAT8.0 model and field survey as well as data collected from the east Haraghe agricultural development bureau; the irrigation water requirement for selected five major crops of Lake Haramaya watershed was calculated. The base period/growth period/and other information for each crop was taken from FAO 56 paper which used as input for the analysis of crop water requirements and the results obtained from the CROPWAT8.0 model were summarized in the above tables. Table 4.24 showed Soil and crop data for the selected major crops in the Lake Haramaya watershed. Table 4.25 describes or shows the model results/outputs/for major crop water requirements, effective rainfall, and irrigation water requirement. Table 4.26 described the monthly irrigation water requirement of each major crop of the watershed and table 4.27 described the total volume of irrigation water requirements for each major crop at the Lake Haramaya watershed. The chat land covers about 2812.4ha of the watershed area and the onion, tomato, potato, and carrot land covers about 4218.6ha of the watershed area.

The depth of irrigation for each major crop chat, onion, tomato, potato, and carrot was summarized as1067.3, 685.7, 679.7, 585.7, and 625.3 (mm) respectively. Based on the analysis, the total volume of irrigation water demand of each major crop such as chat, onion, potato, tomato, and carrot was summarized as 57,401,084 cubic meters respectively. The above analysis indicated that chat is the most consumer of the water and its growing period is throughout the year and potato is the least water consumer in the watershed.

4.5. Irrigation potential by groundwater availability

The irrigation potential of the Lake Haramaya watershed was obtained by comparing available groundwater resources and irrigation requirements of the identified suitable lands for surface irrigation using groundwater. The sustainable groundwater availability for irrigation is the surplus recharge after satisfying human and environmental groundwater needs. This may vary based on the three scenarios (70%, 50%, and 30%). The result of the analysis shows that the total annual groundwater availability for irrigation ranged from 174,165,268.8m3/s (scenario 1) to 302,832,149 m3/s (scenario 3). This indicates that groundwater availability is greater than the crop water demand in all scenario cases except for scenario one over the watershed that is excess recharge as compared to crop irrigation demand which enables irrigation from renewable groundwater recharge. The following table describes the conversion of the monthly groundwater availability into groundwater irrigation potential in terms of monthly crop irrigation demand.

Table 4.28 shows the total monthly groundwater recharge allocations among different users such as domestic water demand, environmental water requirements for scenario 1(70%), scenario 2(50%) and scenario 3(30%), groundwater availability for irrigation for three scenarios1,2,3 and the total monthly crop irrigation requirements (m3/s).

Tables 4.29, 2.30, and 4.31 present the monthly available groundwater and the monthly crop irrigation requirements in m3/s for major crops at scenario 1 (70%), scenario 2 (50%), and scenario 3 (30%) respectively.

The above analysis shows that monthly irrigation requirements of all major crops are greater than the available groundwater for scenario 1, but at scenario 2(50%) and three, the crop irrigation demand exceeds the groundwater availability. The groundwater availability exceeds the crop irrigation requirements in all other months at all scenarios except for January, February, March, November, and February.

Table 4. 28: Water allocation summary for domestic, environmental, and irrigation

No	Water users sectors	Scenarios	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	Estimated monthly groundwater recharge(mm/mnth)		8.37	16.96	40.99	74.1	70.85	31.68	40.1	51.87	38.32	28.4	16.4	12	430.05
2	Estimated monthly groundwater recharge(m3/s)		0.39	0.87	1.91	3.57	3.3	1.53	1.87	2.42	1.85	1.32	0.79	0.56	20.38
4	Domestic groundwater demand(m3/s)		0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.5973
5	Environmental groundwater requirement(m3/s)	Scenario 1(70%)	0.27	0.61	1.34	2.5	2.31	1.07	1.31	1.69	1.29	0.93	0.55	0.39	14.26
		Scenario 2 (50%)	0.2	0.44	0.96	1.78	1.65	0.76	0.93	1.21	0.92	0.66	0.39	0.28	10.18
		Scenario 3(30%)	0.12	0.26	0.57	1.07	0.99	0.46	0.56	0.73	0.55	0.4	0.24	0.17	6.12
6	Groundwater availability for irrigation (m3/s)	Scenario 1(70%)	0.07	0.21	0.52	1.02	0.94	0.41	0.51	0.68	0.51	0.34	0.19	0.12	5.5227
		Scenario 2 (50%)	0.14	0.38	0.9	1.74	1.6	0.72	0.89	1.16	0.88	0.61	0.35	0.23	9.6027
		Scenario 3(30%)	0.2	0.44	0.96	1.78	1.65	0.76	0.93	1.21	0.92	0.66	0.39	0.28	10.18
7	Total irrigation demand for major		1.62	1.17	0.56	0.32	0.38	0.52	0.29	0.15	0.24	0.93	1.4	1.6	9.18

	crops(m3/s)														

Table 4. 29: Comparisons of groundwater availability and Crop irrigation demand at scenario 1(70%)

No	Water users sectors		Area(ha)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	Groundwater availability for irrigation (m3/s)	Scenario1 (70%)		0.07	0.21	0.52	1.02	0.94	0.41	0.51	0.68	0.51	0.34	0.19	0.12	
2	Crop irrigation requirements (m3/s)	Kchat(cata edulis)(m3/s)	1455.2	0.61	0.63	0.56	0.32	0.38	0.52	0.29	0.15	0.24	0.53	0.6	0.59	5.42
		Onion(m3/s)	727.6	0.33	0.24								0.14	0.29	0.33	1.33
		Tomato(m3/s)	545.7	0.27	0.18								0.1	0.18	0.26	0.99
		Potato(m3/s)	545.7	0.24	0.05								0.08	0.21	0.26	0.84
		Carrot(m3/s)	363.8	0.17	0.07								0.08	0.12	0.16	0.6
3	Total crop water demand(m3/s)			1.62	1.17	0.56	0.32	0.38	0.52	0.29	0.15	0.24	0.93	1.4	1.6	9.18

Table 4. 30: Comparisons of groundwater availability and Crop irrigation demand at scenario 2(50%)

No	Water users sectors		Area(ha)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	Groundwater availability for irrigation (m3/s)	Scenario2 (50%)		0.14	0.38	0.9	1.74	1.6	0.72	0.89	1.16	0.88	0.61	0.35	0.23	
2	Crop irrigation requirements (m3/s)	Kchat(cata edulis)(m3/s)	1455.2	0.61	0.63	0.56	0.32	0.38	0.52	0.29	0.15	0.24	0.53	0.6	0.59	5.42
		Onion(m3/s)	727.6	0.33	0.24								0.14	0.29	0.33	1.33
		Tomato(m3/s)	545.7	0.27	0.18								0.1	0.18	0.26	0.99
		Potato(m3/s)	545.7	0.24	0.05								0.08	0.21	0.26	0.84
		Carrot(m3/s)	363.8	0.17	0.07								0.08	0.12	0.16	0.6
3	Total crop water demand(m3/s)			1.62	1.17	0.56	0.32	0.38	0.52	0.29	0.15	0.24	0.93	1.4	1.6	9.18

Table 4. 31: Comparisons of groundwater availability and Crop irrigation demand at scenario 3(30%)

No	Water users sectors		Area(ha)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1	Groundwater availability for irrigation (m3/s)	Scenario3 (30%)		0.2	0.44	0.96	1.78	1.65	0.76	0.93	1.21	0.92	0.66	0.39	0.28	10.2
2	Crop irrigation requirements (m3/s)	Kchat(cata edulis)(m3/s)	1455.2	0.61	0.63	0.56	0.32	0.38	0.52	0.29	0.15	0.24	0.53	0.6	0.59	5.42
		Onion(m3/s)	727.6	0.33	0.24								0.14	0.29	0.33	1.33
		Tomato(m3/s)	545.7	0.27	0.18								0.1	0.18	0.26	0.99
		Potato(m3/s)	545.7	0.24	0.05								0.08	0.21	0.26	0.84
		Carrot(m3/s)	363.8	0.17	0.07								0.08	0.12	0.16	0.6
3	Total crop water demand(m3/s)			1.62	1.17	0.56	0.32	0.38	0.52	0.29	0.15	0.24	0.93	1.4	1.6	9.18

5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The present study assessed the groundwater irrigation potential of the Lake Haramaya watershed based on 34 years metrological available data of four stations, spatial data of the watershed and crop as well as cropland data. The watershed area obtained through watershed delineation using the Arc SWAT model was 12481.3 ha.

In this study the first task was to provide a spatially explicit groundwater irrigation area suitability map for Lake Haramaya watershed. Suitability analysis of the watershed was carried out using Arc GIS based on multi-criteria evaluation technique by considering seven suitability analysis factors and the result of land suitability analysis indicates that 3638ha (29.15%) categorized under highly suitable land, 3393ha (27.19%) categorized under marginally suitable land, 3514ha (28.16) categorized under marginally suitable land, 173ha (1.38) categorized under not suitable for irrigation, and 243ha categorized under water bodies. The evaluation result indicates that, there is modest amount of land suitable for irrigation using groundwater.

The water assessment was carried out using the WetSpass-M model based on the spatial, metrological, and potential evapotranspiration data as input of the model. The WetSpass-M model was simulated the monthly and annual water balance components of the Lake Haramaya watershed successfully. The Simulated model result indicated that the total annual groundwater recharge was 429.6mm. The average annual groundwater recharge in the watershed is 128.2mm. Estimated average monthly groundwater recharge of January, February, March, April, May, June, July, August, September, October, November, and Decemberwere8.37mm,16.96mm,40.99mm,74.11mm,70.85mm,31.68mm,40.10mm,51.87mm, 38.32mm,28.37mm,16.32mm, 12.00mm respectively.

The crop irrigation requirement analysis was carried out using CROPWAT 8.0 model based on the climatic, crop, and cropland data as input parameters. The result of the analysis shows that, the total crop irrigation requirements of all major crops were ranges from 585.7 to 1067.3

mm. The groundwater used for domestic consumption was 1,569,587.6m3/year. In addition to irrigation and domestic water demand, the water requirements of the environment were range from 193,000,320 to 449,703,360 m3/year.

The assessment of groundwater irrigation potential ranged from 174165268.8m3/year to 321036480m3/year based on the proportion of recharge estimated assumed allocation preferentially to the environment requirements from 30 to 70% while assuming constant human needs for groundwater. This indicates that the groundwater irrigation potential is excess over the watershed for scenario 2 and 3. By comparing monthly groundwater available in m3/s at all scenarios with monthly crop gross irrigation demand in m3/s, the obtained total irrigation potential of the study area was 3,638ha. To conclude, this indicates that there is significant potential to increase irrigation sources from the groundwater because the result of the WetSpass model implies that the Lake Haramaya watershed has sufficient groundwater resources to satisfy the water demands of different sectors at scenario 2 and 3.

5.2. Recommendations

- ❖ This study result will be used for future water resources planning purposes, irrigation project expansion and it is highly suitable for different agricultural activities.
- ❖ The Lake Haramaya watershed management is poor which declines groundwater recharge from time to time that may cause groundwater depletion so the land use and land cover management of the area should be improved.
- ❖ The groundwater irrigation potential of the watershed was assessed by considering groundwater availability, crop irrigation demand, soil, slope, land use, and land cover factors, but the effect of other factors such as groundwater quality for irrigation should be assessed to get the sound and reliable result.
- ❖ Artificial recharge sometimes called planned recharge is a way to store water underground in times of water surplus to meet demand in times of shortage. Water recovered from recharge projects can be allocated to non – potable uses such as landscape irrigation or, less commonly, to potable use. The artificial recharge of the watershed is recommended to increase underground water recharge of the Lake Haramaya watershed.

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7. APPENDICES

7.1. Metrological data of the Lake Haramaya watershed

Table 7.1. 1: Mean monthly rainfall data at different meteorological stations.

ID	1	2	3	4
Station Name	HARAMAYA	COMBLCHA	HARAR	KARSA
Y(latitude)	9.400174	9.433333	9.450006	9.450001
X(longitude)	42.03334	42.117	42.08333	41.86667
Z(altitude)	2020	2122	1977	1990
Jan	11.09244	9.71125	9.541432	10.37809
Feb	22.80439	16.34151	12.40323	9.670223
Mar	52.34334	51.98633	54.55025	51.51479
Apr	108.0468	101.8189	112.5527	88.78616
May	94.46205	86.85631	94.87082	68.21443
Jun	50.67386	51.70046	61.06571	39.95941
Jul	103.6965	100.2414	89.09457	76.16432
Aug	138.3683	148.4942	113.7745	132.916
Sep	113.4355	113.535	100.7602	91.32443
Oct	52.29706	52.82703	52.43858	58.01733
Nov	24.34808	21.94171	20.93207	23.67572
Dec	16.77964	15.34658	9.831993	14.37091
Normal	788.35	770.8	731.82	664.99

Table 7.1. 2: Mean Monthly Max-Temperatures of Stations

Code	1	2	3	4
station name	HARAMAYA	COMBLCHA	HARAR	KARSA
Y(Latitude)	9.400174	9.433333	9.450006	9.4500013
X(Longitude)	42.0333408	42.116997	42.08333	41.866667
Z(Elevation)	2020	2122	1977	1990
Jan	25223.00	25223.00191	27044.26	26962.56
Feb	24068.37	24068.37059	25899.30	25781.29
Mar	27749.28	27749.27777	28987.63	29083.23
Apr	26127.41	26127.41409	26858.29	27242.23
May	27225.29	27225.28563	27297.58	28105.01
Jun	26006.96	26006.96314	26161.66	26848.20
Jul	25629.95	25629.94807	26080.77	26588.41
Aug	25296.44	25296.43513	26268.75	26598.42
Sep	25072.79	25072.79317	26030.28	26270.55
Oct	26213.59	26213.59337	27371.36	27554.10
Nov	24876.75	24876.74779	26029.88	26204.38
Dec	24804.04	24804.04214	26178.15	26406.69
Annual	308293.87	308293.87	320207.90	323645.08

Table 7.1. 3: Mean monthly min-temperatures of meteorological stations**.**

Code	1	2	3	4
station name	HARAMAYA	COMBLCHA	HARAR	KARSA
Latitude	9.400174	9.433333	9.450006	9.450001
Longitude	42.0333408	42.116997	42.08333	41.86667
Elevation	2020	2122	1977	1990
Jan	6.99	9.492825803	12.39	9.57
Feb	8.24	10.37982393	12.83	10.39
Mar	10.83	11.95493483	13.48	11.98
Apr	12.78	13.23261711	14.06	13.37
May	13.26	13.60366642	14.10	13.67
Jun	13.78	14.18048789	14.04	14.24
Jul	13.48	13.86010765	13.80	14.05
Aug	13.68	14.09161603	13.83	14.19
Sep	12.86	13.56492131	13.45	13.60
Oct	9.10	10.90964726	12.49	10.91
Nov	6.56	9.403969218	12.39	9.40
Dec	6.45	9.260636165	12.42	9.26
summer	53.80	55.70	55.12	56.08
winter	74.22	88.24	104.15	88.55
Annual	128.02	143.94	159.27	144.63

Table 7.1. 4: Mean monthly sunshine at different meteorological stations.

Id	1	2	3	4
station name	HARAMAYA	COMBLCHA	HARAR	KARSA
Latitude	9.400174	9.433333	9.450006	9.450001
Longitude	42.03334	42.117	42.08333	41.86667
Elevation	2020	2122	1977	1990
Jan	8.664637	8.531049	8.338686	8.531049
Feb	8.52607	8.530806	8.430284	8.530667
Mar	8.041916	8.062254	7.943696	8.061442
Apr	7.598917	7.562555	7.218161	7.563129
May	7.569481	7.577391	7.151257	7.577226
Jun	7.213842	7.379925	6.786912	7.379925
Jul	6.853367	6.995973	6.25191	6.995973
Aug	7.020688	7.105071	6.42572	7.097268
Sep	7.146446	7.254914	6.866312	7.255948
Oct	7.77791	7.884871	7.704254	7.884871
Nov	8.491207	8.396158	8.112972	8.396158
Dec	8.621699	8.562228	8.360109	8.562228

Table 7.1. 5: Mean monthly wind at different meteorological stations.

No	1	2	3	4
station name	HARAMAYA	COMBLCHA	HARAR	KARSA
Latitude	9.40	9.43	9.45	9.45
Longitude	42.03	42.12	42.08	41.87
Elev	2020	2122	1977	1990
Jan	1.37	1.40	1.37	1.87
Feb	1.39	1.31	1.27	1.75
Mar	1.45	1.27	1.12	1.69
Apr	1.38	1.21	1.01	1.61
May	1.33	1.17	0.97	1.56
Jun	1.65	1.43	1.11	1.91
Jul	1.54	1.37	1.02	1.82
Aug	1.42	1.28	0.98	1.71
Sep	1.15	1.06	0.88	1.41
Oct	1.04	1.00	0.92	1.33
Nov	1.10	1.10	1.06	1.46
Dec	1.32	1.28	1.22	1.70
Average	1.34	1.24	1.08	1.65

Table 7.1. 6: Mean monthly relative humidity at different meteorological stations.

Station Name	HARAMAYA	COMBLCHA	HARAR	KARSA
Latitude	9.400174	9.433333	9.450006	9.450001
Longitude	42.03334	42.117	42.08333	41.86667
Elevation	2020	2122	1977	1990
Jan	61.03502	59.79223	59.27768	59.8015
Feb	57.45558	56.34508	55.05211	56.21056
Mar	59.21771	58.4157	57.95477	58.39322
Apr	65.95359	65.55184	66.15361	65.52637
May	68.04247	68.62222	70.27452	68.58999
Jun	69.62577	70.02909	71.76554	70.02909
Jul	72.57264	71.62434	72.94162	71.66671
Aug	72.4155	71.46316	72.83984	71.46816
Sep	71.8083	70.69965	71.70543	70.70142
Oct	63.39588	62.83518	62.81259	62.84679
Nov	58.8773	59.63945	59.92125	59.60784
Dec	60.17397	59.71259	59.19076	59.66262

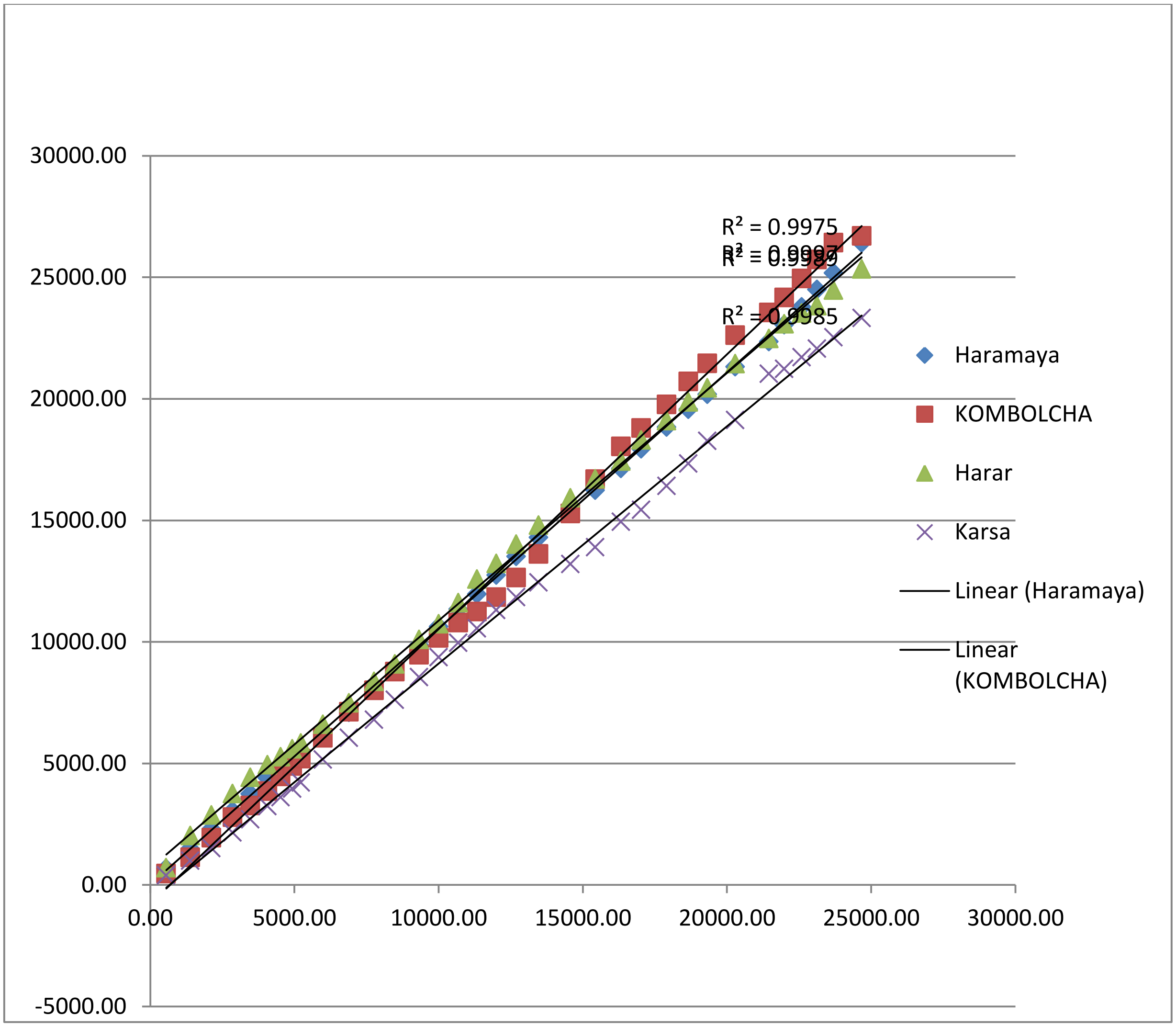

Fig.7. 1.Consistency of metrological data by using double mass curve

7.2. CROPWAT 8.0 input data tables

Table7.2. 1: ETO and climatic data for Haramaya meteorological station

Country Ethiopia Station Gorgora

Altitude 2020 m Lat. 12.25°N Long. 37.3°E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	7	23.9	61	118	8.7	20.3	3.7
February	8.2	25.1	57	109	8.5	21.3	4.02
March	10.8	26.3	59	96	8	21.6	4.23
April	12.8	25.6	65	87	7.6	21.2	4.14
May	13.3	25.8	68	83	7.6	20.8	4.05
June	13.8	25.5	69	95	7.2	19.8	3.94
July	13.5	24.3	72	88	6.8	19.3	3.73
August	13.7	25.5	72	84	7	20	3.92
September	12.8	24.6	71	76	7.2	20.3	3.9
October	9.1	24.9	63	79	7.8	20.4	3.85
November	6.6	24.4	58	91	8.5	20.2	3.7
December	6.4	23.5	60	105	8.6	19.6	3.52
Average	10.7	24.9	65	93	7.8	20.4	3.89

Table 7.2. 2: ET_O and climatic data for Kombolcha meteorological station

Country: Ethiopia Station Combolcha

Altitude: 212 m Lat. 42.11°N Long: 9.43°E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	9.5	23.9	59	121	8.5	20	3.76
February	10.4	25.1	56	113	8.5	21.2	4.11
March	11.9	26.3	58	109	8.1	21.7	4.38
April	13.2	25.6	65	104	7.6	21.2	4.24
May	13.6	25.8	68	101	7.6	20.8	4.14
June	14.2	25.5	70	123	7.4	20.1	4.07
July	13.9	24.3	71	118	7	19.6	3.9
August	14.1	24	71	110	7.1	20.1	3.94
September	13.6	24.6	70	91	7.3	20.5	3.97
October	10.9	24.9	62	86	7.9	20.5	3.93
November	9.4	24.4	59	94	8.4	20	3.73
December	9.3	23.5	59	110	8.6	19.6	3.61
Average	12	24.8	64	107	7.8	20.4	3.98

Table 7.2. 2: ET_O and climatic data for Harar meteorological station

Country: Ethiopia Station: Combolcha

Altitude: 1977 m Lat: 42.11°N Long: 9.45°E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	12.4	25.7	59	118	8.3	19.7	3.88
February	12.8	27	55	109	8.4	21.1	4.28
March	13.5	27.5	57	96	7.9	21.4	4.41
April	14.1	26.3	66	87	7.2	20.6	4.15
May	14.1	25.9	70	83	7.2	20.2	3.99
June	14	25.7	71	95	6.8	19.2	3.85
July	13.8	24.8	72	88	6.3	18.5	3.67
August	13.8	24.9	72	84	6.4	19.1	3.74
September	13.4	25.5	71	76	6.9	19.8	3.85
October	12.5	26	62	79	7.7	20.2	3.92
November	12.4	25.5	59	91	8.1	19.6	3.77
December	12.4	24.8	59	105	8.4	19.3	3.68
Average	13.3	25.8	64	93	7.5	19.9	3.93

Table 7.2. 3: ETO and climatic data for Karsa meteorological station

Country: Ethiopia Station: Combolcha

Altitude: 1977 m Lat: 42.11°N Long: 9.45°E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	9.6	25.6	59	161	8.5	20	4.09
February	10.4	26.9	56	150	8.5	21.2	4.47
March	12	27.6	58	145	8.1	21.7	4.68
April	13.4	26.7	65	138	7.6	21.2	4.46
May	13.7	26.7	68	134	7.6	20.8	4.32
June	14.2	26.3	70	164	7.4	20.1	4.25
July	14	25.2	71	157	7	19.6	4.05
August	14.2	25.2	69	147	7.1	20.1	4.15
September	13.6	25.8	70	122	7.3	20.5	4.14
October	10.9	26.1	62	115	7.9	20.5	4.15
November	9.4	25.7	59	126	8.4	20	3.99
December	9.3	25.1	59	147	8.6	19.6	3.9

Average	12.1	26.1	64	142	7.8	20.4	4.22

Table 7.2. 4: Effective rain (mm) of the Haramaya climatic station

		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Total
Rain	mm	11	21.9	50.3	105	91.9	49.2	101	134	110	51.3	24.3	16	766.4
Eff rain	mm	8.8	17.5	40.2	84	73.5	39.4	81	108	87.8	41	19.4	13	613.1

Table 7.2. 5: Effective rain (mm) of the Combolcha climatic station

		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rain	mm	9.7	16.3	52	102	86.8	51.7	100	148	114	52.8	21.9	15.3	770.4
Eff rain	mm	9.5	15.9	47.7	85.2	74.7	47.4	84.1	113	92.9	48.3	21.1	14.9	655.1

Table 7.2.6: Crop water and irrigation requirement (mm) of synoptic station

Date	Day	Stage	Rain	Ks	Eta	Depl	Net Irr	Deficit	Loss	Gr. Irr.	Flow	Date	Day
			mm	fract.	%	%	mm	mm	mm	mm	l/s/ha		
1-Jan	1	Init	0	1	100	29	17.4	0	0	24.8	2.87	1-Jan	1
10-Jan	10	Init	0	1	100	26	17.5	0	0	25.1	0.32	10-Jan	10
19-Jan	19	Init	0	1	100	25	18.7	0	0	26.7	0.34	19-Jan	19
28-Jan	28	Dev	0	1	100	25	20.3	0	0	29.1	0.37	28-Jan	28
5-Feb	36	Dev	0	1	100	26	22.8	0	0	32.6	0.47	5-Feb	36
13-Feb	44	Dev	3.3	1	100	26	23.5	0	0	33.5	0.49	13-Feb	44
20-Feb	51	Dev	0	1	100	26	25.4	0	0	36.3	0.6	20-Feb	51
28-Feb	59	Mid	0	1	100	26	26.1	0	0	37.2	0.54	28-Feb	59
9-Mar	68	Mid	0	1	100	28	28.1	0	0	40.2	0.52	9-Mar	68
18-Mar	77	Mid	0	1	100	26	26	0	0	37.1	0.48	18-Mar	77
26-Mar	85	Mid	0	1	100	26	25.8	0	0	36.8	0.53	26-Mar	85
1-Apr	91	Mid	0	1	100	28	27.5	0	0	39.3	0.76	1-Apr	91
11-Apr	101	End	0	1	100	25	25.4	0	0	36.3	0.42	11-Apr	101
22-Apr	112	End	0	1	100	26	25.8	0	0	36.9	0.39	22-Apr	112
11-May	131	End	0	1	100	26	25.5	0	0	36.5	0.22	11-May	131
25-May	End	End	0	1	0	14						25-May	End

Total			3.3	16			355.8	0	0	508.28	9.32		

Table 7.2. 7: Effective rain (mm) of the Harar climatic station

		JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Total
Rain	mm	9.5	12.4	54.5	112.5	94.9	61.1	89.1	113.7	100.7	52.4	20.9	9.8	731.5
Eff rain	mm	9.4	12.2	49.7	92.3	80.5	55.1	76.4	93	84.5	48	20.2	9.6	630.9

Table 7.2. 8: Effective rain (mm) of the Karsa climatic station

		Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb
Rain	mm	10	9.7	52	88.8	68.2	40	76	133	91.3	58	23.7	14.4		665.1
Eff rain	mm	10	9.5	47	76.2	60.8	37.4	67	105	78	52.6	22.8	14.1		580.4

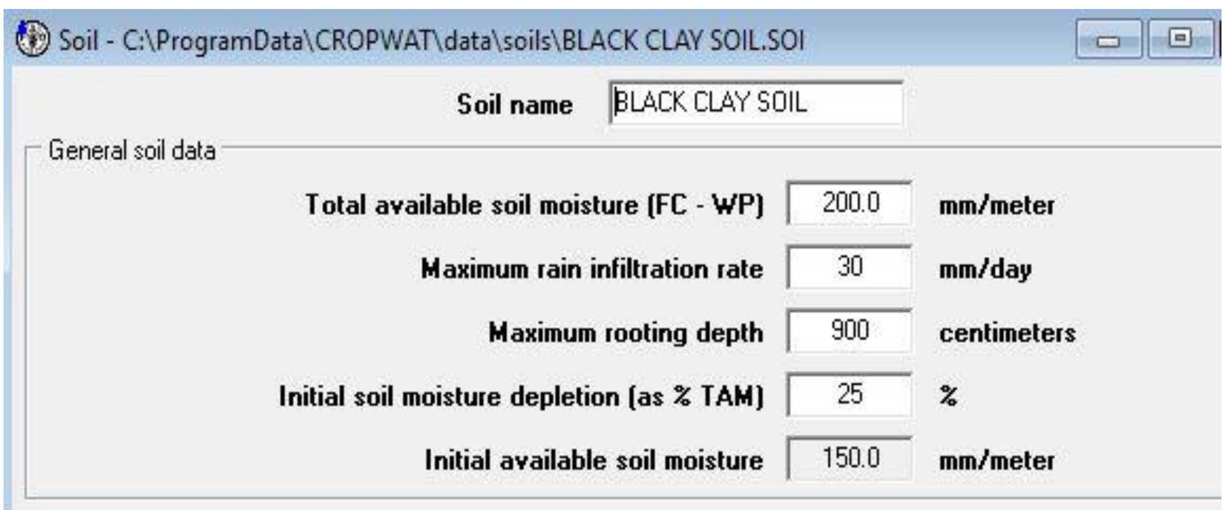

Fig.7. 2.Soil data for Lake Haramaya watershed

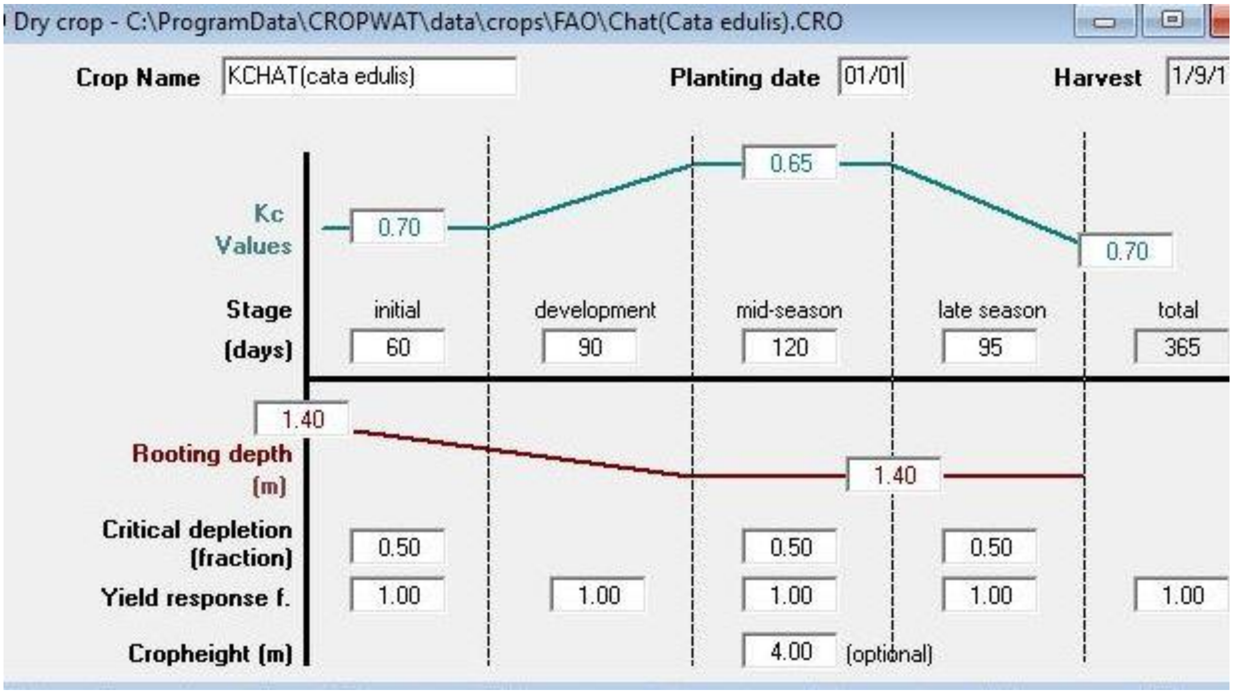

Fig.7. 3. Kchat (cata edulis) crop data

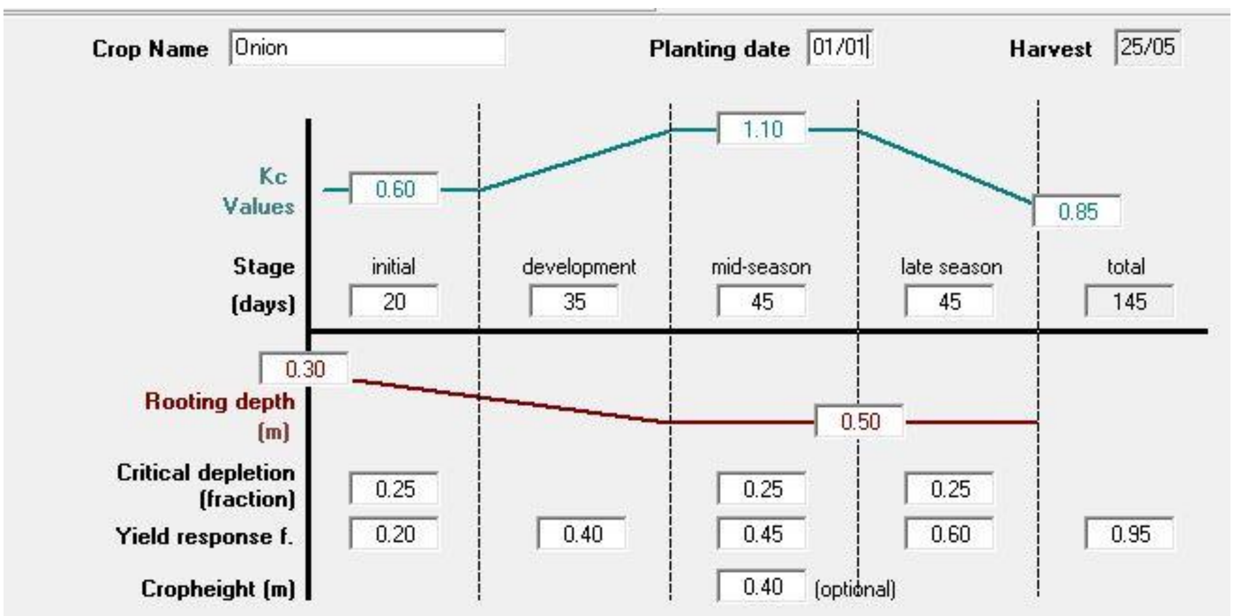

Fig.7. 4.Onion crop data

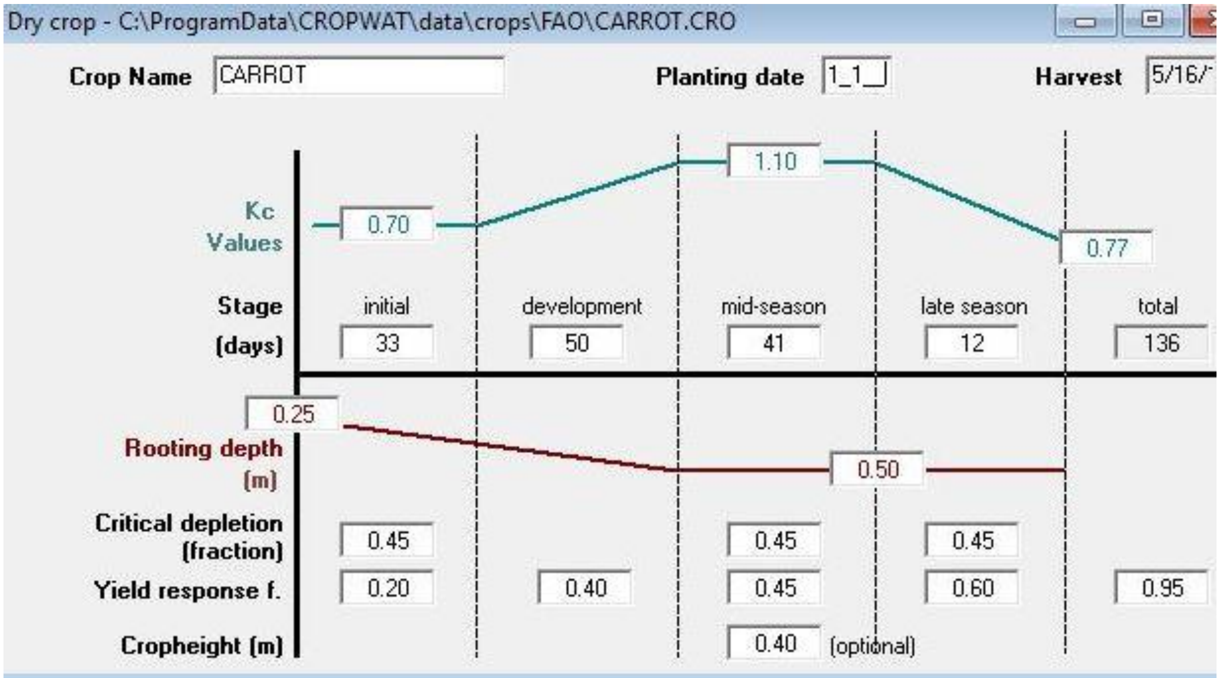

Fig.7. 5. Carrot crop data

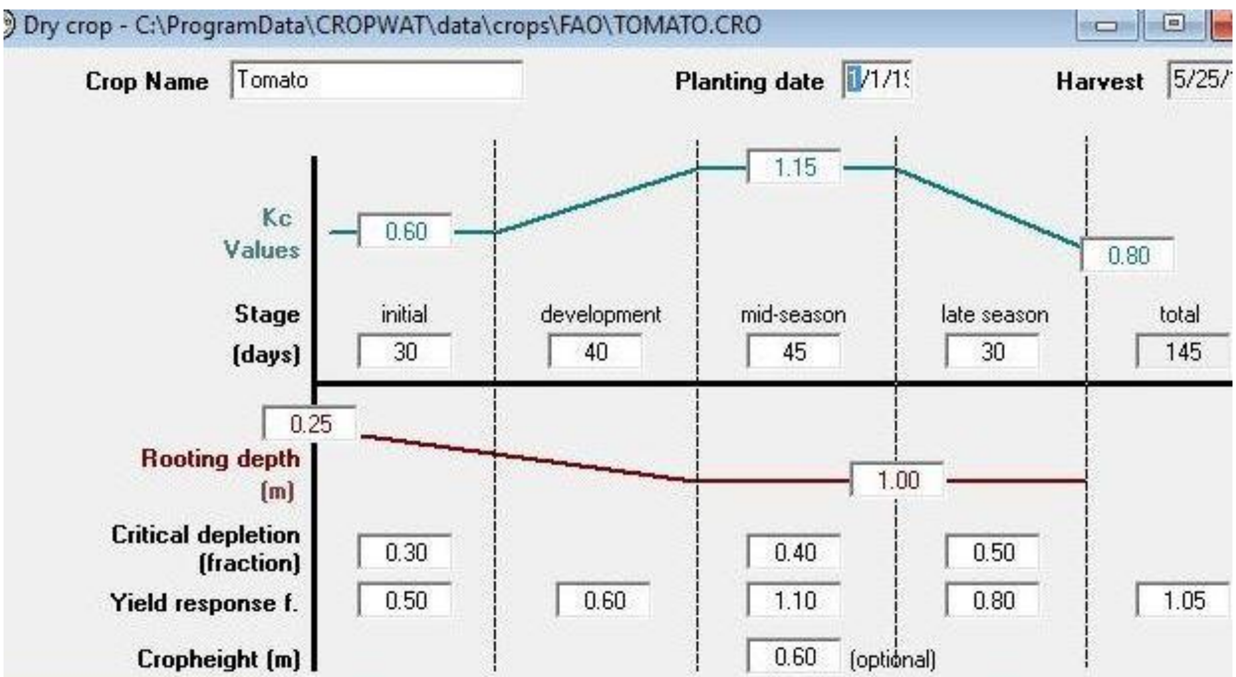

Fig.7. 6.Tomato crop data

7.3. WetSpass model input data for groundwater recharge estimation

Table 7.3. 1: Four months rainy days in Lake Haramaya watershed

Code	Rainy days	Code	Rainy days
1	1	25	1
2	3	26	3
3	2	27	1
4	1	28	4
5	1	29	1
6	5	30	6
7	17	31	11
8	15	32	16
9	11	33	12
10	3	34	3
11	1	35	1
12	2	36	1
13	1	37	4
14	2	38	1
15	3	39	3
16	4	40	2
17	3	41	1
18	7	42	7
19	15	43	14
20	14	44	13
21	21	45	9
22	2	46	2
23	1	47	1
24	2	48	1

Table7.3. 2: Land cover and land use lookup tables data for Lake Haramaya watershed

RUN OFF _VEG	VEG_ AREA	BARE_ AREA	IMP_ AREA	OPENW_ AREA	ROOT_ DEPTH	LAI	MIN_ STORM	VEG_ HEIGHT	n Maning	LandFactor	AerodyResistance
grass	0.2	0	0.8	0	0.3	2	100	0.12	0.03	0.667	212.01
grass	0.5	0	0.5	0	0.3	2	100	0.12	0.04	0.5	212.01
grass	0.4	0	0.6	0	0.3	2	100	0.12	0.035	0.571	212.01
grass	0.6	0.1	0.3	0	0.3	2	100	0.12	0.04	0.5	212.014
grass	0.6	0.1	0.3	0	0.3	2	100	0.12	0.045	0.444	212.0135
grass	0.2	0	0.8	0	0.3	2	100	0.12	0.03	0.667	212.01
bare soil	0	1	0	0	0.05	0	110	0.001	0.09	0.222	692.16
grass	0.6	0.1	0.3	0	0.3	2	100	0.12	0.045	0.444	212.013
crop	0.8	0.2	0	0	0.4	4	180	0.6	0.037	0.541	115.013
grass	1	0	0	0	0.3	2	100	0.2	0.07	0.286	177.467
crop	0.8	0.2	0	0	0.3	4	180	1.5	0.05	0.4	76.024
grass	1	0	0	0	0.3	2	100	0.3	0.055	0.364	152.49
forest	0.8	0.2	0	0	0.8	6	150	3	0.05	0.4	54.699
forest	1	0	0	0	2	5	250	18	0.1	0.2	27.196
forest	1	0	0	0	2	6	500	15	0.1	0.2	28.63
forest	1	0	0	0	2	5	375	16	0.1	0.2	28.098
grass	1	0	0	0	0.2	6	110	0.75	0.05	0.4	104.39
grass	1	0	0	0	0.6	6	110	2	0.05	0.4	66.33
bare soil	0.3	0.7	0	0	0.5	2	110	1	0.04	0.5	91.76
open	0.4	0.2	0	0.4	0.3	2	110	0.5	0.035	0.571	124.22

water											
open water	0	0	0	1	0.05	0	110	0	0.02	1	0
open water	0	0	0	1	0.05	0	110	0	0.02	1	0
open water	0	0	0	1	0.05	0	110	0	0.02	1	0
open water	0	0	0	1	0.05	0	110	0	0.02	1	0
open water	0	0	0	1	0.05	0	110	0	0.02	1	0
grass	0.6	0.1	0.3	0	0.3	2	100	0.12	0.025	0.8	212.03
grass	0.6	0.1	0.3	0	0.3	2	100	0.12	0.04	0.5	212.01
forest	1	0	0	0	2	12	320	13	0.4	0.05	29.92
forest	1	0	0	0	2	6	550	15	0.4	0.05	28.63
forest	1	0	0	0	2	6	320	20	0.4	0.05	26.46
forest	1	0	0	0	2	5	320	16	0.4	0.05	28.09
forest	1	0	0	0	2	4	150	17	0.4	0.05	27.62
forest	1	0	0	0	2	5	250	18	0.4	0.05	27.19
grass	1	0	0	0	0.3	2	140	0.12	0.035	0.571	212.03

Table7.3. 3: Soil lookup tables' data for Lake Haramaya watershed

Code	SOIL	FIELD CAPAC	WILTINGPNT	PAW	RESIDUALWC	A1	EVAPO DEPTH	TENSION HHT	P_FRAC_SUM	P_FRAC_WIN	Teta
1	Sand	0.12	0.05	0.07	0.02	0.51	0.05	0.07	0.09	0.01	0.136
2	loamy sand	0.15	0.07	0.08	0.035	0.47	0.05	0.09	0.09	0.01	0.176
3	sandy loam	0.21	0.09	0.12	0.041	0.44	0.05	0.15	0.09	0.01	0.266
4	silty loam	0.29	0.1	0.19	0.015	0.4	0.05	0.21	0.26	0.07	0.408

5	loam	0.25	0.12	0.13	0.027	0.37	0.05	0.11	0.15	0.02	0.333
6	silt	0.3	0.1	0.2	0.04	0.35	0.05	0.61	0.09	0.01	0.429
7	sandy clay l	0.26	0.16	0.1	0.068	0.32	0.05	0.28	0.54	0.3	0.351
8	silty clay l	0.36	0.19	0.17	0.04	0.29	0.05	0.33	0.62	0.41	0.563
9	clay loam	0.33	0.19	0.14	0.075	0.27	0.05	0.26	0.62	0.41	0.493
10	sandy clay	0.32	0.23	0.09	0.109	0.25	0.05	0.29	0.8	0.68	0.471
11	silty clay	0.43	0.27	0.16	0.056	0.23	0.05	0.34	0.84	0.75	0.754
12	clay	0.46	0.33	0.13	0.09	0.21	0.05	0.37	0.95	0.85	0.852