PHYSICAL IRRIGATION POTENTIAL ASSESSMENT FOR SURFACE IRRICATION: A CASE STUDY IN CHEMOGA WATERSHED, UPPER BLUE NILE BASIN, ETHIOPIA

MASTERS OF SCIENCE THESIS

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ADVISORS' APPROVAL SHEET

This is to certify that the thesis entitled "PHYSICAL IRRIGATION POTENTIAL ASSESSMENT FOR SURFACE IRRIGATION: A CASE STUDY IN CHEMOGA WATERSHED, UPPER BLUE NILE BASIN, ETHIOPIA" is submitted in partial fulfillment of the requirements for the degree of Masters of science with specialization Water Resources Engineering and Management, the Graduate Program of the Department of Water Resources and Irrigation Engineering, and it has been carried out by Kassanesh Melkam Mengiste Id. No PGWREM/ 0009/11 under our supervision. Therefore we recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department.

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We, the undersigned, members of the Board of Examiners of the final open defense by Kassanesh Melkam have read and evaluated her thesis entitled "PHYSICAL IRRIGATION POTENTIAL ASSESSMENT FOR SURFACE IRRIGATION:A CASE STUDY IN CHEMOGA WATERSHED, UPPER BLUE NILE BASIN, ETHIOPIA ", and examined the candidate. This is, therefore, to certify that the thesis has been accepted in partial fulfillment of the requirements for the degree masters of Science.

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SGS Approval	Signature	Date

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DECLARATION

I, here declare that this MSc thesis is my own work and the sources used have been cited properly and this thesis is not submitted to any other institution anywhere for the award of any academic degree, diploma or certificate.

Name: Kassanesh Melkam

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

Name: ____

Signature: ____

Place and date: Hawassa University, 19/11/2020

LIST OF ABBREVIATIONS AND ACRONYMS

AHP	Analytical Hierarchy Process
CWR	Crop Water Requirement
DEM	Digital Elevation Model
EMSA	Ethiopian Metrological Service Agency
ERDAS	Earth Resources Data Analysis System
ET	Actual Evaponspiration
ETc	Crop Evapo-transpiration
ETO	Reference Crop Evapo-transpiration
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
GIS	Geographic Information System
HRU	Hydrologic Response Unit
LULC	Land use /Land cover
MCE	Multi Criteria Evaluation
MODIS	Moderate Resolution Imaging Spectro radiometer
Mha	Million hectares
MWIE	Ministry of Water Irrigation and Electricity
MOWR	Ministry of Water Resource
SNNPRS	Southern Nations, Nationalities and Peoples Regional State
SRTM	Shuttle Radar Topographic Mission
SWAT	Soil and Water Assessment Tool
UNESCO	United Nations Scientific and Cultural Organization
USGS	United States Geographic Survey

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ABSTRACT

Assessment of available land and water resources for irrigation is essential for planning their use, to utilize limited resources efficiently and for the sustainable production of crops and food security of the ever increasing people in developing countries like Ethiopia. The study was mainly focused on assessing the available land and water resources potential for surface irrigation of Chemoga Watershed. This was done by using Geographic Information System (GIS)-based Multi Criteria Evaluation (MCE) tools, a hydrological Soil and Water Assessment Tool (SWAT) model, and a Crop Water and Irrigation Requirements Program of FAO (CROPWAT) model. GIS was used to map the land suitable for surface irrigation based on slope, soil, land use /land cover, and river proximity. SWAT model was used to estimate the water availability, and CROPWAT model calculate the reference crop evapotranspiration, effective rainfall, net and gross irrigation water requirement of crops. Potentially suitable land for surface irrigation development was evaluated by selecting six crops (barley, wheat, bean, maize, onion, and potato). The result of the overall weighted analysis for these factors gave about 25462.08 ha (71.4 %) of the Watershed land considered as high to moderately suitable whereas 10427.53 ha (28.6 %) were not suitable for surface irrigation. The SWAT model was calibrated and validated from the available hydro metrological and spatial data. Model performance result showed in between the observed and simulated stream flow with coefficient of determination (R2) and Nash-Sutcliffe efficiency (ENS) values 0.86 and 0.7 for calibration, and 0.74 and 0.63 for validation, respectively and indicated a good performance of the model in simulating the hydrology. The annual average simulated stream flow was evaluated and 36.2 m^3/s. The water demand required by the selected crops was 228.18m^3/s/ha. From the total available suitable land, only 12376.03 ha can be irrigating with the available water.

Key words: Irrigation potential, Chemoga Watershed, SWAT model, suitability factors, GIS, MCE

1. INTRODUCTION

1.1 Background

The Ethiopian highlands are comprised of land resources, which are potentially suitable for irrigation (Abeyou et al., 2015). Although the Ethiopian highlands are contributing more than 80% flow to Nile River, only a small portion of the Nile water is being used in Ethiopia for irrigation. Hence, the Government of Ethiopia is devoted to solve this contradiction through an agriculture-led development policy that includes irrigation development (Banchiamlak, 2017).

Irrigation developments played a key role towards decreasing food insecurity, increasing agricultural productivity, provide farmers with sustained livelihoods and improve their general wellbeing and enhance socio economic development of the society (Belay and Bewket, 2013: Satpath et al., 2017; Edmealem, 2018; Asirat and Afera, 2020)). Thus, to overcome the problems of irrigation development, Proper use of land depends on the suitability or capability for specific purpose, utilization of water and land resource in irrigated agriculture provides supplementary and full season irrigation to overcome the effect of rainfall variability (Tewedros et al., 2018).

Ethiopia has 12 river basins and it is estimated that the eight major river basins can irrigate about 5.3 million hectares of land comprising of over 3.7 million hectares from surface water sources (rivers and lakes), over 1.16 million hectares from ground water sources and about 0.5 million hectares from rain water harvesting, (Awlachew et al., 2010). But, due to lack of water storage structures and large spatial and temporal variations in rainfall, there is no enough water for most farmers to produce different crops per year. Use of land and water resources for the development of irrigation facilities could lead to substantial increase in food production in many parts of the world (Temesgen and Yonas, 2016; Megersa et al., 2020).

The area which can potentially be irrigated depends on the physical resources 'soil' and 'water', combined with the irrigation water requirements as determined by the cropping patterns and climate. Therefore, physical irrigation potential represents a combination of information on gross irrigation water requirements, area of soils suitable for irrigation and available water resources by basin (FAO, 1997)

The assessment of water resources includes the quantification of water resources as well as the determination of its suitability in terms of surface irrigation system (FAO, 1997). Irrigation potential produced is the total area which can be irrigated from a project on its full utilization. This implies that before an area is to be reported under potential created it is to be confirmed that water is available for the area to be irrigated in each season during a complete irrigation year.

In Chemoga Watershed the water resource of the rivers have been serving as a source of water for livestock and domestic water supply. The efforts to establish irrigation schemes in the study area are constrained by a number of uncertainties .From those, the stream flow of the rivers are not known, suitable area of the watershed have not been identified and the water requirements of crops commonly grown in the watershed are not estimated.

In the Watershed from time to time increasing of population growth, deforestation and agricultural land expansion which magnifies the land cover change of the Watershed. This continuous land cover change has influenced the water balance of the Watershed by changing the magnitude and pattern of stream flow, which results increasing the extent of the water management problem.

The purpose of this study is to assess physical irrigation potential for surface irrigation in Chemoga Watershed which is tributaries of upper Blue Nile basin. The study was used to evaluate suitable land in terms of suitability parameters, estimate the amount of stream flow, determine the gross irrigation requirement of dominant crops cultivating in the study area and providing map for suitable lands for surface irrigation development. Therefore, evaluation and identification of suitable lands and irrigation potential of streams in the area plays a vital role in enhancing people life standards and irrigation sector of the country.

1.2 Statement of the problem

Agriculture plays a major role on Ethiopia economy and most of the population lives in Chemoga Watershed depending on agricultural system and favorable climatic conditions limit the productivity of the area. The basic climatic conditions are major consequences of seasonal or annual fluctuations of rainfall. Correspondingly, livelihoods of the Chemoga Watershed depend on rain fed agriculture and irrigation is intensive. Due to this seasonal rainfall variability, farmers of the Watershed are engaged in mono cropping cultivation system. However, double cropping systems are not familiar for the society who applies agricultural practice.

Since there is no study which was conducted in the study area based on physical irrigation potential for surface irrigation .Surface irrigation development is very important for refining the livelihood of the people.Because surface irrigation method is the most widely used and requir little knowledge to apply. But, to buld up irrigation schems in the study area, recoginition of water resource potential suitable land resource for surface irrigation is essential. Therefore assessing surface irrigation interms of suitable land and available water is a very important option for farmers start iirrigation pracice and apply double cropping system to incrase agricultural productivity and enhance food security.

1.3 Objective

1.3.1 General objective

The general objective of this study was to assess physical irrigation potential of Chemoga Watershed for surface irrigation located in Upper Blue Nile Basin, Ethiopia.

1.3.2 Specific objectives

The specific objectives of this study were to:-

- identify suitable land for surface irrigation with respect to different parameters
- estimate water availability and irrigation water requirement in the Watershed
- evaluate potentially irrigable area in the Watershed

1.4 Research questions

At the end of the research work, the following questions must be answered

- How much of the land in the watershed is suitable for surface irrigation?
- What is the surface water and land potential in the study watershed?
- Does the available surface water satisfy the demand of dominant crops?

1.5 Significance of the study

For growth, agricultural production assessing irrigation potential plays a major role. Irrigation potential assessment will contribute in making suitable land use decisions, which are vital to achieving optimal productivity of the land. In addition to this irrigation potential assessment is important in terms of agricultural development planning and manages the available land water resource in an efficient and sustainable manner. It is also introduce and improve irrigation technology .Therefore this study, help as to identify and assess physical irrigation potential for surface irrigation development under particularly study area of Chemoga Watershed.

1.6 Scope of the study

The scopes of this study mainly focus on the identification of suitable land; evaluate availability of water and potentials of irrigable land for surface irrigation in Chemoga Watershed by considering slope, land use/land cover, soil and river proximity and implementing by GIS application. In addition to this estimating the water availability and irrigation water demand was implementing by SWAT and CROPWAT software respectively. So the Physical surface irrigation potential was conducted in the study area by considering basic suitability parameters, available water and irrigation water requirement of dominant crops were identified for surface irrigation development.

2. LITERATURE REVIEW

2.1 Definition of Irrigation Potential

Irrigation potential created is the total area which can be irrigated from a project on its full utilization. This implies that before an area is to be reported under potential formed, it is to be ensured that; water is available for the area to be irrigated in each season during a complete irrigation year (FAO, 1997). However, to assess the information on land and water resources at the river basin level, knowledge of physical irrigation potential is necessary. The area which can potentially be irrigated depends on the physical resources soil and water, combined with the irrigation water requirements as determined by the cropping patterns and climate. Thus, physical irrigation potential represents a combination of information on gross irrigation water requirements, area of soils suitable for irrigation and available water resources in the basin (Megersa et., 2020)

2.2 Irrigation Potential in Ethiopia

Agriculture is the core driver for development and long-term food security in Ethiopia and irrigation development in Ethiopia is in its infancy stage and not contributing its share to the growth of the agriculture sector accordingly (Abeyou et al., 2015). About 15 to 17% of Government expenditures are committed to the agriculture sector, which directly supports 80% of the population's livelihoods, 47% of gross domestic product (GDP) and over 83.9% of export value (Nazir at et., 2019). But the country has the potential for its development both regarding vast suitable land and availability of freshwater resources suitable for irrigation purpose.

In Ethiopia, under the prevalent rain fed agricultural production system, the progressive degradation of the natural resource base, especially in highly valuable areas of the highlands coupled with climate variability have aggravated the incidence of poverty and food insecurity (Weldeamlak, 2003).

Water resources management for agriculture includes both funding for sustainable production in rain-fed agriculture and irrigation (Awlachew et al., 2005). Previously, the MOWR (Ministry of Water Resources) has identified 560 irrigation potential sites on the major river basins. The total potential irrigable land in Ethiopia is estimated to be around 3.7 million hectares MOWR (2002). Also, similar studies estimated that the country’s irrigation potential is close to 5.3 million hectares, comprising of over 3.7 million hectares from surface water sources (rivers and lakes), over 1.16 million hectares from ground water sources and about 0.5 million hectares from rain water harvesting (Awlachew et al., 2010).

2.3 Land Suitability Assessment for Irrigation

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 based on the evaluation of the biophysical resources (FAO, 2007). Multi-Criteria Evaluation (Malczewski, 2004) and Analytical Hierarchy Process (Saaty, 2008) are the common approaches for land suitability analysis.

Several studies have applied parametric evaluation approach for potential land suitability mapping for irrigation (Teka and Rompaey, 2010; Albaji et al., 2015; Sultan, 2013; Ayalew, 2014; Bagherzadeh and Paymard, 2015) have studied different irrigation methods. The study explained that soil properties such as cation exchange capacity, the percentage of basic saturation, organic matter, and pH were considered in terms of soil fertility.

Studies have carried on irrigation potential assessment (Temesgen and Yonas, 2016; Hamera and Teshone, 2017; Yilak, 2018; Nazir et al., 2019) irrigation suitability factors such as slope, texture, depth, drainage characteristics, land use/cover and distance to water source were taken in to account to identify irrigation suitability. Assessment of irrigated lands by conventional means of survey requires a great deal of time, but the application of geospatial analysis using remote sensing data and GIS techniques minimize time consuming and offer the possibility rapid production of maps and models.

In addition to these factors, land cover/land use types are considered as limiting factors in evaluating suitability of land for irrigation (Meron, 2007; Kebede, 2010; Satpathy et al., 2017) conducted a study on GIS- based surface irrigation potential assessment of river catchments for irrigation development. According to FAO (1997) generally, land suitability map is classified into two classes, i.e., Suitable and Not suitable. These classes are further classified based on their assistances and margins.

The suitability of these factors for surface irrigation method and for the given land utilization types can be expressed consistent to the suitability classes order S-suitability classification:- S1 (highly suitable): land having no significant limitation to sustained application of a given use; S2 (moderately suitable): land having limitation which in aggregate are moderately severe for a sustained application of a given use; S3 (marginally suitable) land having limitation which in aggregate are severe for a sustained application of a given use and will reduce productivity or benefits.

Order N- suitability classification N1 (temporarily not suitable) land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost; N2 (permanently not suitable) land having limitations which appear as severe as to preclude any possibilities of successful sustained use of the land of a given land use.

The basic physical factors in defining the suitability of land for irrigation are:-Slope is the incline or gradient of a surface and is commonly expressed as a percent. Slope is important for soil formation and management because of its influence on runoff, drainage, erosion and choice of irrigation types. Land slope is the most important topographical factor influencing land suitability for irrigation (Ademe, 2016). According to FAO standard guidelines for the evaluation of slope gradient, slopes which are less than 2%, are very suitable for surface irrigation, between 2% and 5% highly suitable and 5% up to 8% moderately suitable. But slopes, which are greater than 8%, are not generally recommended (FAO, 1997).

The assessment of soils for irrigation involves using properties that are permanent in nature that cannot be changed or modified. Such properties include drainage, texture, depth, salinity, and alkalinity (FAO, 1997). Even though salinity and alkalinity hazards possibly improved by soil amendments or management practices, they could be considered as limiting factors in evaluating the soils for irrigation. Several studies provide that Soil is an important determining factor for land suitability assessment (Mandal et al., 2017). And also (Teka et al., 2010) conducted that identifying soil type and study the properties are the main issues for assessing land suitability for irrigation and categorizing methods of irrigation.

Knowing land cover or land use is a basis for classifying the possible land suitability for irrigation with accurate and quantifiable economic evaluation. Therefore, corresponding of existing land cover/land use with topographic and soil characteristics to evaluate land suitability for irrigation with land suitability classes, present possible lands for new agricultural production (Jaruntorn et al., 2004).

It is important to make sure that there will be absence of irrigation water. If water is in short supply during some part of the irrigation season, crop production will suffer, returns will decline and part of the scheme's investment will lay indolent (FAO, 2001). Therefore, water supply (water quantity and seasonality) is the important factor to evaluate the land suitability for irrigation according to the volume of water during the period of year which it is available (FAO, 2007).

Quantifying the amount of water available for irrigation and determining the exact locations to which water can be economically transported are important in the decision to expand its use (Abeyou et al., 2010). Where possible, the water source preferred to be located above the command area so that the entire field can be irrigated by gravity. It is also desirable that the water source be near the center of the irrigated area to minimize the size of the delivery.

2.5 GIS Application for Irrigation Potential Assessment

GIS is a tool that allows users to create users interactive queries, analyze the spatial information, and edit data (Nazir et al., 2019). GIS have been an increasingly important means for understanding and dealing with the persuasive problem of water and related resource management in the world.

The integrated application of GIS and MCE helps land use planners to improve decision making processes (Malczewski, 1999). GIS based MCE found to be a favorable tool to identify potential land limitation to grow different crops (Murayama, 2010). One of the most advantages of this tool is possibility of adjusting standardized FAO land suitability framework for soil, slope, land use/land cover, and river proximity in relative to irrigation potential assessment.

For agronomic, environmental and economic reasons, the need for specialized information about agricultural practices is expected to rapidly increase (Begue et al., 2018). Accurate mapping of the distribution of irrigated land using remote sensing data at a regional scale can facilitate an improved understanding of patterns of water use and food production (Chance et al., 2017). Yet, studies that have used remote sensing to map irrigated lands remain relatively infrequent (Ozdogan et al., 2010).

The main application in GIS is mapping where things are and editing tasks as well as for map-based query and analysis (Nazir et al., 2019). 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. GIS can integrate Remote Sensing and different data sets to create a broad overview of potential irrigable area. While the remotely sensed image of an area gives a true representation of an area based on land use/ cover / use, grid interpolated climate data can serve many purposes and used as climatic data base where meteorological data from gauging networks are not adequate.

An application example in the continental United states, irrigation mapping methodology that relies on remotely sensed inputs from the Moderate Resolution Imaging Spectro radiometer (MODIS) instrument, globally extensive ancillary sources of gridded climate and agricultural data and on an advanced image classification algorithm. The methodology involves four steps, first, climate-based indices of surface moisture status and a map of cultivated areas to generate a potential irrigation index. Second, identify remotely-sensed temporal and spectral signatures that are associated with presence of irrigation. Thirdly, combine the climate-based potential irrigation index, remotely sensed indices, and learning samples within a decision tree supervised classification tool to make a binary irrigated/non-irrigated map. Finally, apply a tree based regression algorithm to derive the fraction of irrigated area within each pixel that has been identified as irrigated (Ozdogan and Gutman, 2008).

2.6 AHP Application for Weighted Overlay Analysis

Weighted overlay is a technique for applying a common measurement scale of values to diverse and dissimilar inputs to create integrated analysis (Malczewski, 1999). The purpose of weighting in land suitability analysis for irrigation is to determine the importance of each factor relative to other factors that affect land for irrigation.

To prioritize the influence of the factor values, weighted overlay analysis uses evaluation scale from 1(represents the least suitable factor) to 9 (represents the most suitable factor) (Saaty, 1980). Weighted overlay accepts integer raster as input, such as a raster of land cover, soil type, and Euclidean (the straight line from the center of the source cell to the center of the surrounding cells) distance output to find suitable land for irrigation.

AHP is a power full and flexible decision-making process to help people set priorities and make the best decision when both quantitative and qualitative aspects of decision need to be considered (Weerakoon, 2014). AHP involves structuring multiple choices criteria into a hierarchy, assessing the relatives for each criterion, determining an overall ranking of the alternatives and completely aggregates various facets of the decision problem in to a single objective function (Saaty, 2000). By organizing and assessing alternatives against a hierarchy of multifaceted objectives, AHP drastically reduces the complex decision cycle (Annonymous, 2015).

According to Shen et al. (2015) the procedure used to establish the weights using the AHP method includes; - a) structure hierarchy, b) construct pairwise comparison matrix, c) calculating the weights (the priority eigenvector), and d) consistency evaluation

2.6 Estimation of Water Availability

Water availability is a crucial factor for deciding water resource conservation in the future as water resource management is becoming a critical issue in Ethiopia as well as for other countries all over the world (Abeyou et al., 2015). Flood forecasting, prediction of sediment loads, assessment of climate change can be possible by properly assessing the stream flows through river.

The available surface water potential for surface irrigation is identified by comparing historical river flow data with crop water requirement of the selected crops (Abeyou et al., 2015; Asfaw et al., 2020). As (Nazir et al., 2019) showed that providing a geo-referenced map of these resources, Watershed delineation, identification of irrigable land, and estimation of surface runoff and irrigation water requirements are the first steps to determine irrigation potential by water available of the Catchments.

Quantifying the amount of water available for irrigation and determining the exact locations to which water can be economically transported are important in decision to expand its use (Kebede, 2010). The water resource assessment and sustainable water resource management practice relay heavily on the accurate modeling of hydrological processes. The water resource in the catchment is a paramount importance not only for irrigation development plane but also a variety of fields, such as for industry, engineering structure design /hydropower/flood control, water resource utilization/households, and Echo hydrological services (Sirak, 2015).

According to (Albaji et al., 2015), available water resources will not be able to meet various demands in the near future and inevitably result into the seeking of newer lands for irrigation in order to achieve sustainable global food security. A crucial question is whether there will be adequate freshwater to satisfy the growing requirements of agricultural and non-agricultural users (Alexandratos and Bruinsma, 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. Thus, assessment of irrigation potential should take into account water boundaries. (Altchenko and Villholth, 2015) applied a methodology which 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 surface water available to maximum irrigation water demand; where surface water availability is calculated as an excess of surface water 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 and monthly crop water requirement very few attempts have been made to estimate surface water irrigation potential in Ethiopia mostly referring master plan studies and official reports (Awulachew et al., 2007; Awulachew et al., 2010; FAO, 2016). Also, there is a scanty of detail study regarding water potentials and its developmental perspectives in the Ethiopian context as it lacks agreed on reports in common consensus (Haile and Kasa, 2015).

To find the irrigable area if all water was stored, they divided the average daily flow by the crop water requirements. The study recommended, to increase the irrigation in the potentially irrigable areas, water falling and flowing during the rainy monsoon phase needs to be stored for the dry phase. Similarly, (Worqlul et al., 2017) 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.

Several hydrological models were used for the assessment of a surface and ground water availability at a river basin level. The assessment of water availability at a watershed level is realized by quantifying runoff generated in the watershed using hydrological models (Daniel et al., 2011). Hydrological models are simplified, conceptual representations of a part of the hydrologic cycle. Hydrological modeling is a process of determining the operation of the hydrological system in the transformation of rainfall in to runoff. They are primarily used for hydrological prediction and for understanding hydrological processes.

From those hydrological models SWAT model was the widely used model because of availability of the model on minimum investment of time and cost, ability of the model to produce the intended output to meet the objective of the project, ability of the model considered to produce the outputs needed to meet the aims of a particular project, Possibility to prepare a list of assumptions made by the model, ability to check the assumptions likely to be limiting in terms of known response of the catchment and the ability to make a list of inputs required by the model and deciding whether all the information required by the model can be provided with in time and cost constraints.

SWAT model is a conceptual river basin model that functions on a semi distributed, continuous time watershed simulator in daily time step developed by US Department of Agriculture (Arnold et al., 2012). In order to effectively simulate the hydrologic processes in a basin, first the basin is divided into sub basins through which streams are directed. The sub units of the basins are referred to as hydrologic response units (HRU's) which are the unique combination of soil and land use characteristics and are considered to be hydrological homogeneous.

Studies have been carried out estimation of water availability by using SWAT model, (Zehan et al., 2019; Abeyou et al., 2015; Nguyen et al., 2014; Getnet et al., 2019) For example, application of SWAT Model for assessing water availability in PoKo Catchment, the result showed that the calibrated SWAT model performed well for simulation of monthly stream flow. Statistical model performance measures, R2 of 0.64, NSI of 0.63 for calibration and 0.78 and 0.72, respectively for validation, indicated good performance of the model simulation on monthly time step. Both calibration and validation results represented fluctuations of discharge relatively well, although some peaks were overestimated by SWAT. Mean monthly and annual water yield simulated with the calibrated model were found to be 109.87 mm and 1,317.63 mm, respectively. Overall, the model demonstrated good performance in capturing the patterns and trend of the observed flow series, which confirmed the appropriateness of the model for future scenario simulation.

The model calculations are performed on a HRU basis and flow variables are routed from HRU to sub basin and subsequently to the watershed outlet (Zehan et al., 2019). The SWAT model simulates hydrology as a two-component system, comprised of land hydrology and channel hydrology. The land portion of the hydrologic cycle is based on a water mass balance. Soil water balance is the primary consideration by the model in each HRU, which is represented as (Arnold et al., 2012). Generally, SWAT model is the only hydrological model which can simulate all of the components of land phase of hydrological cycle (Dhami and Pandey, 2013) and the water availability examined by analyzing long term daily historical river discharge.

2.7 Determination of Crop Water Demand

Crop water need is the depth or amount of water needed to meet the water loss through evapotranspiration. Water requirement is the quantity of water, regardless of its source, required by a crop or diversified patterns of crops in a given period of time for its normal growth under field conditions at a place (Sileshi et al., 2007). Water requirement includes the losses due to evapotranspiration or consumptive use and the losses during the application of irrigation water (unavoidable losses) and the quantity of water required for special operations such as land preparation, transplanting, leaching, etc.

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 be design enough water source 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 of the total quantity of water required from its sowing time up to harvest. Under the same condition different crops require different amount of water and the quantities of water used by a particular crop is differ 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 growth of crop reaching the maximum in most crops as it approaches flowering and then decline towards maturity (FAO, 2011). The Hargreaves method is recommended to be adapted for areas where measured data on daily maximum and minimum temperature and rainfall data's are available. These methods are important specially when there are no full climatic data of meteorological stations. The reference crop evapotranspiration is usually calculated by using CROPWAT8.0 software implementing through FAO (1992).

Abraham (2015) conducted a study of Irrigation potential assessment in Guder River watershed, Ethiopia. In the study, temperature, humidity, sunshine hours, wind speed, rainfall, soil, and crop data of the study were used to estimate irrigation water demand for both surface and sprinkler irrigation methods the first step in calculating crop water demand is to estimate daily ETO values for each watershed using Penman and Hargreaves method. The penman Monteith method is used when all meteorological data are available based on the Thiessen polygon prepared for the study area. When only temperature data are available Hargreaves method is used. The calculation was done using Microsoft excel program. The second step in calculating irrigation water requirement was to estimate ETc (Crop Evapotranspiration) values for selected crops were obtained from the FAO CROPWAT 8 database and from previous studies conducted in the study area. Finally ETc values for each watershed were computed by multiplying Kc values with ETO values. The third step in calculating irrigation water requirement was to estimate Gross Irrigation Water demand. The gross irrigation water requirement was computed

Kebede (2010) conducted GIS- based surface irrigation potential assessment of river catchments for irrigation development in dale woreda, sidama zone, SNNP. In this study, to obtain a spatial coverage of climate data over the study area, each station was assigned to an area of influence using the Thiessen polygon method. Four climatic stations were taken to calculate irrigation water requirement of the identified irrigable area. Recorded data of these stations from the FAO claim has taken for creation of the database. Then based on the cropping pattern of the study area, obtained from the Dale Woreda agricultural office, two crops such as banana and sugarcane, were selected to estimate the water demand on a monthly basis. Planting dates for banana and sugar cane were chosen in such a way that the planting dates coincided with the local cropping calendar at the nearby meteorological stations. Then, ETO and other climatic data were derived from the computation for crop water requirement estimation. The respective crop coefficients for these crops were selected based on FAO (1998). Then, gross irrigation water requirements of the crops of the identified potential irrigable site were estimated by considering application efficiency of 65% for surface irrigation according to FAO (2001) and assuming 75% of water conveyance efficiency from the source to identify the command area.

Edmealem (2018) conducted a study on Assessment of surface irrigation potential in Gilgel Abbay Catchments; Ethiopia. In his study in order to estimate the irrigation water demand for each crop, evapotranspiration, effective rainfall, crop type data, area coverage and soil data were fitted in CROPWAT model. Then, CROPWAT model calculated the irrigation water requirement (mm/month) for each crop. The gross irrigation demand of selected crops for each month is computed for the scenario of starting sowing time analysis on November, December, January and February months.. Based on the result, the total irrigation water demand was 5927.5Mm^3, 370.2 Mm^3, 455.4 Mm^3 and 506.2 Mm^3 for November, December, January and February sowing time scenario respectively

.

3. MATERIALS AND METHODS

3.1 Description of Study Area

3.1.1 Location

The Chemoga Watershed lies within latitudes 10˚18'N - 10˚39'N and longitudes 37˚44'E-37˚53'E. In administrative terms, it is located in Gozamen Wereda East Gojiam Zone Amhara Regional State. The Watershed forms the part of the North Western highlands of Ethiopia within the total area of 35889.61ha.

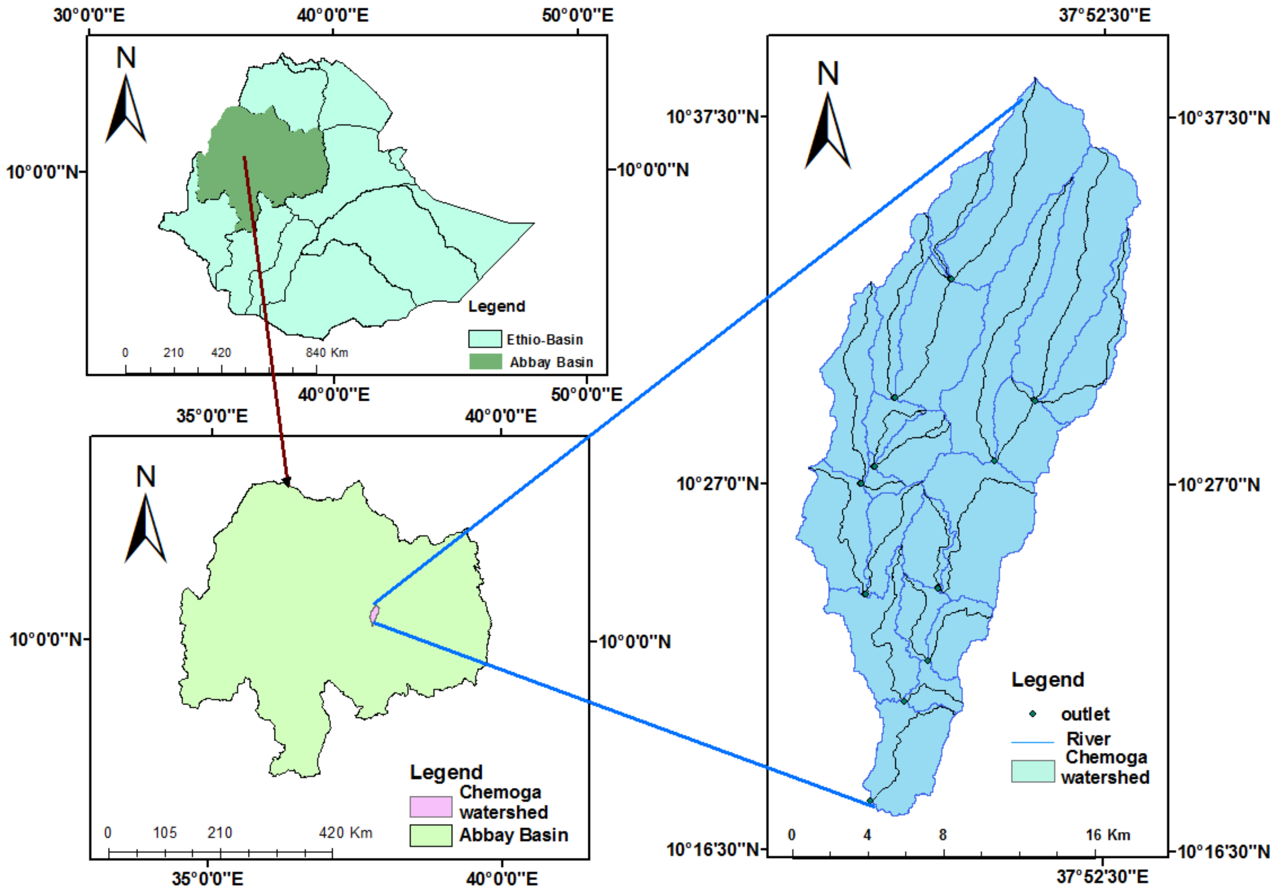

Figure3. 1**:** Location map of the study area

3.1.2 Topography

The Chemoga Watershed is characterized by diverse topographic conditions. The elevation ranges from 2413m to nearly 4000m.Mountainous and highly dissected terrain with steep slopes characterizes the upstream part of the watershed and an undulating topography and gentle slopes characterize the down steam part.

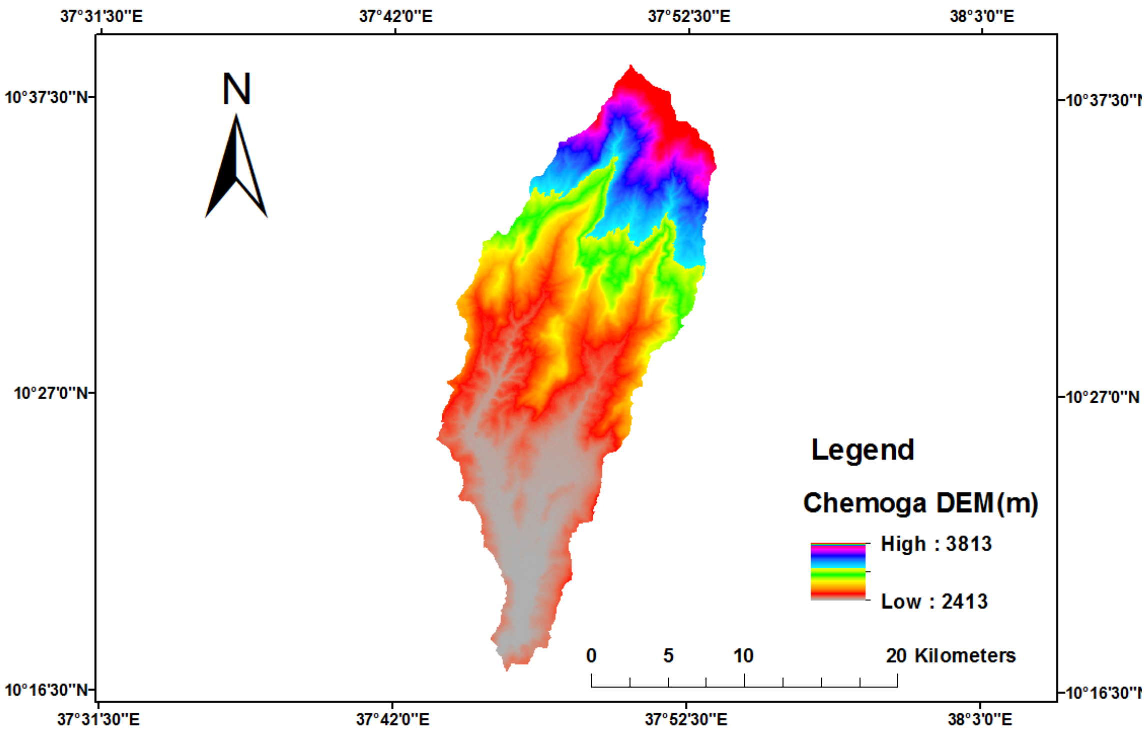

Figure3. 2: Topographic map of the study area

3.1.3 Climate

The climatic condition is generally humid. As measured at Debre markos (10˚20'N, 37˚40'E and elevation 2411m), the mean annual temperature is 14.5°C with a range from 13.2°c in July and August to 17.3°C in March. The average total annual rainfall is 1300mm. The temporal distribution of the rainfall is highly uneven and this gives rise to a serious shortage of water during the dry season in some parts of the watershed (Bewket and Sterk, 2005).

3.1.4 Soil

The major soil types in the watershed that cover much of the total area are classified as Haplic Luvisols (Well drained with sandy clay loam texture), Haplic Alisols (poor drained soil with clay texture), Eutric Leptosols (well-drained soil with clay loam texture), Eutric Cambisols (well-drained soil with clay texture) and Eutric Vertisols (imperfect drained with clay texture) (FAO, 1990).

Table3. 1: Major soil type of the study area

No	Soil type	Area (ha)	Area (%)
1	Eutric Cambisols	1378.13	3.83
2	Eutric Leptosols	4792.93	13.35
3	Eutric Vertisols	4287.47	11.94
4	Haplic Alisols	13919.97	38.78
5	Haplic Luvisols	11511.08	32.07
Total		35889.61	100

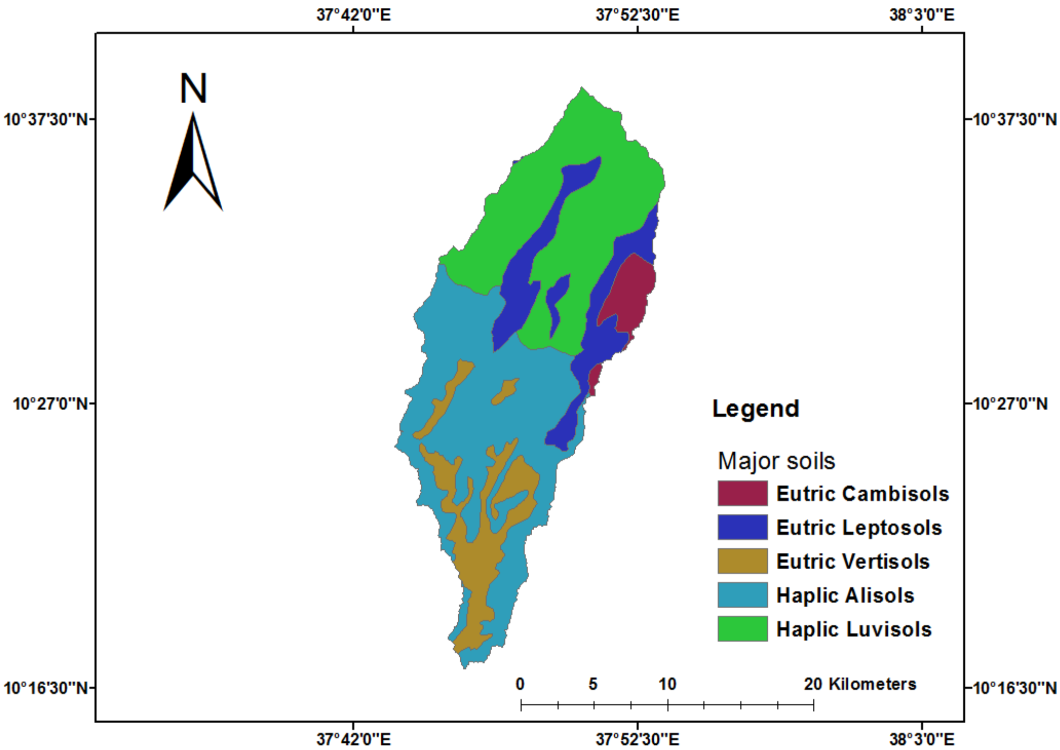

Figure3. 3: Major soil type of the study area

3.1.5 Major crops

Crop production is the major source of income to the households. A Variety of crops are produced by a house hold because of the strong orientation towards self-efficiency. Barely, wheat, oats, bean, maize, potato, and onion are grown in the upstream part of the watershed and teff is additionally cultivated in the downstream part (Woldeamlak, 2003).

3.1.6 Land use/land cover

The actual meaning of land use is the way in which land is used by people in an area to produce what is needed by the people for use through involvement of labor, capital, and available technology (Yilak, 2018). According to (FAO, 2000), land use is characterized by arrangements, activities and inputs people undertake under a certain land cover type to produce, change or maintain it. Definition of land use in this way establishes a direct link between land cover and the action of people in their environment.

Most of the land in the Watershed is used for agro-pastoral land for grazing activities largely rain fed and with a practice of shifting-cultivation. The land is cultivated on long (June-September) and short (February-May) rainy seasons and used for grazing for the rest months (Weldeamlak, 2003). In this study area the land cover consists of: agricultural land, grass land, forest and wood (dense) land, shrub and bush land, degraded land, barren, settlement, and water bodies.

Table3. 2: Land use/land cover of the study area

LULC-class	Area coverage (ha)	Proportion (%)
Water body	41.9	0.1
Shrub and bush	4799.7	13.4
Degraded land	4753.8	13.2
Agriculture	11972.6	33.4
Settlement	3506.8	9.8
Barren	5754.5	16.0
Grass land	1538.8	4.3
Forest and woodland(dense)	3520.5	9.8

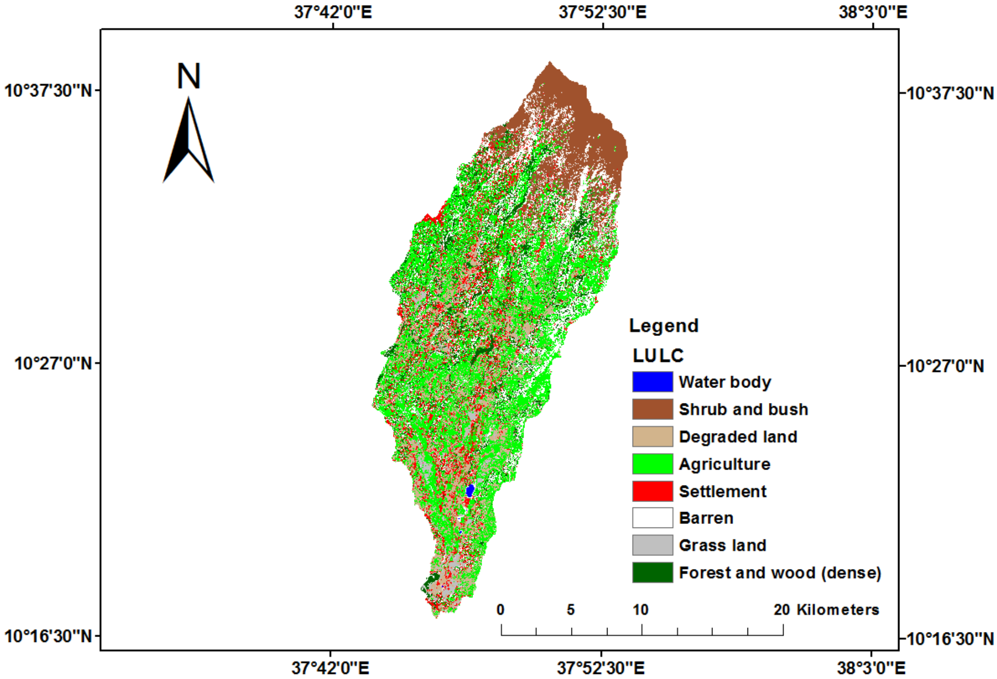

Figure3. 4: Land use/land cover map of the study area

3.2 Data Collection and Analysis

3.2.1 Data collection

Relevant dates which are very important for this study were:-

- **Satellite image:** Satellite imaginary of 2003 30mx30m was downloaded from earth explorer.
- **Digital Elevation Model (DEM):** DEM was downloaded from USGS Earth Explorer.
- **Land use / land cover**: The land use / land cover data was obtained from the downloaded satellite image.
- **Soil data:** The soil data which was obtained from harmonized soil map (2009).
- **Meteorological data:** The climatic data which was used for this study were collected from EMSA.
- **Hydrological data:** Chemoga River flow data obtained from MWIE.
- **Agronomic data:** obtained from FAO-UNISCO.

3.2.2 Data Analysis

3.2.2.1 Identification of suitable land for surface irrigation

This study aims to assess the land suitability based on factors by using Multi-Criterion Evaluation (MCE) method in Geographic information system (GIS). Land suitability was determined by assigning weights (ranks) and pairwise comparison matrix to the factors that likely affect the irrigation potential of a certain land area and finally all the suitability parameters weighting together on the overlay analysis tool to get potential irrigable areas using pairwise comparison method. Factors consider are: land features (soil type, slope, land use and available irrigation water based on distance from the source (Abeyou et al., 2015).

Factors used to assess the land suitability for irrigation

Land suitability analysis is an evaluation/decision problem involving several factors. The assessment of terrain condition and soil characteristics is an essential part of the land evaluation and forecasting exercise applied to agriculture (FAO, 2007). Their assessment provides the information about the limitations of the land for surface irrigation development.

The limitation of the land is derived from the quality of the land (Saptahy et al., 2017). Hence, considered with the suitability classes (S1, S2, S3 and N) included physical land features such as: soil, slope, land use/land cover and distance to water sources (Abeyou et al., 2015). All the parameters have been taken in to account for analysis towards the identification of suitable areas for potential surface irrigation development and they are mapped separately.

Table3. 3: Land suitability classification classes

Class	Suitability	Description
S1	Highly suitable	Land without any significant limitations
S2	Moderately suitable	Moderately severe limitations which reduce productivity or benefits or increase required inputs.
S3	Marginally suitable	Overall severe limitations; given land use is only marginally justifiable
N	Not suitable	Limitations not currently overcome with existing knowledge within acceptable cost limits

Source: (FAO, 1996) an interactive multi criteria analysis for land resource appraisal

1. Slope suitability assessment

Slope of the given area plays an important role for irrigation activities in general and spatially in case surface irrigation (Satpathy et al., 2017). The slope map of the watershed was derived using “spatial analysis” tool in ArcGIS and classified based on the classification system of (FAO, 1997).

Table3. 4: Slope suitability classification for surface irrigation

Slope	Percent (%)	Factor of rating
Horizontal	0-2	S1
Very flat	2-5	S2
Flat	5-8	S3
Steep	>8	N

Source: (FAO, 1997) Irrigation Potential in Africa, Basin approach

2. Soil suitability assessment

Soil is an important determining factor for land suitability assessment of surface irrigation development. The land suitability of the Watershed with regard to soil has been established by evaluating the soil physical property suitable parameters: soil texture, depth, and drainage suitability through overlay analysis. GIS provides an advantage of mapping these properties of soils separately and make them ready for further overlay analysis to identify which unit is the best or worst for the selected surface irrigation. The overlay provide the users flexibility in dealing with the interaction of parameters concerned spatially and there by demonstrate the results spatially as map form (Nazir et al., 2019). The soil parameters considered for this potential surface irrigation analysis purpose are mapped separately as follows.

a) Soil texture

Soil texture is the relative proportion of sand, silt, and clay of the dominant soil for each soil map polygon. Texture determines pore spaces of the soil which influence the soil permeability and infiltration rate (Sapthy et al., 2017).

Table3. 5: Suitability for surface irrigation based on texture

No	Texture	Suitability classes
1	Silty clay, clay	S1
2	Silty clay loam, clay loam	S2

3	Sandy clay, silty loam	S3
4	Sandy loam	N

Source: (FAO, 1997) Irrigation Potential in Africa, Basin approach

b) Soil depth

Soil depth refers to the thickness of the soil materials which provide structural provision, nutrients and water for plants.

Table3. 6: Soil depth suitability for surface irrigation

No	Factor soil depth (cm)	Factor rating
1	>100	S1
2	100-80	S2
3	80-50	S3
4	<50	N

Source: FAO (1997) Irrigation potential in Africa, Basin approach

C) Soil drainage

Drainage controls continuous movement of water and salt through the soil profile. Without this continuous leaching, salt may build up to levels that may be harmful to the land scape and vegetation.

Table3. 7: Suitability for surface irrigation based on soil drainage

No	Drainage	Suitability classes
1	Well drain	S1
2	Moderately drain	S2
3	Poorly drain	S3
4	Imperfectly drain	N

Source: FAO (1997) Irrigation potential in Africa, Basin approach

3. Land use/land covers assessment

Land use/land cover is a factor which is used to evaluate land suitability for irrigation. The land use/land cover of the study area has been obtained by performing supervised classification of satellite imaginary. The major land use of the Watershed was classified as: Water body, shrub and bush, degraded land, agriculture, settlement, barren, grassland, and forest and wood (dense).

Table3. 8: Land use/land covers suitability criteria

Suitability category	Designation	Description of land cover types
S1	Highly suitable	Cultivated-dominantly, moderately grassland, open-bushed ,state farm
S2	Moderately suitable	Woodland-open, riparian, bush land-dense
S3	Marginally suitable	Forest-open, cultivated-irrigation, shrub
N	Not suitable	Woodland, forest-dense, bamboo, urban, water

Source; (FAO, 1996) an interactive multi criteria analysis for land resource appraisal

Image classification

Image classification is based on the different spectral characteristics of different materials on the Earth's surface. Based on Richards (1986), there are two approaches to classify spectral images, the unsupervised and supervised. Un supervised classification is the method in which image pixels are assigned to spectral classes without the user having detail information about the study area .Whereas, supervised classification is a method that requires the analyst to identify known areas i.e. the user have more information/previous knowledge about the study area. The classification was made by using supervised classification with maximum likelihood ERDAS imagine 2014.

Accuracy assessment

The result of an image classification needs to be validated to assess its accuracy. Accuracy assessment is a procedure used to measure the reliability of a classified image. The basic idea is to compare the predicted classification of each pixel with the actual classification. The goal was to quantitatively determine how efficiently pixels were grouped in to the correct land use/cover classes.

In this study, a total of 100 randomly selected points were used. These random points were used to check with reference data in the field to assess the accuracy of the classified image. Then the classified image was along with the selected points to determine the land cover represented by each pixel. The random points were compared with the classified map. When the random point and classification match, then the classification of that pixel was considered accurate. The percentage of accurate pixels gave a good estimate of the accuracy of the whole map.

The overall accuracy was calculated by summing the number of pixels classified and dividing the total number of pixels. Kappa statistics is used to control only those instances that may have been correctly classified by chance.

Kappa coefficient which expresses the proportionate reduction in error generated by a classification process compared with a completely random classification. This measure is more engaging as it considers all elements only as in the case of overall classification accuracy.

According to Rahman et al. (2006) the kappa coefficient greater than or equal to 0.8 represents strong agreement, between 0.4 and 0.8 represents moderate agreement and a value below 0.4 represents poor agreement.

4. Distance from water supply (source)

To identify irrigable land close to the water supply (river) Spatial Analysis Tool in "Arc GIS was used. The distance between rivers was reclassified and the reclassify distance was used for weighted overlay analysis together with other factors.

Table3. 9: Suitability of proximity to water source for surface irrigation

Proximity to water (km)	Suitability classes
<1.5	S1
1.5-3	S2
3-5	S3
>5	N

Source: (Sileshi et al., 2016) Land suitability analysis for agriculture in the Abay basin, Ethiopia

Arc GIS software to identify land suitable for irrigation

GIS is computer software used for integrates, stores, edits, analyzes, shares, and displays geographic information and allows users to analyze spatial information, edit data in maps, and present the result of all these operations (Nazir et al., 2019). The integration of land evaluation and GIS can provide an improved basis for addressing spatial land evaluation (Thapa and Murayama, 2008).

The general application of GIS for this study area was to:

i. delineates the watershed of the study area

ii. Identify and reclassification of suitability factors

iii. Weighted overlay analysis and identifying suitable land for surface irrigation

3.2.2.2 Approaches used to develop suitability map

MCE in GIS environment is the best technique to evaluate different factors for a specific objective. It is concerned with how to combine the information from several criteria to form a single index of evaluation.

The purpose of weighting in land suitability analysis for irrigation is to importance of each factor relative to other factors that affect land for irrigation suitability and making on suitability of land mapping unit (Bagheri et al., 2012). In pairwise comparison each factor was matched head-to head (one to one) with each other and a comparison matrix was prepared to express the relative importance. A scale of importance is broken down from a value of 1to 9 (Table3.10), the highest value 9 corresponds to absolute importance and a reciprocal of all scaled ratio was entered in the transpose position.

These pairwise comparisons are then analyzed to produce a set of weights that sum to l. The actors and their result weight were used as input for the MCE model for weighted linear combination. The procedure by which the weights are produced follows the judgment developed by Saaty under the AHP with a weighted linear combination applying a weight to each followed by a summation of the results to yield a suitability map.

Analytical Hierarchy Process (AHP)

The AHP is a mathematical method that may be applied to resolve highly complex decision making problems involving multiple scenarios, criteria, and factors (Saaty, 1980). The AHP is a powerful and flexible decision making process to help people set priorities and make the best decision when both quantitative and qualitative aspects of decisions need to be considered. The procedure used to establish the weights using AHP method includes several steps:-

a) Structure a hierarchy

The relationship between objectives and their attributes has a hierarchy structure (Malczewski, 1999). At the highest level one can differentiate the objectives and at lower, the attributes can be disintegrated Figure 3.5.

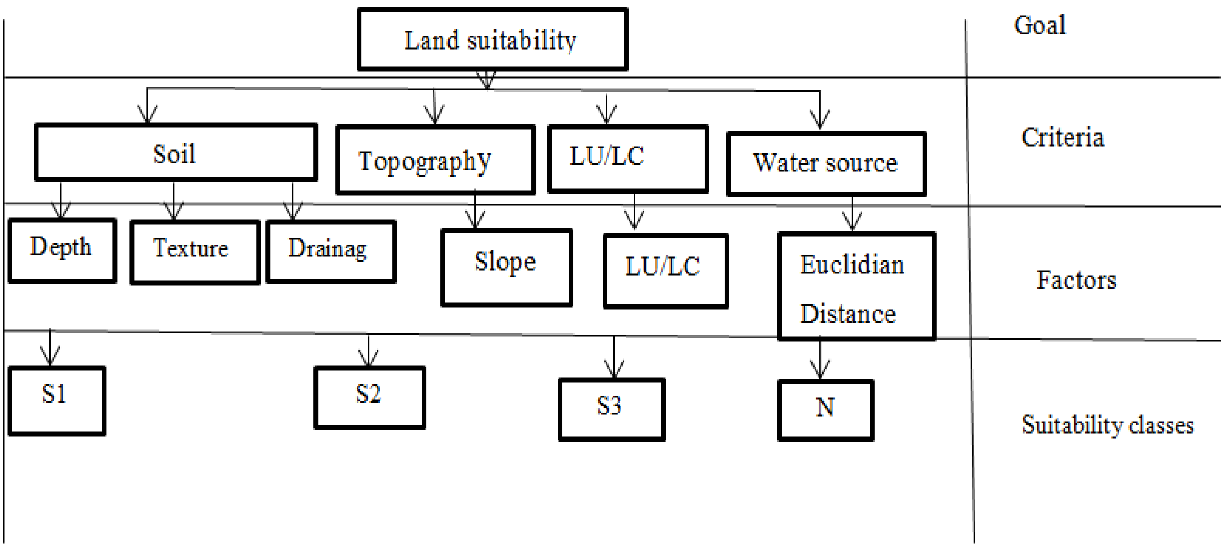

Figure3. 5: Hierarchical organization of criteria

Construct pairwise comparison matrix

In Saaty (1980) technique, weight of this nature can be derived by this the principal eigenvector of squire reciprocal matrixes of pairwise comparisons between the criteria. The comparisons concern the relative importance of the criteria involved in determining suitability for the standard objective, Ratings on a 9 points continuous scale (Ayla et al., 2016).

Table3. 10: The AHP pair-wise comparison scale and definition (Saaty, 1980)

Intensity of importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Weak importance	Experience and judgment slightly favor one activity over another
5	Strong importance	Experience and judgment strongly favor one activity over another
7	Demonstrated importance	An activity is strongly favored and its dominant is demonstrated in practice
9	Absolut importance	The evidence favoring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate values	When compromise is needed
Reciprocals	If activity i has one of the above non zero numbers	

	assigned to it when compared with activity j, then j has the reciprocal value when compared with i

Source: Ayla et al (2016) AHP and GIS based land suitability analysis for Cihanbeyli County

Calculating the criteria weights

The weights of the individual criteria are calculated. First, normalized comparison matrix is created each value in the matrix is divided by the sum of its column. To get the weights of the individual criteria, the mean of each row of this second matrix is determined. These weights are already determined and their sum is 1.

Evaluate consistency of pairwise comparisons

The AHP also provides mathematical measures to determine the consistency of judgment matrix. It is important that the weights derived from a pairwise comparison matrix are consistence. According to Saaty (1980) to ensure the consistency of the pairwise comparison matrix, the consistency judgment must be checked for the appropriate value of n by CR. The CR coefficients should be less than 0.1, that indicating the overall consistency of the pairwise comparison matrix. A consistency ratio (CR) of 0.10 or less indicates a reasonable level of consistency. If the CR is >0.1, the comparison matrix should be revised.

$$CI=\frac{\lambda max-n}{n-1} \quad (3.1)$$

$$CR=\frac{CI}{RI} \quad (3.2)$$

Where CI is the consistency index, n is the number of criteria, λmax is the largest Eigenvalue of the matrix. The RI is the average of resulting consistency.

Table3. 11: Random Consistency Index table (Saaty, 1980)

N	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.42	1.45	1.49	1.51	1.48	1.56	1.57	1.58

Source: Ayla et al (2016) AHP and GIS based land suitability analysis for Cihanbeyli Count

Creating weighted analysis in spatial analysis tool sets are used to find suitable lands for surface irrigation. After the individual suitability was assessed, the irrigation suitability factors which were considered to do the weighting slope factor, soil factor, land use/land cover factor and proximity to river factor as input to find the most suitable site for surface irrigation.

Selected raster layers were overlaid by recognizing their cell values to the same scale, giving a weight value to individual criterion and integrating the weight cell values together. The cell values of each raster layer are also multiplied by their weight value (Ayla et al., 2016).

$$LS = \sum_{I=1}^{n} WiXi \tag{3.3}$$

Where, LS indicates the total land suitability score, Wi indicates the weight of the selected land suitability criteria, Xi indicates the assigned sub-criteria score of i land suitability criteria, and n denotes the total number of land capability criteria. Basically in weighted total overlay the cell values of the rating of suitability class) are multiplied by criteria weights. The resulting cell values were added to produce the final suitability map.

3.2.2 Estimating water availability using SWAT

Prior to irrigation development, the irrigation potential of the watersheds has to be assessed because assessing the suitability of land and water is critical to the development of productive and economically variable irrigation schemes (FAO, 1997). Therefore, water supply (water quantity and seasonality) is the important factor to evaluate the land suitability for irrigation according to the volume of water during the period of year which it is available (Megersa et al., 2020).

Agricultural activities and water potential are closely related to the temporal and spatial patterns of climatic variables such as rainfall, temperature, relative humidity, wind speed and sunshine hours and success of surface water potential strongly depends on climatic situation of an area.

The availability of surface water resources for potential irrigation was assessed for the whole crop growth season. Gross irrigation demand for the selected major crops and the available mean monthly flow of the river were calculated and compared. The measured stream flow data of Chemoga River in the river basin were used to calibrate and validate with the simulated SWAT stream flow output.

There are five surrounding stations in the watershed Debre Markos, Rebugebya, Debre Elias, Yejube and Dembecha climatic stations. From those stations Debre Markos is the principal station selected for the study.

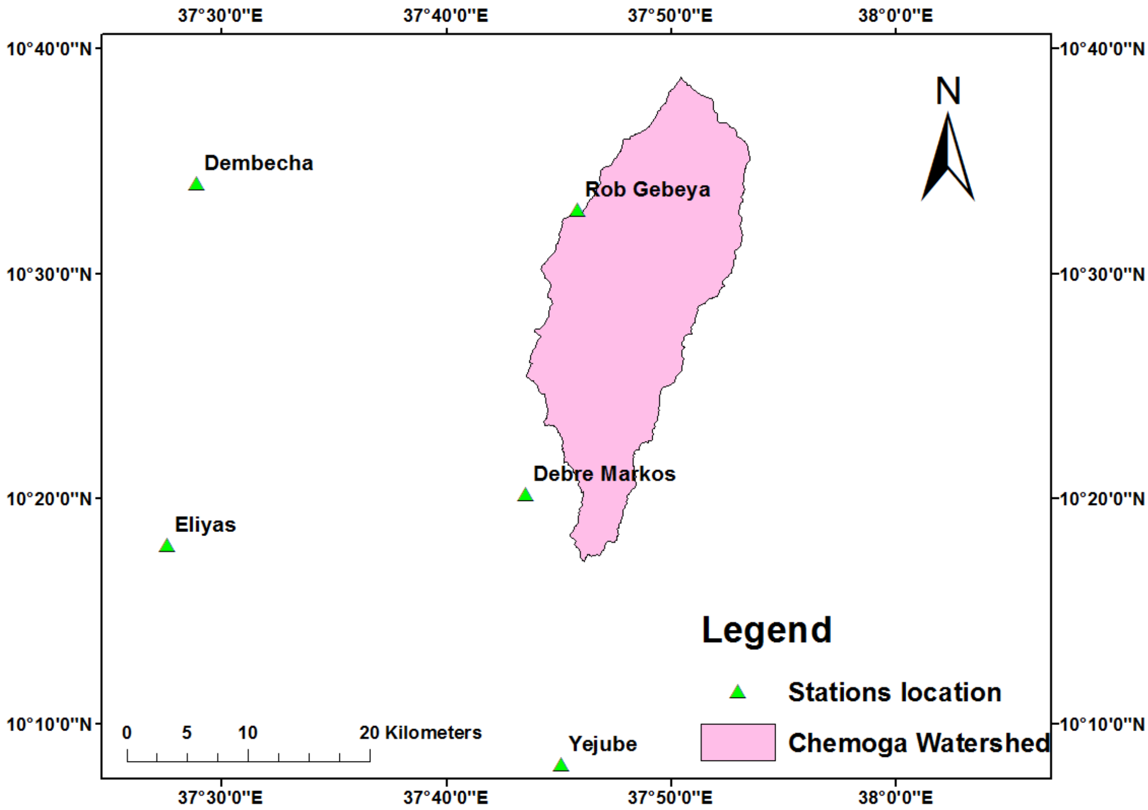

Figure3. 6: Climatic stations in the Watershed

Filling Missing Meteorological and Hydrological Data

The missing data can result from either technical fault or inability of the observer to record it and this is the main factors responsible for gaps and inconsistencies in available series data. If data gaps are big, incomplete time series may hide the pattern of the data and they may considerably distort the results of any statistical analysis. Filling the gaps in daily climate data is therefore an essential issue. There are many available methods of estimating missing values. For this study, the missing values of daily rainfall and temperature recorded were completed by using normal ratio method provided in due to the rainfall measured at a different nearby station of the Watershed shows greater than 10% variation ,whereas other climatic data and stream flow data were corrected with regression method.

$$\frac{\mathrm{Px}}{\mathrm{Nx}} = \frac{\mathrm{Nx}}{\mathrm{n}}\left(\frac{P1}{N1} + \frac{P2}{N2} + \frac{P3}{N3} + \frac{P4}{N4} + \ldots + \frac{Pn}{Nn}\right) \tag{3.4}$$

Where; - Px=missing rainfall data at station x, Nx=missing data stations normal annual rainfall ,(N1,N2,N3,N4…Nn =normal annual rainfall at stations i ,P1,P2 P3 P4,….Pn precipitation at surrounding gauges stations and n is the number of nearby gauges).

Regression analysis is a procedure for fitting an equation to a set of data. Specifically given asset of measurements on two random variables, Y and X. Regression provides a means for finding the values of coefficients 'a' and 'b' for the straight line (y=a+b) that best fits the data. The coefficients 'a' and 'b' can be found using least square method using the following two equations simultaneously: -

$$\sum y = na + b\sum x \quad (3.5)$$

$$\sum xy = a\sum x + b\sum x^2 \quad (3.6)$$

Consistency of rainfall data

Before precipitation records are used in such studies, they should be tested and errors have to be removed to ensure that any trends detected are due to meteorological causes and not to changes in gauge location, in exposure, or in observational methods.

The consistency of rainfall data was checked using double mass curve analysis through plotting the graph of cumulative rainfall collected against the cumulative average records collected as the selected stations in the same periods .The double mass curve method was applied for consistency Figure 3.7.

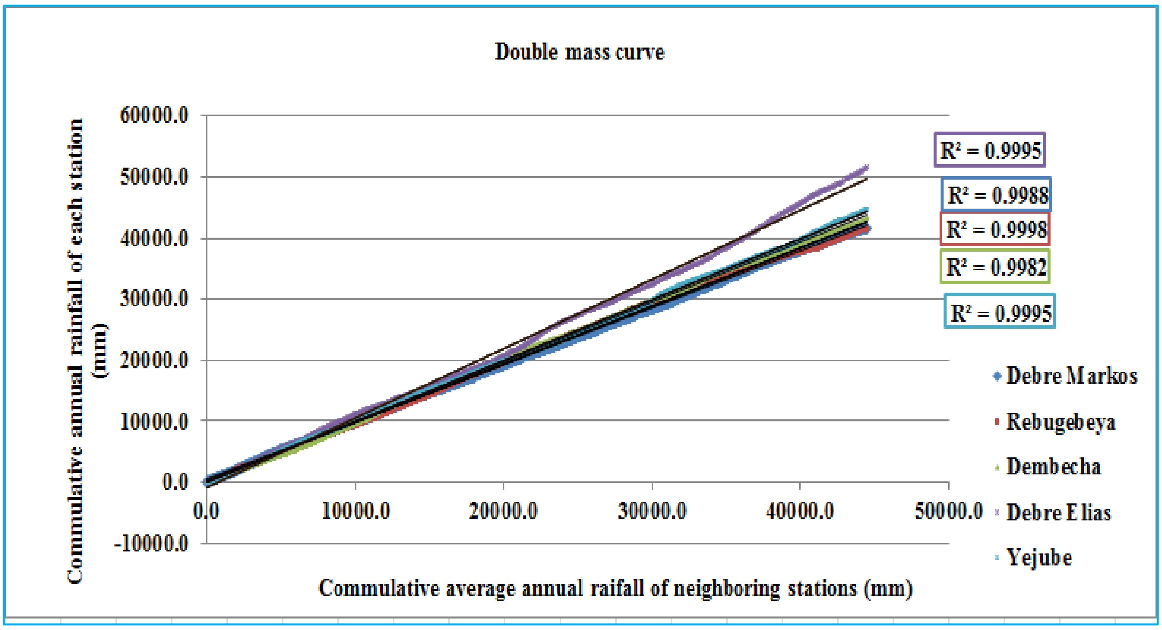

Figure3. 7: Double mass curve of the stations

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

r=1, direct linear correlation,

$0.6 \leq r < 1$: good direct correlation,

$-0.6 < r < 0$: good reciprocal correlation and

r=-1: reciprocal linear correlation. As presented in the above figure all the stations have good correlation between them.

Surface water availability assessment

The available surface water of the watershed was estimated by using the metrological and spatial data of the study area by using SWAT model. The SWAT model is a semi-physically based model for evaluating land management practices, discharge, sediment transport, and nutrient cycling (Getnet et al., 2019).

Un-gauged discharge estimation

Even though hydrometric stations are available in a river, usually it is not common for these gauges to be located precisely at rivers confluence and site of interest. There are several methods to estimate flows at un-gauged Catchments. Regional frequency analysis, areal ratio methods and Arc SWAT are some of them. In this study SWAT model has been used because of: -

1. The model simulates the hydrological process in the watersheds
2. It is readily and freely available
3. SWAT model is computationally efficient

Computing the surface water availability by using hydrological and metrological data for calibration validation, employing SWAT model, mainly based on topography, land management, soils, and climate. In this study, relevant input parameter values for the model were compiled using several different databases. These data bases included both GIS data and information extracted from both soils and lands use/cover maps such digital elevation data (DEM), land use map, soil map and weather data. SWAT simulates the hydrologic cycle for each HRU.

SWAT model input data

SWAT model requires meteorological data, grid land use/cover map, and grid soil map:

Meteorological data: Climatic data which are very important for this study such as;-daily rainfall, temperature, wind speed, sunshine hours, and relative humidity was collected from the Ethiopian Metrological Service Agency (EMSA). All metrological stations having precipitation data but only Debre Markos stations were synoptic stations having all types of climatic data. All the data were prepare in suitable text format for each station so that the SWAT model can understand. These data are used to estimate calibration and validation of SWAT model.

Table3. 12: Representative meteorological stations in the Watershed

Station Name	Year of records	Station class	Latitude (°)	Longitude (°)	Elevation (m)
Debre Markos	1988-2009	1st	10.3423	37.7246	2446
Dembecha	1988-2009	3rd	10.5691	37.4811	2109
Rebugebya	1988-2009	4th	10.5495	37.7658	2865
Yejube	1988-2009	4th	10.1391	37.7524	2282
Debre Elias	1988-2009	3rd	10.3062	37.4585	2203

Grid Land use / land cover data

The watershed is divided into Hydrological Response Units (HRU's) in SWAT model. HRU's are sub units of Watershed with particular land use, management and soil which are downloaded from USGS Earth Explorer websites and by overlaying all similar soil and land use areas in to a single unit.Therfore , this HRU portion of the SWAT model is fed by land use land cover , soil data and slope of the Watershed. Digital Elevation Model (DEM) which was downloaded from USGS Earth Explorer website (http://dds.cr.usgs.gov/srtm/) and which is used to determine the percentage slope of the watershed.

Table3. 13: SWAT land use/land covers classification

Land use/land cover	Land use according to SWAT database	SWAT code
Water body	Water	WATR
Shrub and bush land	Range-Brush	RNGB
Degraded land	Durum Wheat	DWHT
Cultivated land	Agricultural land-Row cops	CUCM
Settlement	Residential	URLD

Barren	Barren	BARR
Grass land	Range-Grasses	RNGE
Forest land	Forest-Mixed	FRSD

Grid Soil data

Study area grid soil map is one of the most important input data in SWAT model and there are five types of soil in the study area. All soil types were entered in to the SWAT data base with their detail properties in the HRU's analysis portion of the SWAT interface.

Table3. 14 SWAT Soil classification of Chemoga Watershed

No	Soil type	SWAT code
1	Haplic Luvisols	ReLp
2	Haplic Alisols	VhAl
3	Eutric Cambisols	VeCm
4	Eutric Leptosols	V/SeLp
5	Eutric Vertisols	VeVr

Sensitivity analysis

Sensitivity analysis ranks parameters that affect the model output. Parameters with small sensitivity values do not significantly affect the output; hence they are neglected from calibration process. Parameters with medium and high sensitive values have significant effect on output of the model and then used for calibration process.

Calibration

Calibration is an effort to better parameterize a model to a given set of local conditions, thereby reducing the prediction uncertainty. Model calibration is the modification of parameter values and comparison of predicted output of interest to measured data until a defined objective function is achieved (James et al., 1982) and sometimes it is necessary to change parameters in the calibration process other than those identified during sensitivity analysis because of the type of miss match of the observed variables and the predicted variables. After each calibration, checking the model performance values R^2 and NSE values and calibrate at least until the minimum recommended values were embraced by the model that is $R^2 > 0.6$, NSE > 0.5 (Santhi et al ., 2001).

Generally calibration is alteration of model parameters based on cheking results against observations to ensure the same response over the given time.This includes compairing generated with the use of recorded long term river flow to historical metrolological data . And the calibration process continues until getting best corospondance between observed and simulated run off from acatchment. Measured flow data of 13 years from the period January 1 , 1988 to December 31,2000 was used for calibreation because of contious time series data.

Validation

Model validation is the process of demonstrating that a given site-specific model is capable of making sufficiently accurate simulations, although “sufficiently accurate” can vary based on project goals (Refsgaard, 1997). Validation is comparison of the model outputs with an independent dataset without further adjustments of the values of the parameters. The process continued (validation process) until simulation of validation period stream flows confirmed that the model performs satisfactorily. Checking the R^2 and NSE values after each simulation and calibrate at least until the minimum recommended values were embraced by the model; $R^2 > 0.6$, NSE > 0.5 (Santhi et al., 2001). Independat measued flow data of 9 years from the period January 1, 2001 to December 31, 2009 was used for validation.

Evaluation of model performance

To evaluate performance of the model during calibration and validation, statistical measures as well as graphical representations at monthly time step were used. These were employed to confirm the relationship between simulated or predicted values and observed values (Ndulue al et., 2015) and to verify the strength of the model.

Two methods for goodness of fit measures of model predictions of coefficient of regression (R^2) and the Nash-Sutcliffe simulation efficiency (NSE) were selected. The R^2 and NSE coefficient measures the fraction of the variation in the measured data that is duplicated in the simulated model results.

3.2.3 Determination of total irrigation water requirement using CROPWAT

CROPWAT a computer program developed by the Land and Water Development Division of FAO which calculates reference evapotranspiration, crop water requirements, irrigation requirement, and scheme water supply, to develop irrigation schedules under various management conditions and to evaluate rain fed production and drought effects (Surendran et al., 2015). CROPWAT is meant as 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 (Vozhehova et al., 2018). The model calculates the Crop Water Requirements using the equation:-

$$CWR = ETo\ Kc\ A \quad (3.7)$$

Where: CWR is crop water requirement (mm/day). ETo reference evapotranspiration which is measured or calculated using the FAO Penman-Montieth equation (mm/day) and Kc is the crop coefficients obtain from FAO.

$$NIR = ETc - Pef \quad (3.8)$$

Where: NIR is net irrigation requirements of crops and Pef is the effective rainfall.

Effective rainfall (Pef) is the portion of rain failing during the growing period of the crop which is available to meet the consumptive water need and calculated by CROPWAT model.

$$GIR = \frac{1}{E}(NIR) \quad (3.9)$$

Where: GIR: Gross water requirement of crops, NIR: Net Irrigation Requirement and E: efficiency of irrigation in percent due to loss. The overall irrigation efficiency was calculated using the recommended formula by FAO (1997) on the irrigation schemes, irrigation efficiency for Ethiopian highlands is given as 50 %.

The assessment of the irrigation potential based on soil and water resources can be done by simultaneously assessing the irrigation water requirement and depends on the cropping pattern and climate and this was done by using CROPWAT model. Calculations of the crop water requirements and irrigation requirements are carried out with inputs of climatic data, crop and soil data.

Climate data

The past 22 year climatic data which are very important for this study such as;-daily rainfall, temperature, wind speed, sunshine hours, and relative humidity was used to calculate irrigation water requirements of the crops which are dominant in the study area, crop pattern, and soil data were the input.

Crop data

The major cultivated crops in study area were potato, barley, maize and wheat. The prominent details of crops considered for the study was as per FAO. Crop coefficient values (Kc) was obtained from available published data and FAO guidelines.

Soil data

Soil characteristics considered for estimation of crop water requirement are important to know available water content and depth of soil. The general methodology frame work is as shown as below in Figure 3.8

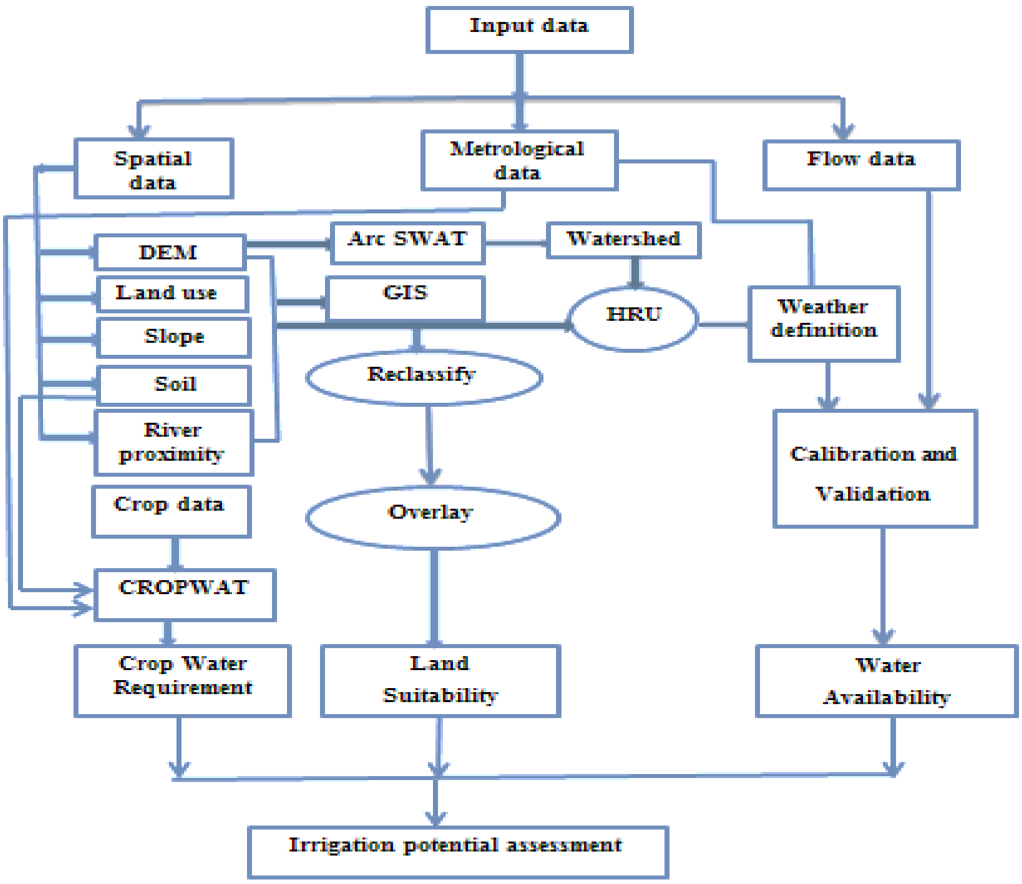

Figure3. 8: Overview of study framework

4. RESULTS AND DISCUSSION

4.1 Land Suitability Analysis for Surface Irrigation

4.1.1 Soil suitability analysis

For this study the soil mapping unit of this area was used for analysis. The physical property of the soil mapping units i.e. depth, texture and drainage that were obtained from UNISCO/FAO guideline were used for interpretation and analysis.

Soil texture suitability analysis

The soils textural class analysis indicates about 54.58% of soils in the area were under highly suitable while, 45.42% of soil textural class were categorized under moderately suitable Table 4.1and Figure 4.1. This means that according to FAO guide line of textural suitability for surface irrigation the clay textural classes were categorized under highly suitable and the sandy clay loam and clay loam soil texture grouped under moderately suitable.

Table4. 1: Soil texture suitability classes of the study area

Soil texture	Area coverage (ha)	Area coverage (%)	Suitability class
Sandy clay loam	1150.90	32.06	S2
Clay	1958.74	54.58	S1
Clay loam	479.10	13.35	S2
Total	35889.61	100	

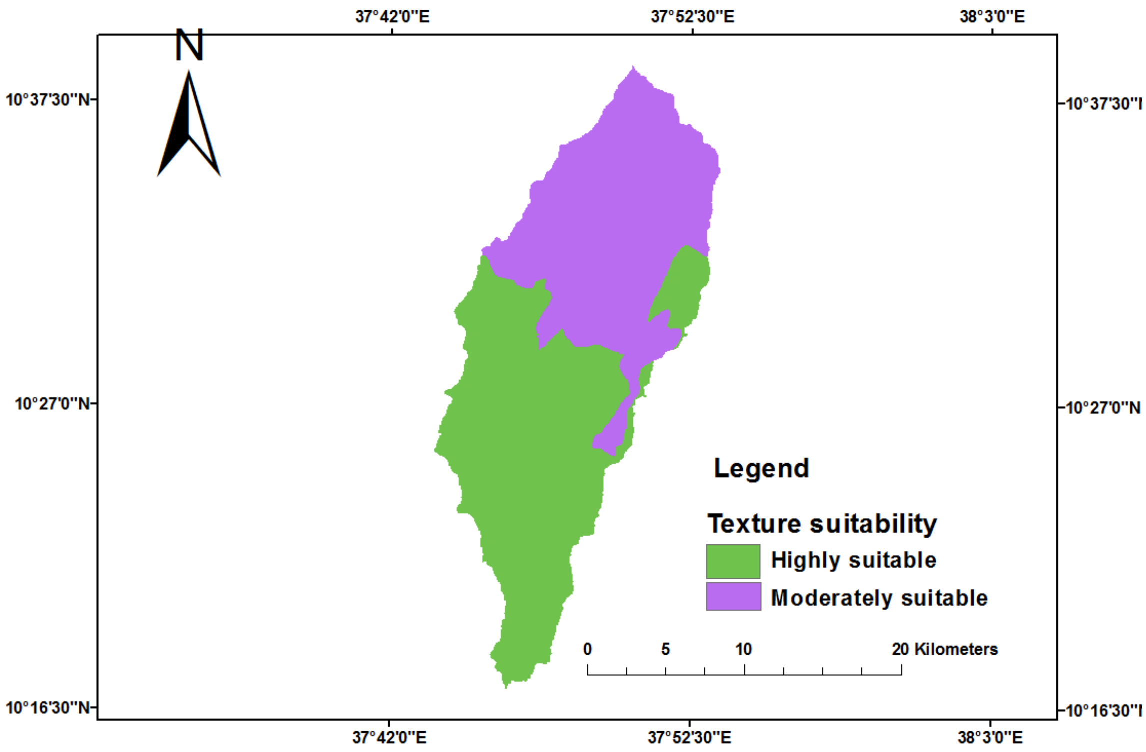

Figure4. 1: Soil texture suitability map of the study area

Soil depth suitability analysis

The soil depth suitability analysis result indicates that about 88.06% of the Watershed area was categorized under moderately suitable (S2) , while 11.94% was categorized under not suitable (N) for surface irrigation development Table 4.2 and Figure 4.2. This means that the Watershed area having the soil depth 80-100 is moderately suitable and <50 cm is not suitable for surface irrigation development according to FAO guideline.

Table4. 2: Soil depth suitability classes of the study area

Soil depth category (cm)	Area (ha)	Area (%)	Suitability classes
80-100	31,602.14	88.06	S2
<50	4287.47	11.94	N

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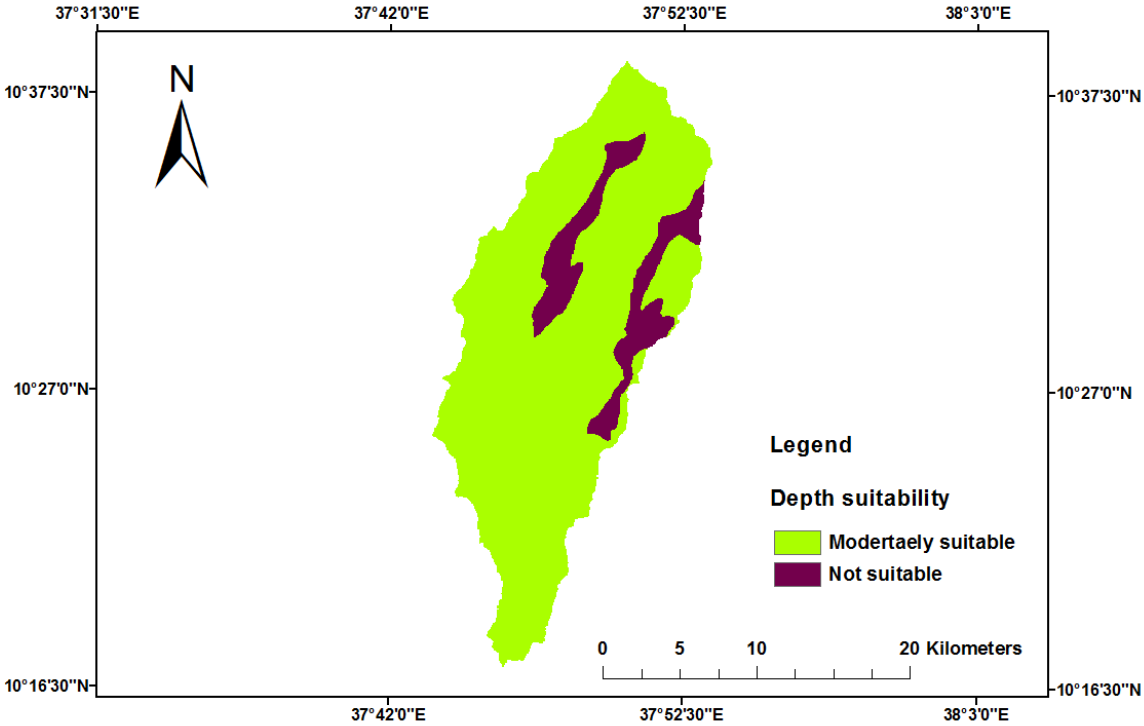

Figure4. 2: Soil depth suitability map of the study area

Soil drainage suitability analysis

Drainage controls continuous movement of water and salt through the soil profile. The drainage suitability result showed that about 49.25% of the Watershed which was 176780 ha categorized as moderately suitable (S2) and 38.81% which covers 13930 ha as marginally suitable (S3) for surface irrigation, while about 11.92% of the watershed which covers 4281.61 ha was regarded as not suitable(N) .According to guide lines of FAO (1985) the soil drainage category of the well drain which was moderately suitable, poorly drain marginally suitable and imperfectly drain not suitable for surface irrigation development.

Table4. 3: Soil drainage suitability classes of the study area

No	Soil drainage category	Area (ha)	Area (%)	Suitability class
1	Well drained	17678.0	49.25	S2
2	Poorly drain	13930.0	38.81	S3
3	Imperfectly drain	4281.61	11.92	N

In the study area the classified soils were: Haplic Luvisols and Haplic Alisols were under well drained, Eutric Cambisols and Eutric Leptosols were poorly drain and the remaining soil which called Eutric Vertisols as imperfectly drainage classes.

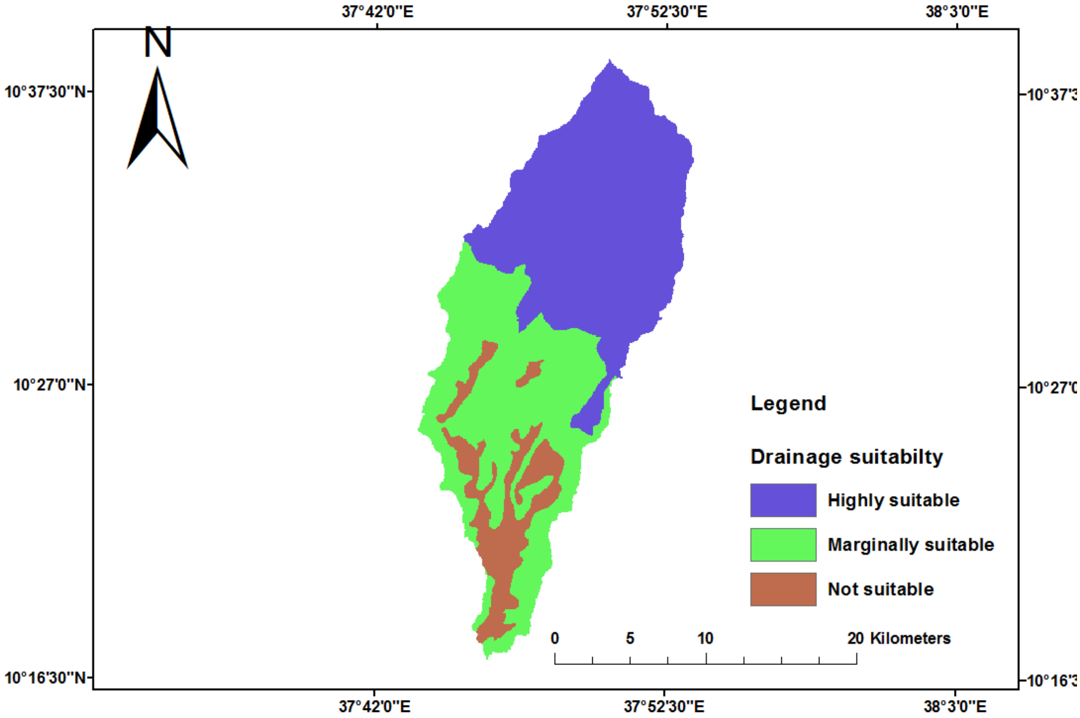

Figure4. 3: Soil drainage suitability map of the study area

4.1.2 Slope suitability

According to the slope classification result, the land having slope range below 2% was classified as highly suitable while the slope range >8% categorized as unsuitable class for surface irrigation. The suitability result indicates that 39.47 of the land was highly suitable ,35.16% moderately suitable ,18.27% marginally suitable and only 7.09% was not suitable class for surface irrigation development. Thus 92.21% of the watershed range is from highly to marginally suitable Table 4.4. As shown in Figure 4.4 the Watershed which have been slope 0-8 % categorized under highly to marginally suitable, while the Watershed part having slope >8% not suitable for surface irrigation development as FAO guide line of slope suitability assessment for surface irrigation.

Table4. 4: Slope suitability classes for surface irrigation

Slope range (%)	Suitability class	Area (ha)	Area (%)
0-2	S1	14166.16	39.47
2-5	S2	12619.56	35.16
5-8	S3	6557.94	18.27
>8	N	2543.58	7.09

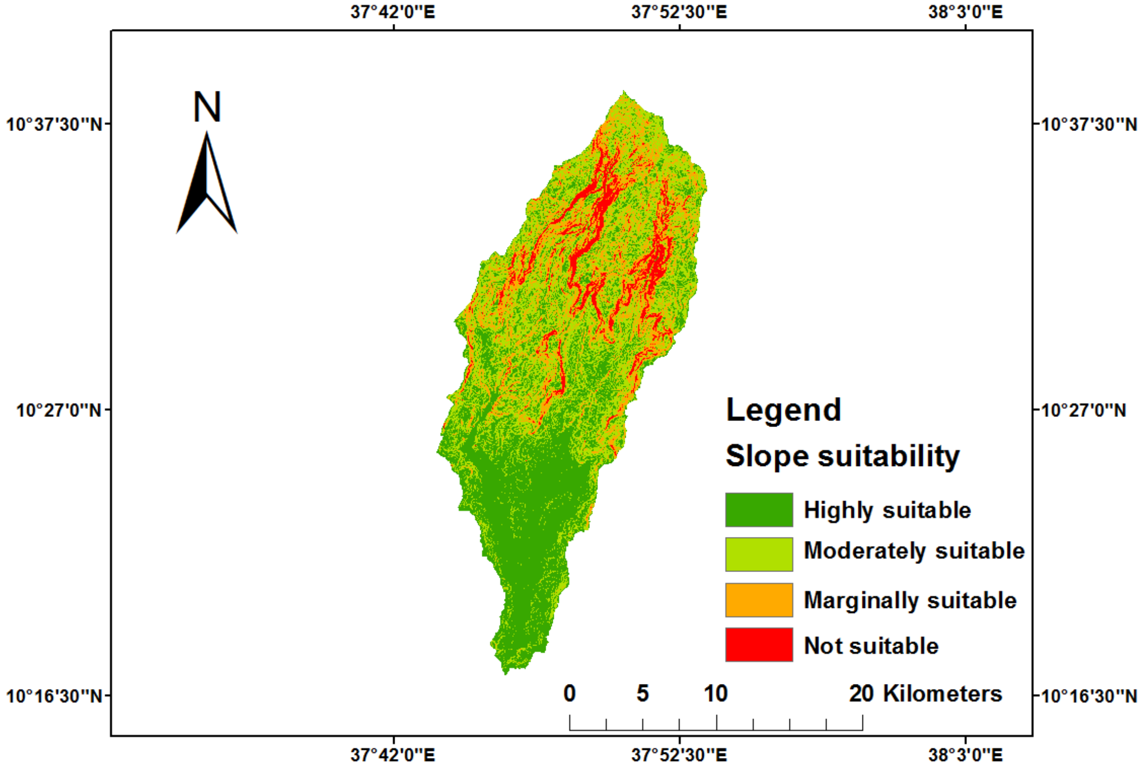

Figure4. 4: Slope suitability map of the study area for surface irrigation

4.1.3 Land use/ land cover type and suitability analysis

The eight land use land cover types in the Watershed included dominantly water body, shrub and bush land , degraded land, agriculture, settlement, barren, forest and woodland (dense), barren and grassland are available. As shown in Table 4.5 and Figure 4.5 the water body, settlement and forest lands cover 19.7 % of the total area were considered as not suitable for irrigation. The wood and shrubs including the barren land with a land cover proportion of 29.41 % were marginally suitable for irrigation. Agricultural land covers the largest area of land use land cover from all the land classes, which covers an area of 33.6 % (11972.63 ha) of the Watershed area and considered as highly suitable for surface irrigation, about 17.53 % of the study area covers with grass and degraded land and considered as moderately suitable for surface irrigation.

Table4. 5: LULC suitability of the study area

LULC classes	Area (ha)	Area (%)	Suitability class
Water body/settlement/forest /wood (dense)	7069.23	19.70	N
Shrub and bush/barren	10554.19	29.41	S3
Agriculture	11972.63	33.36	S1
Grass land/degraded land	6292.62	17.53	S2

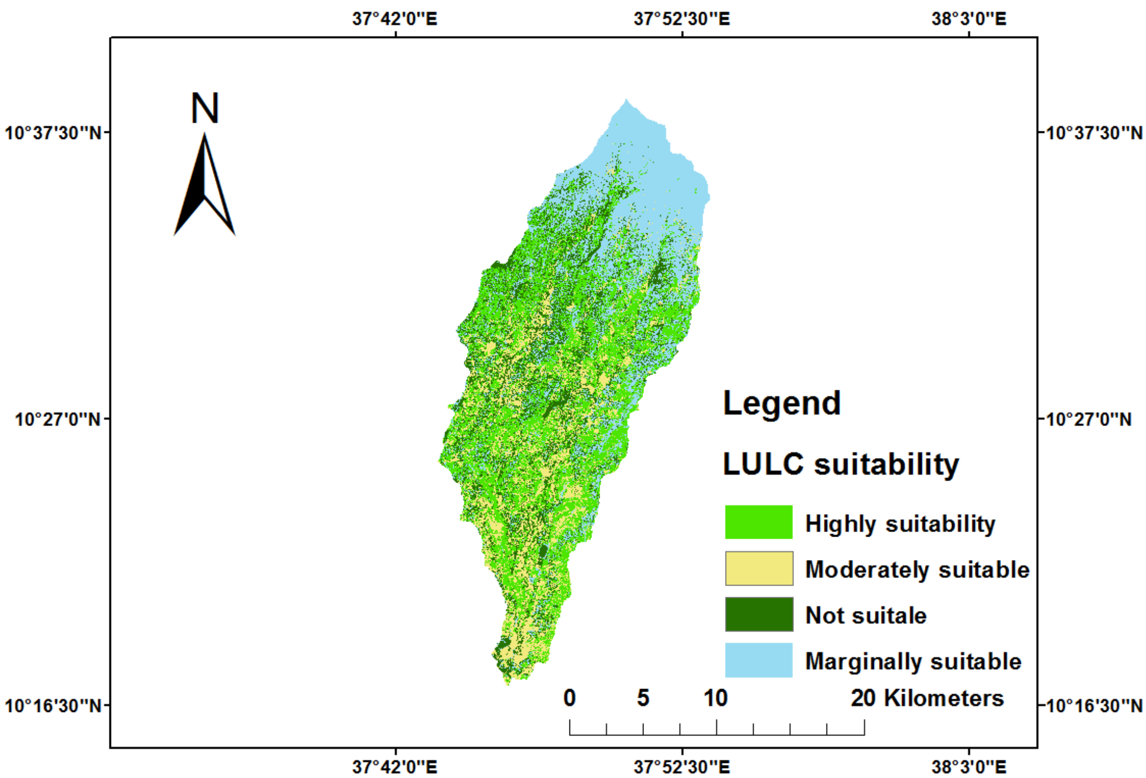

Figure4. 5: Land use land cover suitability map of the study area

4.1.4 Proximity to river suitability analysis

To identify irrigable land close to the water supply (rivers), the reclassified raster data was used. Spatial proximities to water sources were computed using spatial analysis reclassify tools of respective GIS layers Figure 4.7.

Table4. 6: River proximity of the study area

Proximity to water (km)	Suitability classes	Area (ha)	Area (%)
<1.5	S1	23768.78	66.23
1.5-3	S2	9118.29	25.41
3-5	S3	2514.78	7.01
>5	N	486.66	1.36

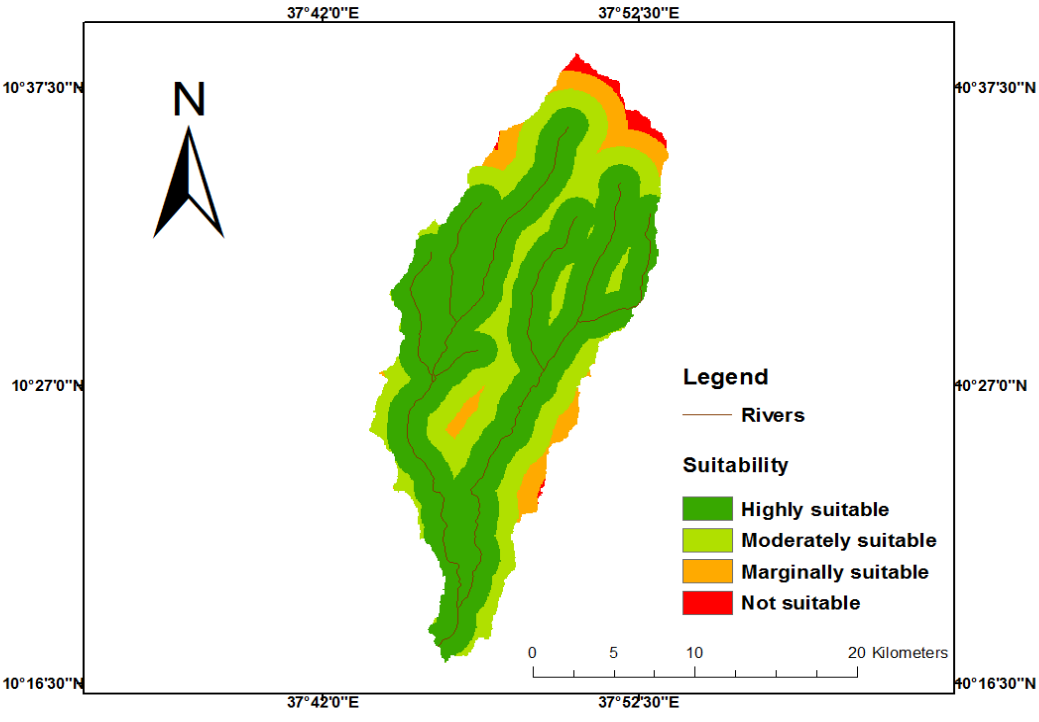

Figure4. 6: River proximity suitability map of the study area

The result showed that about 35401.85 ha of the study area which is about 91.7% was from highly to marginally suitable for surface irrigation, whereas about 486.66 ha which is about 8.3% was not suitable for surface irrigation development Table 4.6.

4.2 Assessing Weights Using AHP for Irrigation Suitability Mapping

Not all selecting factors are equally important for suitability analysis. Comparisons are needed to identify the importance of each factor with the others. For instance, how much is the effect of slope important relative to soil depth or other factors on land suitability. Hence, in this case a comparison is among factors. The pairwise comparison matrix and overall weights of the factors selected for the study is shown in Table 4.7 was constructed first. The six factors are listed in the six columns and rows. The row factors were compared with the factors in the columns or their significance to irrigation, and then using scoring of Saaty (1980) Table 3.11, the pairwise comparison matrix Table 4.7was prepared. These for example, in Tale 4.7 the “slope” factor is far more important for determining the suitability of land than the factor “land use” in the column. Conversely, “land use” in the row of Table 4.7 is far less important than slope in the column. Assigning of factors was made based on studies in the Upper Blue Nile river basin and surface irrigation suitability factors.

The results in Table 4.7 show that the factor “slope” is the most important factor since its values are greater than 1in its row followed by “soil depth” and “river proximity”. The weights of each calculated by using pairwise techniques are listed in Table 4.9 where, the greater the value the more important the factor. In this land suitability analysis the consistency ratio (CR) is 0.0523 which indicates that the comparisons of land characteristics were consistent and that the relative weights were appropriately chosen.

Table4.7: Pairwise comparison matrix based on the selected criteria’s for surface irrigation suitability.

Factors	Soil depth	Soil texture	Soil drainage	Land use/cover	River proximity	Slope
Soil depth	1	2	2	7	2	1/2
Soil texture	1/2	1	2	5	1	1/3
Soil drainage	1/2	1/2	1	5	1	1/3
Land use/cover	1/7	1/5	1/5	1	1/5	1/7
River proximity	1/2	1	1	5	1	1/2
Slope	2	3	3	7	2	1

Normalize the matrix

Normalizing the matrix means add the columns of the matrix and then divide each element in every column by the sum of that column.

Table4. 8: Normalized criteria comparison matrix

Factors	Soil depth	Soil texture	Soil drainage	Land use/cover	River proximity	Slope
Soil depth	0.2303	0.2597	0.2174	0.2333	0.1784	0.1961
Soil texture	0.0461	0.1299	0.2174	0.1667	0.1177	0.098
Soil drainage	0.1151	0.0649	0.1087	0.1667	0.1177	0.098
Land use/cover	0.0329	0.026	0.0217	0.0333	0.051	0.0196
River proximity	0.1151	0.1299	0.1087	0.1667	0.1784	0.098
Slope	0.4605	0.3896	0.3261	0.2333	0.3568	0.4902
Sum	1	1	1	1	1	1

To get the weight of factors average each row in the normalized matrix and the weight percentage was calculated by the average of each row by 100.

Potential irrigable areas by the intended irrigation method were obtained using irrigation suitability analysis model developed on Arc GIS. The suitability model involved weighting of values of data sets such as: soil, slope, land use land cover and proximity from water source. Rasterized and reclassified suitability map of each parameter were used as input for the overlay analysis tool. As elaborated below in Table 4.9 overall suitable areas for surface irrigation development in the Watershed were identified with their area coverage.

Table4. 9: Weighting factors

Factors	Weight	Weight (%)
Soil depth	0.2192	22
Soil texture	0.1293	13
Soil drainage	0.1119	11
Land use/cover	0.0308	3
River proximity	0.1328	13
Slope	0.3761	38
λ_{max}	6.79	
CR	0.0523	

In the irrigation suitability analysis, evaluation scale of 1 to 3 was used .1 represents highly suitable class, 2 moderately suitable classes, and 3 marginally suitable classes. In the weighted overlay analysis high weight (% of influence) was given for slope, since it is the determinant factor in the evaluation of the given area for surface irrigation development.

The general weighted overlay analysis result showed that about 25462.08 ha (71.4 %) was suitable and 10427.53 ha (28.6 %) of the total area was categorized under not suitable for surface irrigation. The area distribution of the suitability classes for surface irrigation over the Watershed is presented in Table 4.10 and Figure 4.7.

Table4. 10: Overall land suitability of surface irrigation

No	Suitability	Area (ha)	Area (%)
1	Highly suitable	17779.46	34.48
2	Moderately suitable	13681.62	36.94
3	Not suitable	10427.53	28.56

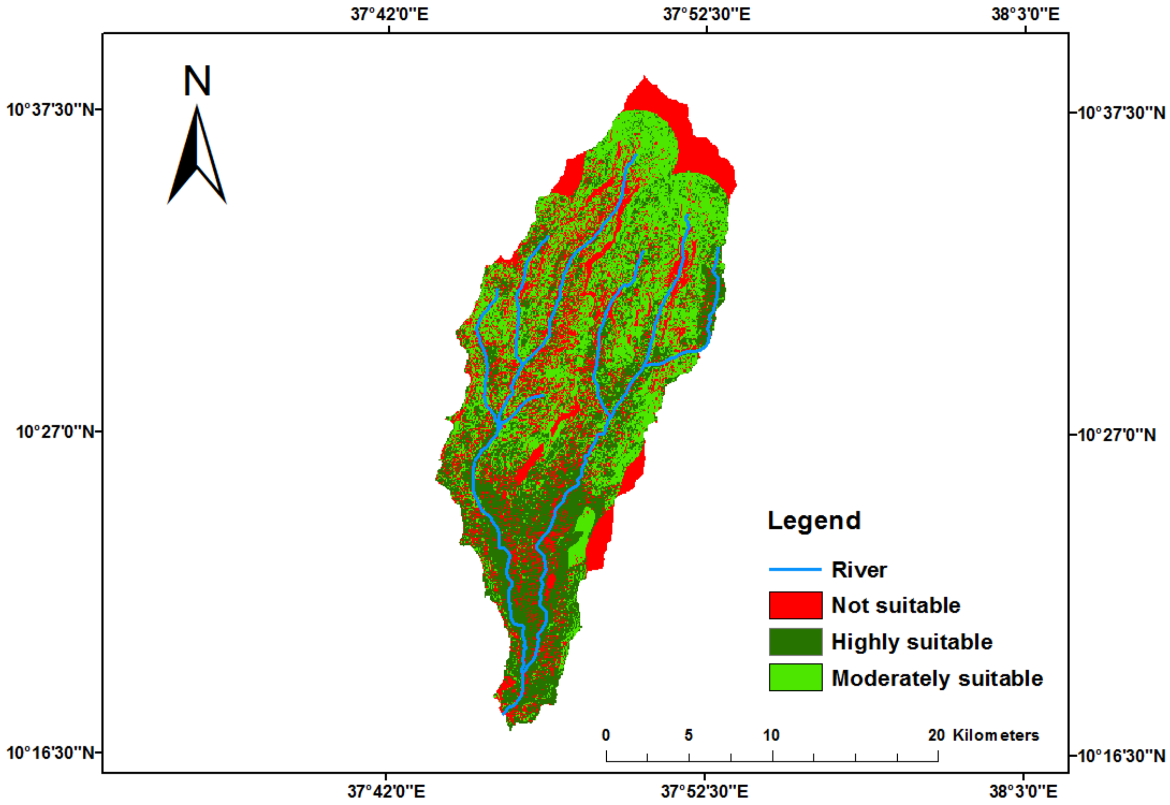

Figure4. 7: Overall land suitability for surface irrigation

Table4. 11: Overall land suitability of sub Watersheds

Sub Watrsheds	Suitability class	Area (ha)	Sub Watrsheds	Suitability Class	Area (ha)
1	Highly suitable	133.11	12	Highly suitable	63.36
	Moderately suitable	397.21		Moderately suitable	116.61
2	Highly suitable	256.74	13	Highly suitable	627.76
	Moderately suitable	39.72		Moderately suitable	123.53
3	Highly suitable	314.68	14	Highly suitable	1074.06
	Moderately suitable	592.62		Moderately suitable	999.42
4	Highly suitable	422.87	15	Highly suitable	899.95
	Moderately suitable	1125.08		Moderately suitable	308.93
5	Highly suitable	460.67	16	Highly suitable	560.04
	Moderately suitable	2062.20		Moderately suitable	236.94
6	Highly suitable	685.27	17	Highly suitable	461.64
	Moderately suitable	728.93		Moderately suitable	15.97

7	Highly suitable	817.95	18	Highly suitable	436.08
	Moderately suitable	3836.83		Moderately suitable	208.19
8	Highly suitable	655.55	19	Highly suitable	1438.04
	Moderately suitable	1013.26		Moderately suitable	117.14
9	Highly suitable	118.74	20	Highly suitable	359.41
	Moderately suitable	245.46		Moderately suitable	55.91
10	Highly suitable	203.40	21	Highly suitable	1291.20
	Moderately suitable	474.95		Moderately suitable	139.32063
11	Highly suitable	498.91			
	Moderately suitable	843.41			

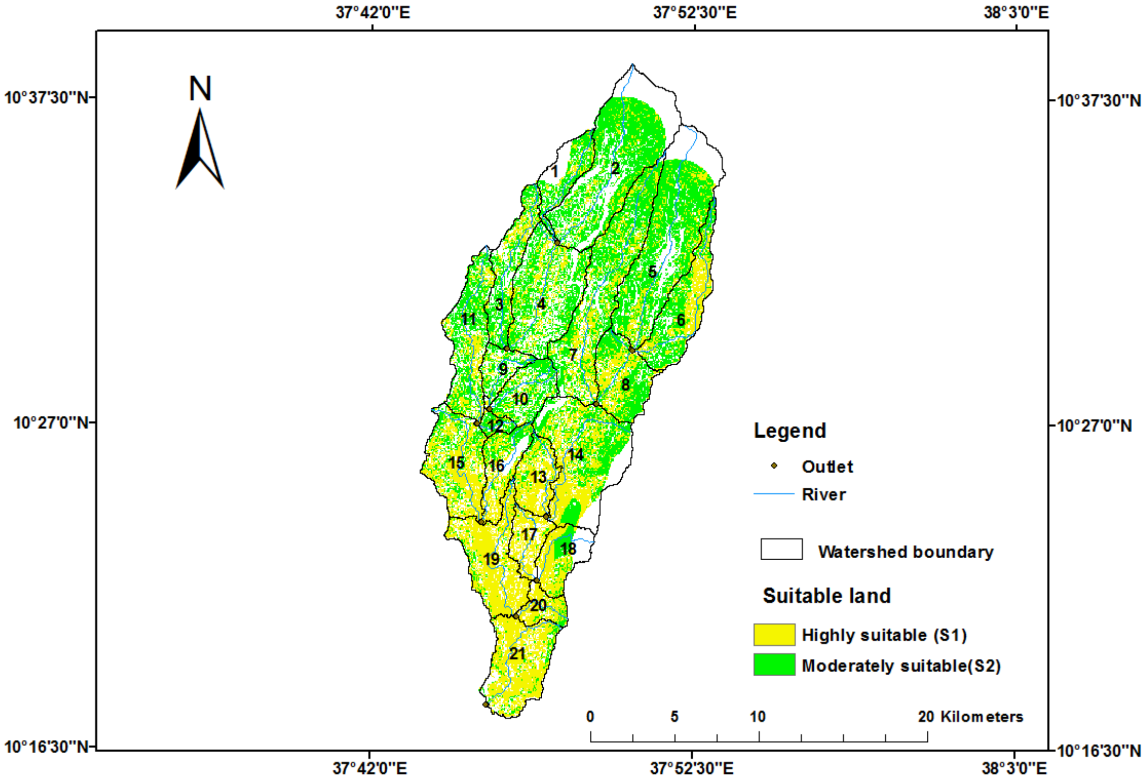

Figure4. 8: Over all land suitability map of sub Watersheds

4.3 Water availability

Water availability assessment has been analyzed from the simulated stream flow, realizing through Arc SWAT model in each sub watershed. The observed flow data wear used for calibration and validation by considering sensitivity parameters using SWAT CUP Sufi _2 software appendix.

The water availability assessment understands the potential of irrigation water supply in each sub basin obtained from SWAT simulated output.

Table4. 12: Mean monthly simulated flow (m^3/s)

Sub Watersheds	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1	0.087	0.069	0.213	0.161	0.223	0.339	0.735	0.888	0.681	0.488	0.295	0.169
2	0.377	0.245	0.563	0.766	0.865	1.698	3.522	3.748	2.689	1.819	0.918	0.596
3	0.116	0.084	0.180	0.294	0.395	0.557	1.132	1.241	0.905	0.588	0.334	0.226
4	0.633	0.502	1.004	1.713	2.156	3.238	6.273	6.603	4.640	3.129	1.862	1.237
5	0.498	0.497	0.711	0.791	1.048	1.995	3.786	3.562	2.648	1.592	1.038	0.706
6	0.154	0.120	0.234	0.319	0.392	0.754	1.487	1.695	1.194	0.769	0.439	0.299
7	0.302	0.223	0.423	0.589	0.730	1.280	2.756	3.126	2.322	1.576	0.918	0.597
8	0.627	0.403	0.950	1.208	1.487	2.863	6.157	6.679	4.855	3.212	1.746	1.204
9	0.771	0.607	1.250	1.707	2.138	3.753	7.734	8.096	5.785	3.880	2.184	1.515
10	0.095	0.064	0.123	0.161	0.245	0.433	0.859	0.917	0.681	0.438	0.271	0.172
11	0.209	0.146	0.253	0.390	0.421	1.067	1.829	2.850	1.315	1.521	0.567	0.429
12	0.865	0.695	1.453	2.033	2.516	4.331	9.124	9.866	7.210	4.542	2.782	1.861
13	0.192	0.058	0.063	0.118	0.175	0.331	0.633	0.903	1.914	0.600	0.348	0.196
14	1.590	1.035	1.669	2.356	2.921	5.204	10.773	12.788	9.710	6.436	3.809	3.093
15	1.301	0.940	1.868	2.638	3.298	5.985	11.670	13.745	10.402	6.528	4.059	2.906
16	0.091	0.047	0.213	0.123	0.188	0.379	0.717	0.974	0.849	0.586	0.327	0.171
17	1.227	0.850	1.759	2.467	3.595	6.809	11.888	12.927	10.760	6.655	4.576	3.088
18	0.092	0.053	0.088	0.119	0.198	0.345	0.679	0.909	0.812	1.182	0.608	0.718
19	1.695	1.180	2.043	2.737	3.779	6.939	13.843	15.914	12.724	8.063	5.146	3.439
20	1.595	1.017	1.841	2.809	3.593	6.627	13.174	15.595	12.727	8.568	4.808	3.227
21	3.158	2.597	4.363	6.300	8.946	15.948	29.090	32.007	26.804	16.914	9.525	6.211

4.3.1 Sensitivity analysis

Sensitivity analysis was carried to identify which model parameter is sensitive. Sensitivity analysis was carried out for a period of 13 years and 8 parameters were selected with different degree of sensitivity for flow.

Table4. 13: List of sensitive parameters

Parameter Name	Description	Fitted value	Min value	Max value	Rank
CN2	SCS runoff curve number (%)	42.45	30	90	1
ALPHA-BF	Base flow alpha factor (days)	0.707	0	1	2
GW-DELAY	Ground water delay (days)	131.8	30	450	3
EPCO	Plant uptake compensation factor	0.55	0	1	4
GWQMN	Threshold depth of water in the shallow aquifer required for return flow (mm)	0.325	0	2	5
ESCO	Soil evaporation compensation factor	0.278	0	0.5	6
REVAPMN	Threshold depth of water in the shallow aquifer for "revap" to occur	220	0	250	7
RCHRG-DP	Deep aquifer percolation fraction	0.66	0	1	8

The result of the sensitivity analysis showed that curve numbers (CN2), ALPHA-BF, GW-DELAY, and EPCO are identified as highly sensitive parameters. The result the analysis was found that curve number (CN2) is the most important factor influencing stream flow in the Chemoga Watershed.

4.3.2 SWAT model calibration and validation

The Calibration and Validation of the model have been conducted by using SWAT_CUP model. The performance measures which have been used in this model were the coefficient of determination (R^2) and Nash-Sutcliffe efficiency (NSE). The coefficient of determination (R^2) and Nash-Sutcliffe efficiency (ENS) values 0.86 and 0.7 for calibration, 0.74 and 0.63 for validation, respectively Table 4.13. Hence, the resulted value of coefficient of determination (R^2) between $R^2 > 0.6$ and Nash-Sutcliffe simulation (ENS) ENS >0.5 have been shown that model calibration and validation performance were confirmed. The observed and simulated comparison results are shown in the Figure 4.9 and 4.10 for the calibration model and validation model respectively. The model mostly under estimated and overestimated for some periods in calibration period.

Table4. 14: R^2 and ENS values both for calibration and validation

Period	Value	
	R^2	ENS
Calibration period (1988-2000)	0.86	0.7
Validation period (2001-2009)	0.74	0.63

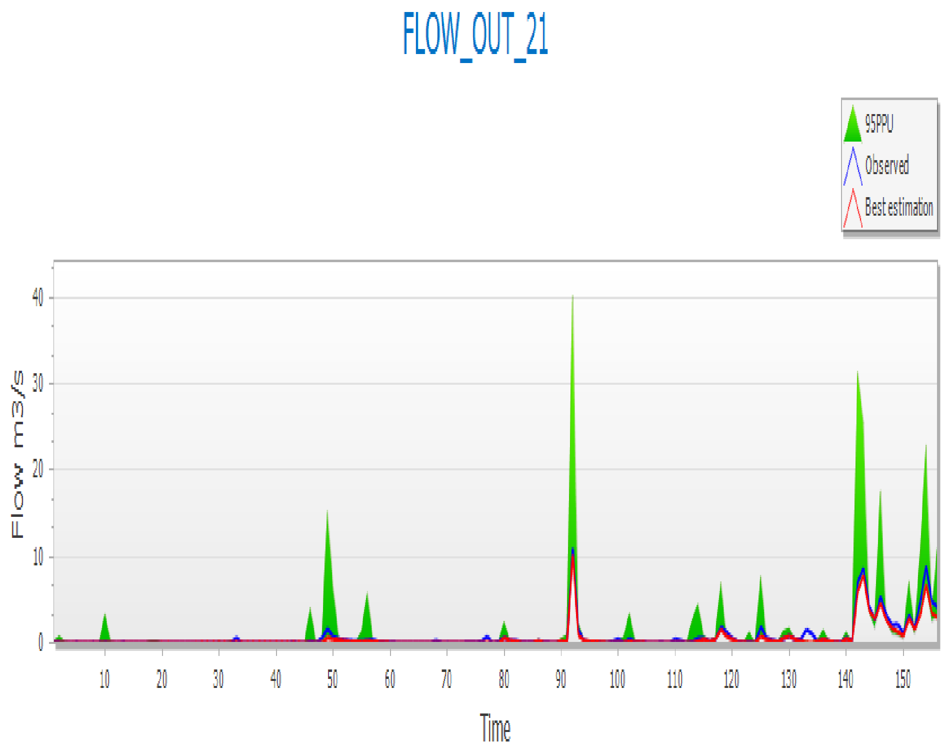

Figure4. 9: Comparison of observed and simulated discharge for the calibrated model

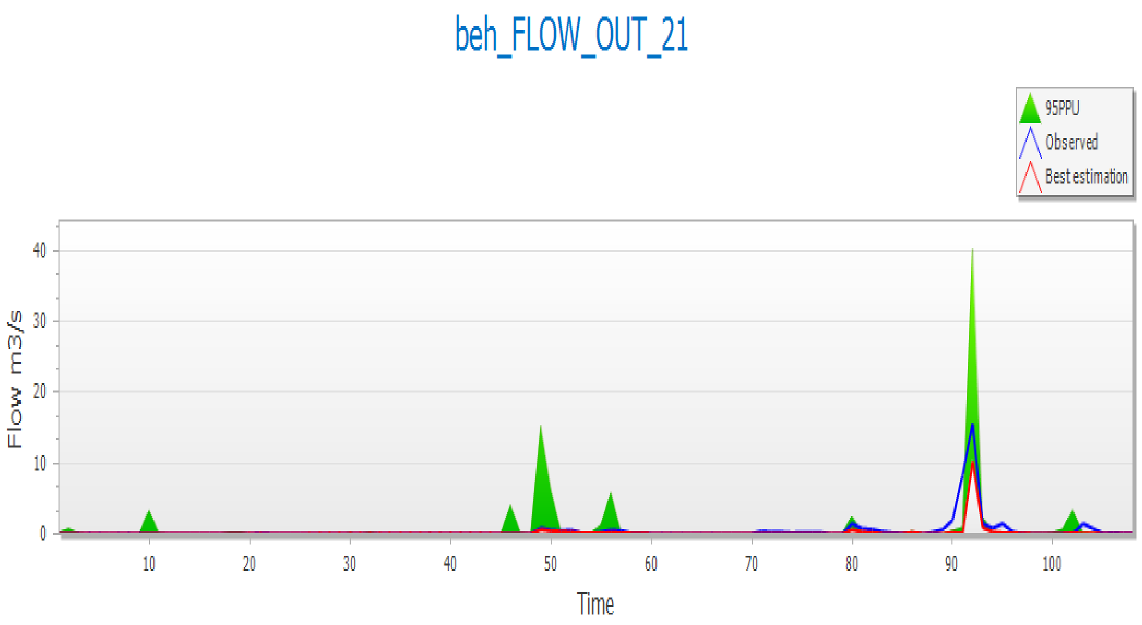

Figure4. 10: Comparison of observed and simulated discharge for the validated model

4.4 Irrigation Water Requirement

To evaluate the surface irrigation potential of the watershed knowing of the water demand by selected crops are essential. Determination of irrigation water requirement of the six selected crops (barley, wheat, bean, maize, potato and onion) in terms of water availability in the potential irrigable lands Debre Markos climatic station was selected to calculate irrigation water requirement of the identified irrigable area, because of having complete climatic records and can be represent the whole area of the Watershed.

Table4. 15: Monthly crop water requirement of selected crops in mm/ha

Months Type of crops	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Total
Barely	58.5	102.2	103.7	78.8	0	0	0	0	0	0	0	0	284.7
Wheat	42.6	12.8	10.8	43	0	0	0	0	0	0	0	0	109.2
Bean	55.6	97.7	31.2	0	0	0	0	0	0	0	0	0	184.5
Maize	54.1	71.4	95.7	117.9	114.4	100	0	0	0	0	0	0	553.5
Potato	37.2	84.9	102.3	39.4	0	0	0	0	0	0	0	0	263.8
Onion	72.4	105.1	106.1	132.2	102.2	0	0	0	0	0	0	0	518

Within the study area different crops have different crop water requirement. From the selected crops such as, barley, wheat, bean, maize, potato and onion, maize has needed the highest crop water requirement which recorded 553.6mm/growing period and Wheat has the minimum water requirement was evaluated 109.2mm/growing period Table 4.15.

4.4.1 Irrigation water potential estimation

The analysis was done by using the gross monthly irrigation requirement of the selected crops (barley, wheat, bean, maize, potato, and onion) and available minimum monthly flow.

From the overall suitability map of the Chemoga Watershed most of the area was identified under highly to moderately suitable. The result shows that the total irrigation water demand required by crops was 228.18 m^3/s/ ha with the total suitable land of 25462.08 ha of suitable land. But due to lack of available water the area that can be irrigate is only 12376 ha with in the total average annual flow of 36.2, m^3/s the comparison of available water and gross irrigation requirement showed that the gross crop water requirement of crops was greater than available flow.

Table4. 16: Comparisons of irrigation demand ($m^3/s/ha$) and available stream flow (m^3/s)

Sub - Watershed	Command area (ha)			Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov
1	34	Flow (m^3/s)		0.17	0.09	0.07	0.21	0.16	0.22	0.34	0.74	0.89	0.68	0.49	0.29
		GIR ($m^3/s/ha$)	Barley	0.16	0.14	0.15	0.13								
			Wheat	0.24	0.40	0.40									
			Bean	0.19	0.39	0.45	0.46								
			Maize	0.17	0.33	0.53	0.14								
			Potato	0.34	0.40	0.42	0.51	0.39							
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.45	2.06	2.37	1.74	0.77							
2	69	Flow(m^3/s)		0.60	0.38	0.24	0.56	0.77	0.87	1.70	3.52	3.75	2.69	1.82	0.92
		GIR (m3/s/ha)	Barley	0.24	0.43	0.41	0.30								
			Wheat	0.17	0.15	0.16	0.20								
			Bean	0.24	0.40	0.40									
			Maize	0.14	0.38	0.45	0.46	0.40							
			Potato	0.17	0.33	0.53	0.14								
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.31	2.10	2.37	1.61	0.79							
3	75	flow(m^3/s)		0.23	0.12	0.08	0.18	0.29	0.39	0.56	1.13	1.24	0.90	0.59	0.33
		GIR ($m^3/s/ha$)	Barley	0.24	0.43	0.41	0.30								
			Wheat	0.17	0.05	0.06	0.20								
			Bean	0.24	0.40	0.40									
			Maize	0.14	0.28	0.45	0.46	0.40							
			Potato	0.17	0.33	0.53	0.14								
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.31	1.90	2.27	1.61	0.79							
4	725	flow(m3/s)		1.24	0.63	0.50	1.00	1.71	2.16	3.24	6.27	6.60	4.64	3.13	1.86
		GIR ($m^3/s/ha$)	Barley	0.24	0.43	0.41	0.30								
			Wheat	0.17	0.15	0.16	0.20								
			Bean	0.24	0.40	0.40									
			Maize	0.14	0.38	0.45	0.46	0.40							
			Potato	0.17	0.33	0.53	0.14								
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.31	2.10	2.37	1.61	0.79							
5	744	flow(m3/s)		0.71	0.50	0.50	0.71	0.79	1.05	2.00	3.79	3.56	2.65	1.59	1.04
		GIR (m3/s/ha)	Barley	0.24	0.43	0.41	0.30								
			Wheat	0.17	0.15	0.16	0.20								
			Bean	0.24	0.40	0.40									
			Maize	0.14	0.38	0.45	0.46	0.40							
			Potato	0.17	0.33	0.53	0.14								
			Onion	0.34	0.34	0.34	0.34	0.39							
			Total	0.97	2.04	2.28	1.43	0.79							

6	147	flow(m3/s)		0.30	0.15	0.12	0.23	0.32	0.39	0.75	1.49	1.69	1.19	0.77	0.44
		GIR (m3/s/ha)	Barley	0.24	0.43	0.41	0.30								
			Wheat	0.17	0.15	0.16	0.20								
			Bean	0.24	0.40	0.40									
			Maize	0.14	0.38	0.45	0.46	0.40							
			Potato	0.17	0.33	0.53	0.14								
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.31	2.10	2.37	1.61	0.79							
7	914	Flow (m3/s)		0.60	0.30	0.22	0.42	0.59	0.73	1.28	2.76	3.13	2.32	1.58	0.92
		GIR (m3/s/ha)	Barley	0.24	0.43	0.41	0.30								
			Wheat	0.17	0.15	0.16	0.20								
			Bean	0.24	0.40	0.40									
			Maize	0.14	0.38	0.45	0.46	0.40							
			Potato	0.17	0.33	0.53	0.14								
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.31	2.10	2.37	1.61	0.79							
8	675	Flow(m3/s)		1.20	0.63	0.40	0.95	1.21	1.49	2.86	6.16	6.68	4.86	3.21	1.75
		GIR (m3/s/ha)	Barley	0.24	0.43	0.41	0.30								
			Wheat	0.17	0.15	0.16	0.20								
			Bean	0.24	0.40	0.40									
			Maize	0.14	0.38	0.45	0.46	0.40							
			Potato	0.17	0.33	0.53	0.14								
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.31	2.10	2.37	1.61	0.79							
9	196	flow(m3/s)		1.52	0.77	0.61	1.25	1.71	2.14	3.75	7.73	8.10	5.79	3.88	2.18
		GIR (m3/s/ha)	Barley	0.24	0.43	0.41	0.30								
			Wheat	0.17	0.05	0.06	0.20								
			Bean	0.24	0.40	0.40									
			Maize	0.14	0.28	0.45	0.46	0.40							
			Potato	0.17	0.33	0.53	0.14								
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.31	1.90	2.27	1.61	0.79							
10	678	Flow (m3/s)		0.17	0.10	0.06	0.12	0.16	0.25	0.43	0.86	0.92	0.68	0.44	0.27
		GIR (m3/s/ha)	Barley	0.24	0.43	0.41	0.30								
			Wheat	0.17	0.15	0.16	0.20								
			Bean	0.24	0.40	0.40									
			Maize	0.14	0.38	0.45	0.46	0.40							
			Potato	0.17	0.33	0.53	0.14								
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.31	2.10	2.37	1.61	0.79							

11	1342	Flow (m3/s		0.43	0.21	0.15	0.25	0.39	0.42	1.07	1.83	2.85	1.31	1.52	0.57
		GIR	Barley	0.24	0.43	0.41	0.30								
		(m3/s/ha)	Wheat	0.17	0.05	0.06	0.20								
			Bean	0.24	0.40	0.40									
			Maize	0.14	0.28	0.45	0.46	0.40							
			Potato	0.17	0.33	0.53	0.14								
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.31	1.90	2.27	1.61	0.79							
12	180	Flow (m3/s		1.86	0.87	0.70	1.45	2.03	2.52	4.33	9.12	9.87	7.21	4.54	2.78
		GIR	Barley	0.24	0.43	0.41	0.30	0.00							
		(m3/s/ha)	Wheat	0.17	0.15	0.16	0.20	0.00							
			Bean	0.24	0.40	0.40									
			Maize	0.14	0.38	0.45	0.46	0.40							
			Potato	0.17	0.33	0.53	0.14								
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.31	2.10	2.37	1.61	0.79							
13	751	flow (m3/s)		0.20	0.19	0.06	0.06	0.12	0.18	0.33	0.63	0.90	1.91	0.60	0.35
		GIR	Barley	0.24	0.43	0.41	0.30								
		(m3/s/ha)	Wheat	0.17	0.15	0.16	0.20								
			Bean	0.24	0.40	0.40									
			Maize	0.14	0.38	0.45	0.46	0.40							
			Potato	0.17	0.33	0.53	0.14								
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.31	2.10	2.37	1.61	0.79							
14	2073	Flow(m3/s)		3.09	1.59	1.04	1.67	2.36	2.92	5.20	10.77	12.79	9.71	6.44	3.81
		GIR	Barley	0.24	0.43	0.41	0.30								
		(m3/s/ha)	Wheat	0.17	0.15	0.16	0.20								
			Bean	0.24	0.40	0.40									
			Maize	0.14	0.38	0.45	0.46	0.40							
			Potato	0.17	0.33	0.53	0.14								
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.31	2.10	2.37	1.61	0.79							
15	1209	flow(m3/s		2.91	1.30	0.94	1.87	2.64	3.30	5.99	11.67	13.74	10.40	6.53	4.06
		GIR	Barley	0.31	0.48	0.46	0.35								
		(m3/s/ha)	Wheat	0.24	0.14	0.15	2.47								
			Bean	0.29	0.45	0.45									
			Maize	0.14	0.28	0.45	0.46	0.40							
			Potato	0.17	0.33	0.53	0.14								
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.26	2.08	2.46	1.46	0.79							
16	797	Flow (m3/s)		0.17	0.09	0.05	0.21	0.12	0.19	0.38	0.72	0.97	0.85	0.59	0.33
		GIR	Barley	0.24	0.43	0.41	0.30								
		(m3/s/ha)	Wheat	0.17	0.15	0.16	0.20								

			Bean	0.24	0.40	0.40									
			Maize	0.14	0.38	0.45	0.46	0.40							
			Potato	0.17	0.33	0.53	0.14								
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.31	2.10	2.37	1.61	0.79							
17	478	flow(m3/s)		3.09	1.23	0.85	1.76	2.47	3.60	6.81	11.89	12.93	10.76	6.65	4.58
		GIR(m3/s/ha)	Barley	0.31	0.48	0.46	0.35								
			Wheat	2.24	0.14	0.15	2.47								
			Bean	0.29	0.45	0.45									
			Maize	0.14	0.28	0.45	0.46	0.40							
			Potato	0.17	0.33	0.53	0.14								
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.26	2.08	2.46	1.46	0.79							
18	644	flow(m3/s)		0.72	0.09	0.05	0.09	0.12	0.20	0.35	0.68	0.91	0.81	1.18	0.61
		GIR (m3/s/ha)	Barley	0.21	0.09	0.10	0.25								
			Wheat	0.28	0.44	0.44									
			Bean	0.18	0.32	0.49	0.50	0.44							
			Maize	0.21	0.37	0.57	0.18								
			Potato	0.38	0.44	0.43	0.55	0.43							
			Onion	0.34	0.40	0.42	0.51	0.39							
			Total	1.61	2.06	2.44	1.98	1.26							
19	1555	flow(m3/s)		3.44	1.69	1.18	2.04	2.74	3.78	6.94	13.84	15.91	12.72	8.06	5.15
		GIR (m3/s/ha)	Barley	0.33	0.49	0.47	0.36								
			Wheat	0.17	0.15	0.16	0.20								
			Bean	0.31	0.46	0.46									
			Maize	0.20	0.34	0.31	0.52	0.46							
			Potato	0.23	0.39	0.59	0.20								
			Onion	0.37	0.46	0.48	0.57	0.47							
			Total	1.61	2.30	2.47	1.85	0.93							
20	415	flow(m3/s)		3.23	1.59	1.02	1.84	2.81	3.59	6.63	13.17	15.59	12.73	8.57	4.81
		GIR (m3/s/ha)	Barley	0.33	0.49	0.47	0.36								
			Wheat	0.23	0.39	0.59	0.20	0.23							
			Bean	0.31	0.46	0.46									
			Maize	0.20	0.34	0.31	0.52	0.46							
			Potato	0.23	0.39	0.59	0.20								
			Onion	0.37	0.46	0.48	0.57	0.47							
			Total	1.67	2.10	2.37	1.61	0.79							
21		flow(m3/s)		6.21	3.16	2.60	4.36	6.30	8.95	15.95	29.09	32.01	26.80	16.91	9.52
		GIR (m3/s/ha)	Barley	0.33	0.49	0.47	0.36								
			Wheat	0.17	0.15	0.16	0.20								

			Bean	0.31	0.46	0.46									
			Maize	0.20	0.34	0.31	0.52	0.46							
			Potato	0.23	0.39	0.59	0.20								
			Onion	0.37	0.46	0.48	0.57	0.47							
			Total	1.61	2.30	2.47	1.85	0.93							

Table4. 17: Summary of irrigation potential of Sub watersheds

Sub Watersheds	Irrigation potential in (ha)
1	34
2	69
3	75
4	725
5	744
6	147
7	914
8	675
9	196
10	38
11	176
12	114
13	43
14	1859
15	1074
16	47
17	413
18	63
19	1588
20	401
21	2979
Total	12376.03

The irrigation potential of streams in sub Watersheds obtained (Table 4.12) and the suitable land obtained (Table 4.11). Therefore, the irrigation potential of the Chemoga Watershed was found to be 12376.03 ha.

5. SUMMARY AND CONCLUSIONS

5.1 Summary

A representative irrigation water supply determination increases agricultural productivity and improve food security in the rural economy, thus developing irrigation infra-structure is important. However, this can be achieved by assessing available land and water resources for irrigation development. Surface irrigation potential in the Chemoga Watershed located in Upper Blue Nile Basin was assessed in this study. The finding of this study was evaluating surface irrigation potential of Chemoga Watershed which covers an area of 35889.16 ha by considering soil physical properties (soil texture, soil depth and soil drainage), slope, land use/cover, and river proximity using weighted overlay analysis on GIS based MCE. This is expected to reduce further if more factors are considered in the weighted evaluation process and may provide a better estimation of the land potential for surface irrigation.

Modeling available water resource and crop water demand for dominant crop by SWAT and CROPWAT model was done. The water resources availability tells that due to very high spatial and temporal variability of precipitation the stream flow is less than the crop water demand.

The long term measured flow data of Chemoga River which was obtained from Ministry of Water Irrigation and was Electricity used for SWAT-CUP model to do calibration and validation of the model. Model performance was confirmed in this study. The model result showed in the observed and simulated stream flow with Coefficient of determination (R^2) and Nash-Sutcliffe 0.86 and 0.7 for calibration, and 0.74 and 0.63 for validation respectively.

Irrigation water demand of dominant crop (barley, bean, wheat, maize, potato, and onion) during the growing season was estimated using the available climate data, average monthly simulated output flow, soil and crop pattern data of the study area were inputs for CROPWAT 8.0 software.

5.2 Conclusions

Surface irrigation land suitability analysis showed that 88.06 % of soil depth, 76.51% of slope, 80.3% land use/cover, and 98.65% river proximity of the study area were identified in the range of highly to marginally suitable whereas, 7.09% slope, 17.53% land use/cover, and 1.36% river proximity were classified as not suitable for surface irrigation. Based on the factors which were considered for land Suitability slope was the most important factor in terms of deterring the overall suitable land. The overall suitability of the area for surface irrigation, about 25462.08 ha (71.4 %) were in the range of highly to moderately suitable, whereas 10427.53 ha (28.6 %) were grouped as not suitable for surface irrigation development.

Surface irrigation potential was identified by comparing available stream flow and gross crop water requirement depending on sowing time was December. The result sowed that total irrigation water demand (water required by crops) was 228.18 m^3/s/ha. From the total suitable land of 25462.08 ha from only 12376.03 ha can be irrigable with the available monthly flow of 110$m^{3/}$s.

Recommendations

Based on the results of the study the following points are recommended for further considerations.

- In this study land suitability evaluation was in terms of slope, soil, land use/ land cover and distance from water source, but other factors should be assesses to get reliable result.
- Surface irrigation potential analysis result shows that only 25467.08 ha of the study area were suitable for surface irrigation. Further research is recommended to increase irrigable land by considering other irrigation methods.
- The analysis shows that the available water supply (stream flow) was less than irrigation water demand. So, constructions of different storage structures are recommended to increase surface irrigation potential.

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APPENDIXES

Appendix A: Meteorological data

1. Average monthly precipitation at Debre Markos station (mm)

Year	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC
1988	0.5	2.1	0.0	1.7	1.0	5.8	10.2	10.8	8.7	3.1	0.1	0.0
1989	0.2	0.8	4.6	3.0	0.8	5.4	11.5	10.7	6.8	0.3	0.3	2.8
1990	0.2	0.7	1.7	2.1	1.1	5.1	10.2	11.1	9.2	0.4	0.7	0.0
1991	0.3	0.2	3.1	2.3	3.8	6.1	7.5	10.1	5.6	2.0	1.1	1.6
1992	0.9	1.3	1.2	3.8	2.8	4.6	5.3	9.9	5.6	3.1	2.4	0.2
1993	0.3	1.0	1.2	5.0	5.9	7.0	9.9	9.8	10.7	5.1	0.2	0.0
1994	0.3	0.2	1.2	1.4	4.5	4.9	9.1	9.7	7.3	0.2	0.4	0.0
1995	0.0	0.0	0.7	3.0	4.7	4.2	7.9	10.2	5.0	0.5	0.2	3.1
1996	0.9	0.2	2.4	3.6	7.4	9.7	8.1	11.6	5.0	1.1	1.2	0.7
1997	0.5	0.0	1.0	3.3	4.0	5.1	9.3	10.9	6.9	5.9	2.9	0.2
1998	0.5	0.1	0.8	0.1	4.9	3.3	6.6	8.1	9.0	6.5	0.2	0.0
1999	2.3	0.0	0.1	1.4	1.6	6.0	8.1	11.0	5.5	6.8	0.1	0.9
2000	0.0	0.0	0.1	3.7	1.0	5.8	10.9	7.1	9.3	8.6	1.1	0.4
2001	0.0	0.1	2.0	3.5	4.2	5.5	11.8	10.7	6.3	2.3	0.0	0.1
2002	1.8	0.6	3.0	2.5	0.4	5.3	8.9	11.1	8.3	0.3	0.1	2.0
2003	0.1	2.1	2.3	0.6	0.2	7.2	7.1	11.3	8.8	0.3	0.0	0.7
2004	0.1	0.3	0.5	4.2	0.9	6.5	9.6	10.2	6.8	2.9	1.3	0.7
2005	0.1	0.0	3.6	1.7	1.6	5.3	10.4	8.5	8.0	2.9	1.4	0.0
2006	0.1	0.7	3.1	2.4	3.5	6.7	11.7	9.1	10.5	1.4	1.0	1.2
2007	0.6	0.0	2.6	2.5	5.2	6.4	8.7	10.8	9.1	1.2	0.0	0.0
2008	0.3	0.3	1.9	2.0	4.7	7.8	9.9	9.9	8.8	1.7	0.8	0.6
2009	0.4	0.8	1.6	0.8	0.7	4.2	9.1	20.0	4.3	3.8	0.4	0.6

2. Average mean monthly precipitation at Yejube station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	0.1	2.1	0.2	1.1	2.2	3.2	11.1	13.1	7.1	2.4	0.6	0.2
1989	0.1	0.2	3.7	1.8	4.3	3.0	8.2	10.5	4.8	2.6	0.6	0.2
1990	0.0	0.6	1.1	2.8	1.7	4.7	10.3	10.9	6.4	2.5	0.6	0.2
1991	0.3	0.1	1.1	2.2	3.6	7.6	13.2	15.4	6.7	0.1	0.0	0.2
1992	0.1	0.2	1.1	2.2	3.4	7.2	11.8	11.7	7.4	2.7	0.6	0.2
1993	0.2	0.2	1.1	2.2	3.5	7.2	11.2	11.5	7.4	2.7	0.6	0.2
1994	0.2	0.2	1.1	2.2	3.4	7.6	11.7	11.6	7.4	2.7	0.6	0.2
1995	0.1	0.2	1.1	2.2	3.6	7.2	11.7	11.6	7.4	2.7	0.6	0.2
1996	0.2	0.0	0.7	3.2	4.8	4.0	11.0	9.1	4.5	3.2	0.6	0.2
1997	0.2	0.0	1.7	5.0	5.6	10.2	11.8	8.8	5.8	5.0	0.9	0.2
1998	0.1	0.3	0.5	0.5	5.3	6.1	10.2	9.1	8.1	4.8	1.2	0.0
1999	0.6	0.0	0.0	1.3	1.5	7.0	11.4	10.8	4.4	5.9	0.2	0.0
2000	0.0	0.0	0.2	6.8	2.6	5.0	10.4	10.4	8.6	5.2	1.3	1.0
2001	0.0	0.0	2.7	0.2	7.1	8.5	10.6	8.1	3.8	2.4	0.0	0.2
2002	0.1	0.0	2.8	0.7	1.0	8.2	7.5	5.8	5.0	0.0	0.0	1.0

2003	0.0	1.3	1.3	0.8	0.0	7.9	10.5	13.2	8.3	2.0	0.6	0.1
2004	0.1	0.3	0.4	2.4	1.1	7.7	11.5	11.2	4.3	2.0	0.8	0.1
2005	0.1	0.3	3.9	2.2	1.1	11.0	17.5	13.4	8.6	2.0	0.6	0.1
2006	0.2	0.2	0.8	2.2	3.6	8.6	13.1	11.2	13.4	1.6	0.3	0.1
2007	0.1	0.5	1.5	2.7	5.6	5.5	9.7	8.5	8.2	2.5	0.0	0.0
2008	0.0	0.0	0.0	1.3	8.8	12.2	18.6	20.6	15.4	3.4	2.9	0.0
2009	0.1	0.5	0.4	2.2	3.4	5.7	14.1	13.5	7.2	3.3	0.1	0.5

3. Average mean monthly precipitation at Debre Elias station (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	0.8	1.3	0.1	0.1	3.2	5.4	9.1	10.9	10.6	3.9	0.0	0.0
1989	0.0	0.1	3.3	2.6	2.6	6.9	12.3	7.2	9.8	0.6	0.0	0.0
1990	0.3	0.4	0.7	1.5	2.3	8.7	10.4	11.2	11.5	0.2	0.4	0.0
1991	0.0	0.1	0.9	1.6	0.5	11.0	9.3	11.8	11.9	0.2	0.1	0.7
1992	0.3	0.2	1.2	2.4	2.4	2.5	10.2	8.9	10.7	7.3	1.8	0.7
1993	0.4	0.6	1.9	4.8	6.1	7.6	16.4	13.8	12.4	6.3	0.5	0.0
1994	0.2	0.4	1.3	0.8	4.2	6.2	15.1	10.7	8.4	0.2	1.1	0.0
1995	0.0	0.0	1.2	2.4	3.0	6.9	9.3	10.8	8.6	1.3	0.2	1.3
1996	0.3	0.0	0.0	1.4	2.9	4.7	11.1	14.5	6.2	0.5	0.0	0.0
1997	0.1	0.0	0.0	1.2	1.2	9.0	13.6	12.5	11.0	0.0	0.0	0.0
1998	0.1	0.0	0.0	0.0	3.6	9.5	13.8	11.4	11.1	0.0	0.0	0.0
1999	0.1	0.0	0.0	0.0	0.2	8.6	13.1	11.6	9.7	0.0	0.0	0.0
2000	0.8	1.3	0.0	0.1	3.2	5.4	13.5	10.9	10.4	0.0	0.0	0.0
2001	0.0	0.0	0.0	0.4	1.1	8.6	12.5	13.6	15.7	0.0	1.4	0.0
2002	0.3	0.2	1.2	2.4	2.4	9.1	10.2	9.1	11.5	7.4	1.8	0.7
2003	0.4	0.6	1.9	5.1	6.1	16.6	18.6	18.8	14.5	0.2	0.1	0.0
2004	0.1	0.4	0.5	3.8	1.6	5.2	11.3	10.6	15.0	5.3	2.1	0.0
2005	0.0	0.1	2.4	1.2	1.9	8.0	9.8	10.2	11.2	6.8	0.8	0.0
2006	0.0	0.2	1.3	0.8	3.8	11.0	14.0	14.5	1.8	0.0	0.0	0.0
2007	0.0	0.5	0.8	2.0	6.8	9.3	12.5	13.9	6.1	3.9	0.0	0.0
2008	0.2	0.0	0.3	3.4	4.8	10.2	16.3	13.6	8.2	5.4	2.4	0.0
2009	0.4	0.0	1.5	0.0	0.7	2.2	9.9	13.1	7.9	5.0	0.2	0.2

4. Average mean monthly precipitation at Dembecha station (mm)

year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	0.4	1.2	0.2	0.3	3.0	4.0	18.6	9.6	3.3	0.8	0.2	0.0
1989	0.1	0.1	1.6	2.8	1.5	7.0	10.9	9.3	0.7	0.1	0.0	0.1
1990	0.0	0.0	0.0	0.0	0.0	3.8	10.6	10.5	7.4	0.7	0.7	0.0
1991	0.2	0.3	0.4	0.3	1.3	9.3	11.3	5.5	4.4	3.8	0.6	0.0
1992	0.6	0.3	1.6	0.9	2.8	8.0	9.7	9.7	5.9	6.0	0.9	0.9
1993	0.1	0.1	1.7	4.0	4.0	8.6	11.0	9.1	10.1	5.0	3.4	0.0
1994	0.0	0.0	0.9	0.6	4.4	11.7	14.1	9.8	6.2	0.9	1.9	0.0
1995	0.0	0.0	0.2	5.3	4.0	9.1	10.6	9.0	6.2	0.6	1.1	1.2
1996	0.6	0.2	2.6	2.4	6.2	13.5	17.6	6.9	4.5	0.6	2.6	0.2
1997	0.1	0.0	1.6	2.7	6.3	9.4	7.7	9.2	9.1	5.6	3.1	0.6
1998	0.3	0.0	2.1	0.0	3.0	9.0	12.2	12.1	7.6	5.3	0.8	0.0
1999	1.5	0.0	0.0	1.5	2.8	6.5	13.5	8.9	11.2	7.6	1.3	0.4
2000	0.1	0.0	0.0	2.0	0.8	8.1	9.3	7.0	10.7	7.3	5.1	0.3

2001	0.0	0.4	4.0	1.7	6.7	6.7	11.9	13.8	5.9	3.3	1.0	0.6
2002	0.8	0.3	1.9	0.5	0.4	6.6	9.5	9.3	5.3	0.7	0.0	2.3
2003	0.0	0.5	1.5	0.7	0.1	8.3	11.9	8.8	7.5	4.1	0.2	0.2
2004	0.1	0.1	0.9	2.8	0.7	7.0	10.2	7.2	6.1	1.9	1.8	0.0
2005	0.3	0.0	2.7	0.5	1.6	5.3	14.1	9.2	6.4	2.5	1.5	0.4
2006	0.0	0.2	1.5	0.4	3.9	7.9	13.6	10.7	8.2	3.6	3.7	0.1
2007	0.0	0.0	0.9	2.6	6.4	8.1	9.7	9.8	9.0	2.9	1.0	0.0
2008	0.7	0.0	0.0	2.1	7.3	8.3	9.5	9.5	6.6	2.8	1.5	0.1
2009	0.0	0.7	2.1	0.0	0.0	5.4	10.7	12.5	4.6	3.6	0.5	0.2

5. Average monthly maximum temperature at Debre Markos station (^{o}c)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	24.6	24.4	26.7	26.3	25.8	20.8	18.0	18.9	19.7	21.1	21.8	22.6
1989	23.3	23.7	23.6	22.4	23.2	20.5	18.5	19.1	20.2	21.5	23.3	22.0
1990	23.7	24.4	25.1	25.0	24.9	21.3	18.7	18.8	19.9	21.8	23.3	24.0
1991	24.7	25.4	24.8	24.7	23.4	20.7	18.0	18.6	20.4	22.0	22.9	22.6
1992	22.7	23.6	25.6	24.8	23.5	20.3	18.2	17.7	19.4	20.6	21.2	23.3
1993	23.7	23.8	25.8	23.9	22.7	20.5	19.5	19.4	20.2	21.9	23.5	24.3
1994	25.4	26.3	25.5	26.0	24.0	20.3	18.9	18.7	20.7	23.1	24.1	24.9
1995	25.5	26.4	26.7	25.4	23.6	22.3	18.4	19.2	21.0	23.0	24.4	24.1
1996	23.5	25.6	25.1	24.3	22.7	19.5	19.1	19.0	20.6	22.2	22.7	22.4
1997	23.4	25.3	25.9	24.2	23.8	21.2	18.9	19.7	21.6	22.0	22.0	23.2
1998	24.2	25.4	26.1	27.8	24.5	21.4	18.9	18.6	20.2	20.5	21.9	22.8
1999	22.8	25.5	25.8	26.0	24.4	21.1	18.1	18.4	20.4	20.2	22.1	22.4
2000	24.3	25.7	27.3	23.8	24.6	21.3	19.0	18.8	20.5	21.0	21.8	23.2
2001	23.6	25.6	23.9	25.3	23.6	20.0	19.3	18.9	21.5	21.8	22.8	23.7
2002	23.5	25.6	25.4	25.8	26.6	21.4	20.1	19.2	20.8	23.0	24.0	23.5
2003	24.2	24.9	25.0	26.0	27.9	21.4	18.2	18.9	20.2	22.2	23.4	23.8
2004	24.7	25.6	26.0	24.7	25.6	21.1	19.0	19.4	20.2	21.4	23.1	23.7
2005	24.0	27.3	26.0	25.6	25.4	21.8	19.1	19.7	20.5	21.3	22.4	23.6
2006	23.3	25.5	25.5	25.1	24.0	21.1	19.4	19.0	20.1	22.7	23.3	21.6
2007	22.6	24.5	26.5	25.2	24.1	20.4	19.1	19.4	20.4	31.8	23.9	24.0
2008	24.8	25.5	26.9	26.2	23.1	20.8	19.7	19.2	21.2	22.0	22.1	23.3
2009	24.2	25.8	26.8	26.5	26.6	23.9	19.2	18.6	21.6	21.9	23.6	23.5

6. Average monthly minimum temperature at Debre Markos station (^{o}C)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	9.9	11.4	12.0	12.3	12.3	10.9	10.7	10.8	10.5	10.1	5.9	6.1
1989	5.9	8.0	8.9	9.0	9.5	8.7	9.0	8.8	8.7	7.8	7.1	8.8
1990	7.9	9.0	9.7	10.3	11.2	9.8	10.3	10.1	9.7	8.8	9.1	8.3
1991	9.9	9.8	11.3	11.8	11.6	10.9	11.3	10.9	10.4	9.4	8.5	8.6
1992	9.4	9.8	12.0	12.0	12.5	10.9	10.7	11.0	10.0	10.1	8.8	8.9
1993	8.5	9.5	10.8	11.3	11.3	10.7	10.7	11.0	9.9	10.0	8.8	8.6
1994	9.1	10.0	11.0	12.3	11.5	11.1	11.0	10.9	10.1	9.6	9.4	8.3
1995	9.1	10.8	10.8	12.6	12.3	10.6	11.4	10.9	9.8	9.7	9.2	9.6

1996	9.9	10.3	11.5	11.9	11.1	11.1	10.9	11.0	10.4	9.0	9.0	9.0
1997	9.2	9.9	11.7	11.7	11.5	11.2	11.1	10.9	10.5	10.9	10.7	9.3
1998	9.7	10.7	12.7	13.6	12.8	10.7	11.4	11.7	10.7	10.8	8.1	7.5
1999	8.9	10.5	10.2	12.5	11.3	10.2	10.7	10.5	9.8	10.0	7.6	8.0
2000	8.7	10.1	11.6	11.4	10.9	10.5	10.6	10.6	10.3	10.2	8.7	7.6
2001	7.8	10.1	11.0	12.0	11.5	10.7	10.8	11.3	10.1	10.4	8.4	9.0
2002	9.4	10.7	11.3	12.0	12.4	11.1	11.0	10.6	10.1	9.9	10.0	9.5
2003	9.4	10.2	11.3	12.1	14.0	10.8	11.5	11.2	10.5	9.6	9.5	8.7
2004	9.5	10.2	11.8	12.4	11.8	11.3	10.7	10.7	10.0	8.9	9.0	8.8
2005	8.6	11.3	11.5	13.5	12.0	11.2	11.1	11.2	11.0	9.7	8.8	7.4
2006	9.2	10.3	11.5	12.0	11.6	10.9	11.5	11.3	10.5	10.7	9.3	8.7
2007	8.2	9.5	11.7	12.5	12.2	11.4	11.2	11.1	11.2	9.5	9.1	7.6
2008	10.0	10.6	12.0	12.8	11.8	10.8	11.0	11.0	10.3	10.3	8.7	8.6
2009	9.2	11.4	11.8	12.5	12.5	11.3	11.6	11.5	10.5	10.2	8.3	9.7

7. Average monthly wind speed at 2m at Debere Markos station (m/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	1.2	1.4	1.4	1.4	1.4	1.2	1.2	1.0	1.0	1.1	1.1	1.1
1989	1.6	1.4	1.3	1.5	1.5	1.5	1.6	1.4	1.4	1.4	1.5	1.3
1990	1.3	1.4	1.3	1.3	1.6	1.4	1.1	1.0	1.1	1.4	1.1	1.2
1991	1.2	1.3	1.5	1.5	1.4	1.3	1.2	1.0	1.1	1.3	1.1	1.4
1992	1.3	1.1	1.3	1.2	1.3	1.2	1.0	1.0	1.0	1.1	1.1	1.1
1993	1.3	1.5	1.5	1.5	1.4	1.3	1.2	1.1	1.1	1.2	1.2	1.2
1994	1.2	1.2	1.2	1.3	1.2	1.0	0.9	0.9	1.1	1.5	1.1	1.2
1995	1.2	1.2	1.3	1.2	1.2	1.1	0.9	0.9	0.9	1.3	0.9	1.0
1996	1.0	1.1	1.2	1.2	1.1	1.0	1.1	1.1	1.1	1.4	1.3	1.2
1997	1.2	1.7	1.6	1.4	1.5	1.3	1.1	1.1	1.3	1.5	1.1	1.1
1998	1.3	1.3	1.5	1.6	1.3	1.3	1.1	1.1	1.0	1.2	1.4	1.5
1999	1.4	1.8	1.5	1.7	1.4	1.3	1.3	1.2	1.1	1.0	1.3	1.1
2000	1.3	1.5	1.5	1.7	1.4	1.3	1.3	1.2	1.1	1.2	1.2	1.0
2001	1.1	1.3	1.4	1.6	1.2	1.2	1.1	1.0	1.1	1.2	1.3	1.3
2002	1.2	1.5	1.3	1.7	1.3	1.2	1.3	1.2	1.3	1.6	1.4	1.2
2003	1.3	1.5	1.6	1.4	1.5	1.3	1.3	1.2	1.1	1.3	1.1	1.0
2004	1.2	1.4	1.4	1.5	1.4	1.3	1.3	1.2	1.1	1.2	1.3	1.3
2005	1.2	1.4	1.4	1.5	1.4	1.3	1.3	1.2	1.1	1.2	1.3	1.3
2006	1.4	1.4	1.5	1.4	1.5	1.2	1.2	1.2	1.0	1.1	1.0	1.2
2007	0.9	1.0	1.6	1.6	1.4	1.2	1.3	1.1	1.1	1.4	1.4	1.3
2008	1.4	1.7	1.6	1.8	1.5	1.3	1.4	1.3	1.2	1.3	1.2	1.2
2009	1.3	1.4	1.5	1.6	1.9	1.5	1.9	1.0	1.1	1.2	1.2	1.1

8. Average monthly sunshine hour at Debre Markos station (hours)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	8.8	8.8	7.6	7.0	8.8	5.2	3.2	8.8	8.8	7.8	8.8	8.8
1989	8.8	8.8	7.6	7.0	8.8	5.2	3.2	8.8	8.8	7.8	8.8	8.8
1990	8.4	8.5	8.6	6.8	8.1	6.4	4.2	4.8	6.5	9.7	8.0	10.3
1991	8.9	9.1	7.7	6.9	6.8	5.4	3.3	3.7	6.6	8.9	8.7	8.5
1992	7.6	7.7	7.7	6.9	8.3	7.0	3.8	2.5	5.9	6.8	6.8	8.5
1993	9.2	7.6	8.3	7.0	7.0	6.3	2.9	3.0	4.9	7.7	9.2	9.6
1994	9.5	9.5	7.4	7.5	8.3	4.1	3.3	3.4	7.1	10.0	8.7	10.5
1995	9.8	9.2	8.9	6.2	7.6	6.9	3.1	4.0	6.6	8.9	8.2	8.3
1996	7.8	9.0	7.3	7.1	6.6	3.8	3.9	4.2	5.8	9.2	8.5	8.0
1997	8.0	10.3	8.1	7.0	8.5	5.8	3.6	4.8	8.0	7.7	7.7	9.6
1998	9.2	8.4	6.9	7.8	6.7	5.9	3.5	3.2	5.9	5.9	10.0	10.8
1999	9.2	10.8	9.7	7.4	7.5	5.3	3.3	4.0	6.3	5.7	10.5	9.3
2000	10.3	10.4	9.4	6.8	7.2	6.0	4.0	3.4	6.2	6.8	8.6	9.4
2001	9.8	9.3	6.0	8.0	6.5	4.9	3.3	3.5	7.4	7.5	8.9	9.5
2002	8.0	9.1	7.9	7.3	7.0	5.8	5.5	3.9	7.6	9.6	9.7	8.7
2003	9.6	9.2	7.8	8.4	7.1	5.1	2.7	3.3	5.5	9.1	9.5	10.1
2004	9.4	9.5	7.4	6.3	8.0	4.6	3.9	4.0	5.4	8.1	8.8	9.3
2005	9.2	9.9	8.5	7.6	7.5	5.3	3.4	4.0	6.3	8.1	9.5	10.5
2006	10.0	9.8	7.9	7.1	6.9	5.1	3.4	3.3	5.1	7.8	9.3	10.0
2007	9.0	8.5	9.0	6.9	6.8	4.8	3.3	4.1	3.8	11.8	9.9	10.5
2008	10.1	10.0	9.3	9.7	10.1	5.3	3.3	4.8	6.5	7.1	8.0	9.0
2009	8.7	8.4	8.4	7.9	8.2	6.6	2.7	6.1	6.0	7.9	9.7	7.8

9. Average monthly Relative humidity at Debre Markos station (%)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	48	54	42	42	55	77	83	87	83	66	48	39
1989	41	45	52	61	63	81	86	84	77	57	41	61
1990	48	53	48	52	51	73	85	87	81	52	53	36
1991	41	34	39	45	55	74	87	87	75	51	46	44
1992	47	47	45	49	56	79	86	88	77	67	56	54
1993	45	46	38	55	68	80	87	85	89	66	50	41
1994	39	36	40	44	54	72	80	79	72	55	45	39
1995	32	32	34	54	61	72	89	91	79	52	50	50
1996	52	37	51	56	67	84	85	86	74	55	48	48
1997	49	26	41	53	59	73	85	84	70	63	66	52
1998	48	40	44	35	57	77	86	88	82	74	48	31
1999	40	22	28	37	55	70	77	84	76	73	43	47
2000	32	21	26	53	56	76	85	86	79	70	56	46
2001	38	36	47	46	63	80	85	86	72	63	49	40
2002	48	35	49	43	41	73	84	86	73	47	39	48
2003	38	32	39	43	29	74	85	86	80	52	43	40
2004	37	30	40	52	49	76	85	85	78	59	53	48

2005	43	29	47	47	50	72	84	84	79	67	54	34
2006	36	38	50	49	60	78	85	86	80	52	49	36
2007	39	38	37	53	63	81	86	85	81	52	42	34
2008	35	29	21	41	68	81	85	86	76	63	58	49
2009	40	39	37	38	33	59	82	81	70	54	34	44

10. Average monthly flow of Chemoga River (m3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	0.275	0.336	0.130	0.041	0.071	0.470	7.919	48.147	19.643	6.826	1.059	0.310
1989	0.180	0.290	0.210	1.060	0.290	0.470	17.950	27.360	9.410	1.920	0.220	0.610
1990	0.400	0.190	0.050	0.160	0.270	0.160	16.360	24.010	12.220	3.750	0.560	0.440
1991	0.160	0.210	0.300	0.390	1.120	5.810	37.500	50.310	14.650	1.300	0.570	0.750
1992	0.280	0.660	0.710	0.500	0.390	0.530	8.390	22.290	23.300	3.660	1.860	0.570
1993	0.470	0.450	0.190	1.830	4.510	9.320	21.090	39.130	28.570	6.210	1.540	0.560
1994	0.240	0.130	0.030	0.110	0.310	0.500	7.690	19.830	0.800	0.360	0.040	0.000
1995	0.000	0.060	0.070	0.320	0.940	0.430	9.910	21.030	10.100	1.360	0.350	0.760
1996	0.940	0.430	0.300	2.170	3.910	5.670	17.310	21.880	10.950	1.840	0.860	0.510
1997	0.300	0.050	0.050	0.180	0.230	1.450	12.050	20.960	7.470	3.920	2.890	0.950
1998	0.520	0.200	0.200	0.030	0.890	1.390	14.610	17.440	13.360	13.250	1.240	0.290
1999	0.210	0.060	0.010	0.010	0.050	1.020	15.180	29.170	12.430	13.340	1.000	0.360
2000	0.170	0.050	0.020	0.090	0.330	0.310	11.820	23.350	24.310	11.010	4.020	0.670
2001	0.240	0.180	0.220	0.160	0.400	2.450	21.550	33.990	6.240	1.650	0.470	0.280
2002	0.590	0.110	0.470	0.450	0.070	0.920	1.870	20.210	20.140	1.600	1.610	1.530
2003	0.080	0.210	0.620	0.590	0.550	0.540	10.890	21.880	15.600	2.250	0.330	0.190
2004	0.090	0.050	0.110	0.350	0.480	0.940	13.500	22.730	8.910	4.360	0.480	0.340
2005	0.210	0.090	0.380	0.210	0.220	2.070	12.880	12.390	12.500	2.050	0.450	0.230
2006	0.130	0.090	0.150	0.570	0.260	1.210	14.060	21.460	14.370	1.120	0.410	0.280
2007	0.300	0.190	0.240	0.220	0.230	2.440	12.260	17.200	12.420	4.460	0.360	0.190
2008	0.100	0.030	0.010	0.260	0.660	1.960	8.390	15.590	8.300	0.870	1.490	0.320
2009	0.100	0.050	0.080	0.060	0.070	0.130	6.190	20.380	4.640	2.880	0.100	0.120
Mean	0.270	0.180	0.210	0.460	0.770	1.890	13.880	23.930	12.890	3.960	0.990	0.470
Max	0.940	0.660	0.710	2.170	4.510	9.320	37.500	50.310	28.570	13.340	4.020	1.530
Min	0.000	0.030	0.010	0.010	0.050	0.130	1.870	12.390	0.800	0.360	0.040	0.000
STDEV	0.215	0.162	0.198	0.569	1.184	2.318	7.223	8.477	6.706	3.882	0.991	0.339

Appendix B: PCP and Dew point out put

Statistical Analysis of Daily Precipitation Data (1988 - 2009)

Input Filename = pcpp.txt

Number of Years = 22

Number of Leap Years = 6

Number of Records = 8036

Number of No Data values =4

Month	PCP_MM	PCPSTD	PCPSKW	PR_W1	PR_W2	PCPD
Jan	14.13	2.4164	8.8348	0.0672	0.4306	3.27
Feb	14.36	2.1682	5.9213	0.0657	0.4189	3.36
Mar	51.91	4.3525	4.4894	0.1738	0.6444	10.86
Apr	70.38	5.3605	4.3717	0.2618	0.6711	13.68
May	92.30	5.6810	3.0046	0.2451	0.7090	14.68
Jun	177.98	6.7888	2.0374	0.6897	0.8656	26.05
Jul	283.48	9.0029	2.1202	0.8421	0.9442	30.14
Aug	327.79	11.4091	2.7300	0.8387	0.9263	29.59
Sep	223.09	9.1423	2.1505	0.5725	0.8065	23.73
Oct	85.96	6.7531	3.7952	0.1329	0.6726	10.14
Nov	22.36	3.0389	6.4766	0.0982	0.4300	4.55
Dec	22.46	3.2050	6.7119	0.0759	0.5392	4.64

PCP_MM = average monthly precipitation [mm]

PCPSTD = standard deviation

PCPSKW = skew coefficient

PRW1 = probability of a wet day following a dry day

PRW2 = probability of a wet day following a wet day

PCPD = average number of days of precipitation in month

(Written by Stefan Liersch, Berlin, August 2003)

This file has been generated by the program 'dew02.exe'

Input Filename = dew.txt

Number of Years = 22

Number of Records = 8036

Number of No Data Values

tmp max = 1

tmp_min = 0

hmd = 0

Average Daily Dew Point Temperature for Period (1988 - 2009)

Month	tmp _max	tmp_ min	hmd	dewpt
Jan	23.94	8.97	41.59	4.17
Feb	25.29	10.19	36.32	3.16
Mar	25.73	11.28	40.74	5.28
Apr	25.21	12.02	48.34	7.88
May	24.46	11.81	56.67	9.71
Jun	21.06	10.78	74.97	11.88
Jul	18.87	10.93	84.33	12.65
Aug	18.96	10.87	85.78	12.97
Sep	20.51	10.21	78.65	12.27
Oct	21.78	9.80	59.68	8.49
Nov	22.89	8.73	49.30	6.03
Dec	23.29	8.49	43.89	4.49

tmp_max = average daily maximum temperature in month [°C]

tmp_min = average daily minimum temperature in month [°C]

hmd = average daily humidity in month [%]

dewpt = average daily dew point temperature in month [°C]

(Written by Stefan Liersch, August, 2003)

Weather generator input parameters for Debre Markos station

Parameters	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
TMPMX	23.94	25.29	25.73	25.21	24.46	21.06	18.87	18.96	20.51	21.78	22.89	23.29
TMPMN	8.97	10.19	11.28	12.02	11.81	10.78	10.93	10.87	10.21	9.80	8.73	8.49
TMPSTDMX	0.80	0.90	0.93	1.13	1.37	0.90	0.57	0.45	0.59	2.27	0.87	0.81
TMPSTDMN	0.92	0.79	0.84	0.97	0.87	0.60	0.54	0.59	0.51	0.73	0.98	0.84
PCPMM	14.13	14.36	51.91	70.38	92.30	177.98	283.48	327.79	223.09	85.96	22.36	22.46
PCPSTD	2.42	2.17	4.35	5.36	5.68	6.79	9.00	11.41	9.14	6.75	3.04	3.21
PCPSKW	8.83	5.92	4.49	4.37	3.00	2.04	2.12	2.73	2.15	3.80	6.48	6.71
PRW1	0.07	0.07	0.17	0.26	0.25	0.69	0.84	0.84	0.57	0.13	0.10	0.08
PRW2	0.43	0.42	0.64	0.67	0.71	0.87	0.94	0.93	0.81	0.67	0.43	0.54
PCPD	3.27	3.36	10.86	13.68	14.68	26.05	30.14	29.59	23.73	10.14	4.55	4.64
RAINHHM	7.07	7.18	25.96	35.19	46.15	88.99	141.74	163.90	111.55	42.98	11.18	11.23
SOLARAV	9.05	9.18	8.06	7.30	7.65	5.49	3.49	4.35	6.41	8.17	8.90	9.35
DEWPT	4.17	3.16	5.28	7.88	9.71	11.88	12.65	12.97	12.27	8.49	6.03	4.49
WNDAV	1.24	1.37	1.43	1.48	1.39	1.26	1.24	1.12	1.11	1.26	1.20	1.20

Appendix C:Crop water requirements

ETo and climatic data for Debre Markos station

Monthly ETo Penman-Monteith - C:\Users\ErMi MoBiLe\Desktop\THESIS\1988-2009\Monthly ...

Country: Ethiopia   Station: Debremarkos

Altitude: 2446 m.   Latitude: 10.34 °N   Longitude: 37.72 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	9.0	23.9	42	1	9.1	20.6	2.99
February	10.2	25.3	36	1	9.2	22.1	3.35
March	11.3	25.7	41	1	8.1	21.7	3.58
April	12.0	25.2	48	2	7.3	20.8	3.61
May	11.8	24.5	55	1	7.7	21.0	3.70
June	10.8	21.1	76	1	5.5	17.4	3.15
July	10.9	18.9	85	1	3.5	14.5	2.65
August	10.9	19.0	86	1	4.3	15.9	2.85
September	10.2	20.5	77	1	6.4	19.0	3.26
October	9.8	22.2	60	1	8.2	20.9	3.37
November	8.7	22.9	49	1	8.9	20.5	3.08
December	8.5	23.3	44	1	9.4	20.5	2.92
Average	**10.3**	**22.7**	**58**	**1**	**7.3**	**19.6**	**3.21**

Crop water requirement using CROPWAT8.0

Crop Water Requirements

ETo station: Debremarkos | Crop: Barely

Rain station: Debremarkos | Planting date: 01/12

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	1	Init	0.55	1.63	16.3	0.2	16.0
Dec	2	Deve	0.58	1.71	17.1	0.2	16.8
Dec	3	Deve	0.80	2.36	25.9	0.2	25.7
Jan	1	Mid	1.04	3.08	30.8	0.2	30.6
Jan	2	Mid	1.12	3.35	33.5	0.2	33.4
Jan	3	Mid	1.12	3.49	38.3	0.2	38.2
Feb	1	Mid	1.12	3.62	36.2	0.2	36.0
Feb	2	Mid	1.12	3.75	37.5	0.2	37.3
Feb	3	Mid	1.12	3.84	30.7	0.3	30.4
Mar	1	Late	0.99	3.47	34.7	0.5	34.2
Mar	2	Late	0.76	2.71	27.1	0.6	26.5
Mar	3	Late	0.52	1.87	18.7	0.6	18.1
					346.8	**3.5**	**343.3**

Crop Water Requirements

ETo station: Debremarkos | Crop: Wheat

Rain station: Debremarkos | Planting date: 01/12

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	1	Init	0.55	1.63	16.3	0.2	16.0
Dec	2	Deve	0.52	1.53	15.3	0.2	15.1
Dec	3	Deve	0.36	1.07	11.7	0.2	11.5
Jan	1	Mid	0.18	0.55	5.5	0.2	5.3
Jan	2	Mid	0.12	0.37	3.7	0.2	3.5
Jan	3	Mid	0.12	0.38	4.2	0.2	4.0
Feb	1	Mid	0.12	0.40	4.0	0.2	3.8
Feb	2	Mid	0.12	0.41	4.1	0.2	3.9
Feb	3	Mid	0.12	0.42	3.4	0.3	3.1
Mar	1	Late	0.42	1.47	14.7	0.5	14.2
Mar	2	Late	0.42	1.50	15.0	0.6	14.4
Mar	3	Late	0.42	1.50	15.0	0.6	14.4
					112.8	**3.5**	**109.3**

Crop Water Requirements

ETo station: Debremarkos | Crop: Bean

Rain station: Debremarkos | Planting date: 01/12

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	1	Init	0.52	1.54	15.4	0.2	15.2
Dec	2	Deve	0.55	1.62	16.2	0.2	15.9
Dec	3	Deve	0.76	2.25	24.7	0.2	24.5
Jan	1	Mid	0.99	2.95	29.5	0.2	29.3
Jan	2	Mid	1.07	3.21	32.1	0.2	31.9
Jan	3	Mid	1.07	3.34	36.7	0.2	36.5
Feb	1	Late	0.86	2.77	27.7	0.2	27.5
Feb	2	Late	0.38	1.26	3.8	0.0	3.7
					186.0	**1.4**	**184.5**

Crop Water Requirements

ETo station: Debremarkos | Crop: Maize

Rain station: Debremarkos | Planting date: 01/12

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	1	Init	0.60	1.77	17.7	0.2	17.5
Dec	2	Init	0.60	1.75	17.5	0.2	17.3
Dec	3	Deve	0.60	1.77	19.5	0.2	19.3
Jan	1	Deve	0.66	1.97	19.7	0.2	19.5
Jan	2	Deve	0.76	2.27	22.7	0.2	22.6
Jan	3	Deve	0.86	2.68	29.5	0.2	29.3
Feb	1	Deve	0.96	3.11	31.1	0.2	31.0
Feb	2	Mid	1.06	3.54	35.4	0.2	35.3
Feb	3	Mid	1.09	3.72	29.7	0.3	29.4
Mar	1	Mid	1.09	3.80	38.0	0.5	37.5
Mar	2	Mid	1.09	3.88	38.8	0.6	38.2
Mar	3	Mid	1.09	3.90	42.8	0.7	42.2
Apr	1	Mid	1.09	3.91	39.1	0.8	38.3
Apr	2	Late	1.09	3.92	39.2	0.8	38.4
Apr	3	Late	1.06	3.86	38.6	0.9	37.7
May	1	Late	1.02	3.74	37.4	0.9	36.5
May	2	Late	0.98	3.62	36.2	0.9	35.2
May	3	Late	0.94	3.30	29.7	1.0	28.4
					562.7	**8.9**	**553.6**

Crop Water Requirements

ETo station: Debremarkos | Crop: Potato

Rain station: Debremarkos | Planting date: 01/12

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	1	Init	0.40	1.18	11.8	0.2	11.6
Dec	2	Init	0.40	1.17	11.7	0.2	11.4
Dec	3	Deve	0.45	1.31	14.4	0.2	14.2
Jan	1	Deve	0.68	2.01	20.1	0.2	19.9
Jan	2	Deve	0.92	2.74	27.4	0.2	27.3
Jan	3	Mid	1.11	3.44	37.9	0.2	37.7
Feb	1	Mid	1.12	3.62	36.2	0.2	36.0
Feb	2	Mid	1.12	3.75	37.5	0.2	37.3
Feb	3	Late	1.07	3.66	29.3	0.3	29.0
Mar	1	Late	0.83	2.91	29.1	0.5	28.6
Mar	2	Late	0.62	2.23	11.1	0.3	10.8
					266.5	**2.6**	**263.9**

Crop Water Requirements

ETo station: Debremarkos | Crop: Onion

Rain station: Debremarkos | Planting date: 01/12

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Dec	1	Init	0.73	2.15	21.5	0.2	21.3
Dec	2	Deve	0.75	2.20	22.0	0.2	21.8
Dec	3	Deve	0.91	2.69	29.6	0.2	29.3
Jan	1	Mid	1.09	3.22	32.2	0.2	32.0
Jan	2	Mid	1.15	3.43	34.3	0.2	34.1
Jan	3	Mid	1.15	3.56	39.2	0.2	39.0
Feb	1	Mid	1.15	3.70	37.0	0.2	36.8
Feb	2	Mid	1.15	3.83	38.3	0.2	38.2
Feb	3	Mid	1.15	3.92	31.4	0.3	31.1
Mar	1	Mid	1.15	4.01	40.1	0.5	39.6
Mar	2	Mid	1.15	4.10	41.0	0.6	40.4
Mar	3	Late	1.11	3.99	43.9	0.7	43.2
Apr	1	Late	1.05	3.79	37.9	0.8	37.1
Apr	2	Late	1.00	3.59	35.9	0.8	35.1
Apr	3	Late	0.94	3.43	30.8	0.8	30.0
					515.0	**5.9**	**508.9**

Appendix D: Accuracy assessment

Overall accuracy= 107/113 0.95

Kappa coefficient 0.81

	WB	FL	SRL	GL	AGL	SL	BL	DL	Total
WB	3	0	0	0	0	0	0	0	3
FL	0	3	0	0	0	0	0	0	3
SRL	0	0	7	0	1	0	0	0	8
GL	0	0	0	13	1	0	0	0	14
AGL	0	0	1	0	63	0	0	0	64
SL	0	0	0	1	0	5	0	0	6
BL	0	0	0	0	0	0	6	1	7
DL	0	0	0	0	0	0	1	7	8
Total	3	3	8	14	65	5	7	8	113

Appendix E: Sample calculation

λ_{max} was calculated by multiplying the score of the factors by its normalizing weight and add together and finally approximate it i.e. the result got in the first step were divided by the weights of respective factor weights.

Row1= 1*0.2303+2*0.2597+2*0.2174+7*0.2174+2*0.1784+0.5*0.1961= 1.59

Row2= 0.5*0.0461+1*0.1299+2*0.2174+5*0.1667+1*0.1177+0.3333*0.098= 1.01

Row3= 0.5*0.1151+0.5*0.0649+1*0.1087+5*0.1667+1*0.1177+0.3333*0.098= 0.85

Row4=0.1428*0.0329+0.2*0.026+0.2*0.0217+1*0.051+0.2*0.051+0.1428*0.0196= 0.22

Row5=0.5*0.1151+1*0.1299+1*0.1087+5*0.1667+1*0.1784+0.5*0.098= 0.98

Row6=2*0.4605+3*0.3896+3*0.3261+3*0.2333+2*0.3568+1*0.4902= 2.36

Approximation of λ_{max}

Row1=1.59/0.2192=7.09

Row2=1.01/0.1293=7.06

Row3= 0.85/0.1119=9.19

Row4=0.22/0.0308=3.41

Row5=0.98/0.1328=7.23

Row6=2.36/0.3761=6.75

λ_{max} =(7.09+7.06+9.19+3.41+7.23+6.75)/6=6.79