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INSTITUTE OF TECHNOLOGY

FACULTY OF BIO-SYSTEMS AND WATER RESOURCES ENGINEERING

DEPARTMENT OF WATER RESOURCES AND IRRIGATION ENGINEERING

**GIS-BASED SURFACE IRRIGATION POTENTIAL ASSESSMENT: A CASE STUDY
OF TEME WATERSHED, EAST GOJAM ZONE, AMHARA REGION, ETHIOPIA**

MSC IN IRRIGATION AND DRAINAGE ENGINEERING

BY GETNET GUADIE

HAWASSA UNIVERSITY, ETHIOPIA

Jun, 2022

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OF TEME WATERSHED, EAST GOJAM ZONE, AMHARA REGION, ETHIOPIA**

GETNET GUADIE

**THESIS SUBMITTED TO THE DEPARTMENT OF WATER RESOURCES AND
IRRIGATION ENGINEERING, HAWASSA INSTITUTE OF TECHNOLOGY,
SCHOOL OF GRADUATE STUDIES, HAWASSA UNIVERSITY, ETHIOPIA**

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MASTER OF SCIENCE IN WATER RESOURCES AND IRRIGATION
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ENGINEERING**

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DECLARATION

I hereby declare that this MSc thesis is my original work and has not been presented in any other universities and institutions for the award of any academic degree, diploma or certificates. I also solemnly declare all source of material used for this thesis.

Name: Getnet Guadie

Signature:- _____

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This is to certify that the thesis entitled "GIS-BASED SURFACE IRRIGATION POTENTIAL ASSESSMENT: A CASE STUDY OF TEME WATESHED, EAST GOJAM ZONE, AMHARA REGION, ETTHIOPIA, Submitted in partial fulfillment of the requirements for the degree of Master's with specialization in irrigation and drainage engineering, the Graduate program of the department of water resources and irrigation engineering, and has been carried out by **GETNET GUADIE (ID No: - PGIrDrR/010/2012)** under my supervision. Therefore I recommend that the student has fulfilled the requirements and hence hereby can submit the thesis to the department for defense.

Name of Advisor

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Date

Name of Co-Advisor

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_____	_____	_____
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_____	_____	_____
Name of Co-Advisor	Signature	Date
_____	_____	_____
Name of Internal Examiner-I	Signature	Date
_____	_____	_____
Name of Internal Examiner-II	Signature	Date
_____	_____	_____
Name of External Examiner	Signature	Date
_____	_____	_____
SGS APPROVAL	Signature	Date

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LIST OF ACRONYMS AND ABBREVIATIONS

AHP	Analytical Hierarchy Process
ARCU	Application Resource Context User
CWR	Crop Water Requirement
CROPWAT	Crop Water Assessment Tool
DEM	Digital Elevation Model
DSSAT	Decision Support System for Agro- Technology
ELECTRE	ELimination Et Choix Traduisant la REalite
ERDAS	Earth Resource Data Analysis
ESRI	Environmental System Research Institute
ETM	Enhanced Thematic Mapper
FAO	Food and Agricultural Organization
GIS	Geographic Information System
GIR	Gross Irrigation Requirement
HRU	Hydrological Response Unit
IWMI	International Water Management Institute
LULC	Land Use Land Cover
MCDM	Multi-Criteria Decision Making
Mha	Million hectares
MoA	Ministry of Agriculture
MoIWEE	Ministry of Irrigation Water Resource Energy and Electricity
NMSA	National Meteorological Services Agency

NIR	Net Irrigation Requirement
RWH	Rain Water Harvesting
SWA	Simple Additive Weighting
SRTM	Shuttle Radar Topographic Mission
SWAT	Soil Water Assessment Tool
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
UNESCO	United Nations Educational Scientific & Cultural Organization
USGS	United State Geological Survey
UTM	Universal Transverse Mercator
WOFOST	World Food Study

ABSTRACT

Assessment of available land and water resources for surface irrigation development within watershed level using Geographic Information System (GIS) is important for planning its use. Due to the development of irrigated agriculture is less regardless of its important to alleviate food insecurity and food production problem in the study area, improving of agricultural productivity within the study area needs a quantified irrigable land and potential of water resources through in a systematic and scientific way. Identification of suitable land and mapping to it for surface irrigation, estimation of available flow, determination of irrigation water requirement and Comparing the Gross irrigation water requirement of the selected crops for the identified suitable land with simulated river flow were the main steps that were followed. To identify suitable land, the land suitability parameters like slope, soil (texture, depth and drainage), river proximity, and LULC of the study area were used. Application of weighted overlay tool was used for analysis of these factors to give a suitable land among river sub watershed of Tejatil, G/Teme, Tige Bahar and Tiwa as 578ha, 735ha, 234ha and 955ha respectively, which accounts 13.7% of the total study area. Simulated flow of the four manually added outlets and one linking stream added outlet in the watershed after calibration and validation by considering 12 sensitivity parameters and observed flow of gauged river were conducted. The mean monthly flow of $4.34\text{m}^3/\text{s}$ was determined at the outlet of the watershed. Three crops (Tomato, Maize and Potato) were selected to grow on the identified irrigable areas and its irrigation water requirement of these crops were estimating by implementing CROPWAT8.0 model as an input of climatic, crop and soil data .By comparing gross irrigation water requirement of the selected crops for identified irrigable land and simulated river flow at the area of selected site, the total irrigation potential site of the study area for surface irrigation was found to be 555ha, which accounts 3.04% of the total study area. In conclusion, the potential irrigable land is very small due to the scarcity of water. Therefore, the irrigation potential of the area could be increased either by harvesting rainwater and using ground water or by analysis a suitability of other method of irrigation such as trickle/drip and sprinkler irrigation method.

Key words: Arc GIS, Arc SWAT, CROPWAT, ERDAS, land suitability, Surface irrigation, Surface water availability.

1. INTRODUCTION

1.1 Background

The Ethiopian economy is commonly supported by agricultural sector. The agricultural sector of the country contributes approximately 44% of the national gross domestic product and 70% of export earnings, but the irrigation sub-sector accounting for only 3% of the food crop. The sector of irrigation is mostly characterized by small-sector, limited access to technology and weak institutional support service (Mendes & Paglietti, 2015). The agricultural economy of the country is largely based on rain-fed agriculture, which employs 80% of the population and it contributes approximately 50% of the growth domestic product. Around 74 Mha of the country or 66% is suitable for agriculture (Getnet et al., 2019).

Ethiopia has huge potential for expanding irrigated agriculture by considering the available water and land resources. Irrigation potential is a combination of information on gross irrigation water requirement, suitable land and available water resource for irrigation in a particular area. The country is gifted by sufficient water resources with an estimated volume of 122Bm³ surface water potential and 5.3 Mha land irrigation potential of which 3.7 Mha can be developed using surface water resource (Anmut et al, 2019). Yet, the actual and potential irrigated land is not precisely investigated, since estimates of irrigable land in Ethiopia varies from time to time study, such as Awulachew et al., (2007) 0.16 to 0.2 Mha, Seleshi and Mekonnen (2010) 0.7 Mha and MoA (2011) 10 to 12 % of the total irrigable land that is from 0.53 to 0.64 Mha are currently under production using traditional and modern surface irrigation schemes. The term Surface irrigation refers to a broad class of irrigation method in which water is distributed over the field by a free surface gravity flow. A flow is introduced at

a high point along high edges of the field and allowed to cover the field by over land flow. It offers a number of benefits for the less skilled and poor farmers. Under such circumference more than 90% of the world uses surface irrigation (FAO, 2002). Due to lack of investment and declining of large scale irrigation schemes, interests has been developing in recent year for seeking ways to improve the productivity and livelihoods of the country's small-scale irrigation scheme. At the same time, smallholders are capable of managing irrigation systems efficiently provided they have access affordable technology that are easy to operate, maintain and repair. Small-scale systems and technologies are attractive, since they put the operation, maintenance and management of systems directly in the hand of the individual farmers, thus eliminating any need for centralized control or management (Bitew, 2013). The principal purpose of irrigation is to increase the productivity of land and labor, mainly applicable for future constraints due to population growth and reduction of dependence in rainfall due to climate change for the development of irrigation infrastructure. As irrigation increases the opportunity of job and country's export increase alarmingly and it promotes the economy dynamically within rural and urban entrepreneurships (Seleshi, 2010).

Geographic information system (GIS) is an organized collection of computer hardware, software, geographical data and personal designed to efficiently capture, store, update, manipulate, analysis and display all form of geographically referenced data. With an acceptable file, GIS can serve as a powerful analysis and decision making tool for irrigation development. In this situation, different issues are involved for irrigation potential assessment, such as availability of irrigable land, land use land cover, slope (topography) and soils should be weighted and evaluated by the use of geographic information system according to their suitability for irrigation (Ross et al., 1995).

Teme watershed is one of among other watershed of Abbay basins and has its own small tributary rivers (Cherinet et al., 2019). Most of the inhabitant under this watershed manages themselves through agricultural practice while few of them are manage themselves through trading. The development of irrigated agriculture in the watershed is less regardless of its important to alleviate food insecurity and food production problems in the watershed. Therefore, improving of agricultural productivity within the study are needs a quantified irrigable land and potential of water resources through in a systematic and scientific way.

1.2 Statement of the Problem

Based on the stastical agency of Ethiopian census results and latest official projections, the number of population is increased from year to year over the national level alarmingly. As the consequence of this, food demand is increased at the same level. So as to supply food for the increasing population, improvement and expansion of irrigated agriculture must be enhanced. Therefore wise land use and adequate estimation of physical resources like land and water at the basin as well as at the watershed scale are an essential basis for a healthy and prosperous future for the human race (Negash, 2015).

In Ethiopia, specifically Amhara region has different agro-ecologies and fertile soils that are suitable for surface irrigation production. The production practice of surface irrigation in this region is predominantly using traditional farming system for local markets as cash crop. The area allocated for production of surface irrigation system and their productivity in the region is very low (Masho et al., 2015). Correspondingly, In Abbay sub basins particularly in Teme watershed, surface irrigation production practice predominantly using traditional farming system for local markets as cash crop. Due to there is no study conducted concerning with irrigation potential assessment within the study area, wise use of land and water resources for

irrigation purpose within the inhabitant is not adapted. Even though, little traditional irrigation has been takes place, there are no well-defined stream flow estimations and potential irrigable area identifications matched with the water requirement of crops commonly grown in this watershed. Consequently to overcome this problem with development of irrigated agriculture, it is necessary to carry out geographic information system (GIS) based surface irrigation potential assessment within the study area. Since, by assessing surface irrigation in terms of suitable land and available water, updating of information's about potential of available resources and matching the available water resources potential with crop water requirement of the watershed should be conducted for improvement and expansion of irrigated agriculture.

1.3 Objective of the study

1.3.1 General objective

The main objective of this study was to assess surface irrigation potential of Teme watershed using geographic information system (GIS).

1.3.2 Specific objectives

The specific objectives of the study were:-

1. To identify suitable irrigable land and mapping to it for surface irrigation development using geographic information system (GIS) in the study area.
2. To estimate the available surface water in the study area using SWAT 2012 model.
3. To estimate the crop water requirement for dominant crops in the study area for the available suitable land.
4. To compare the available river flow with irrigation requirement of dominant crops domesticated for identified suitable land.

1.4 Research questions

To address the above listed specific objectives, the next research questions were identified:-

1. Which and how much suitable land is mapping for surface irrigation development using the physical suitability factor in the study area?
2. How much surface water is available in the study area?
3. How much is the irrigation water requirement of dominant crops in the watershed?
4. Can the available surface water meet the demand of the dominant crops within the identified suitable land?

1.5 Significance of the study

In Ethiopia, most irrigation project design is not consider or taken the available water resources data for each suitability irrigable land leads to insufficient water resource in irrigation season (Tadesse, 2017). Teme watershed is one among Abbay basin watershed of Ethiopia in which, the available irrigable land and potential of water resource is not assessed in a scientific way for optimizing utilization of water and land resources. This study is necessary to identify and quantify the water resources potential and land suitability (how much hectare of land is suitable for surface irrigation) of this watershed for the purpose of helping the planners and decision makers for developing any term plan for water resources improvement. It is also essential to assist the decision makers to evaluate the existing irrigation schemes and provide facts or suggestion for plan and manage the surface irrigation based on the result of the study; leads to the agricultural production suitability will be improved.

1.6 Scope of the study

Even if, a lot of problems are exist in the study area, the scope of the study mainly focus on assessing the availability of surface water and potentials of irrigable land with respect to slope, physical property of soil (depth, drainage and texture), LULC and availability of surface water for surface irrigation to associate with irrigation water demand for selected crops. However, because of financial constraints, lack of data and accessibilities of materials, this study was not assessed chemical property of soil, irrigation water quality and the impact of climate change on surface irrigation sustainability.

1.7 Thesis layout

The thesis consists of five chapters. Chapter one is the introduction part of the study which holds background information's about the study, statement of the problem, objective of the study, question of the research, significant of the study and scope of the study. Chapter two describes the literature review part related to study area regarding to specific objective of the study. Material and method of the study then followed in chapter three which includes details of the study area, data collections and analyses, surface water availability assessment, descriptions about estimation of water requirement for dominant crops and graphical procedure of the study methods. The fourth chapter is the result and discussion part which presents the result of analysis on irrigation potential of the study area with suitable land and available water resources. Finally, Chapter five presents the main conclusions drawn from the study finding and recommendations proposed for future consideration.

2. LITERATURE REVIEW

2.1 Irrigation potential

Irrigation potential is a combination of information on gross irrigation water requirement, suitable land and available water resource for irrigation in a particular area. For knowing information's on land and available water resource in a particular area, knowledge of physical irrigation potential is important. The area in which potentially can irrigate is influenced by the physical resources like soil, topography, land use/ land cover and climate. However, climate is different from others due to its uniformity in a particular area to be assessed (Stanhill, 2002).

2.2 Irrigation potential in Ethiopia

Ethiopia is gifted with sufficient water resource by twelve River basins with an annual run-off volume of 124.4 billion cubic meter (BCM) river water, 30 BCM ground water and 70 BCM lake water resources. The country has a potential to develop 3.8 Mha of irrigation and 45000 MW hydropower productions (Belete et al., 2014). However the potential and actual irrigate area of the country is not precisely estimated due to lack of standard and/or conventional criteria (Belay & Bewket, 2013).

Ethiopia can develop at least 5.3 Mha of irrigation potential by assuming use of available technologies, like rain water harvesting and ground water exploration, which accounts 3.7 Mha from gravity-fed surface water, 1.1 Mha from ground water and 0.5 Mha from rain water harvesting. The country has massive cultivable land, however only about third of this land is currently cultivated (approximately 15 Mha) with current irrigation scheme covering about 640,000 ha (128,000 ha from rain water harvesting, 383,000 ha from small-scale irrigation and 129,000 ha from medium to large scale irrigation schemes) across to it (Seleshi, 2010).

While Yimere and Assefa, (2021) on the other hand publicizes, Ethiopia has 12 river basins, the annual stream flow from those river basin is approximately 122 BM³ and 40 BM³ ground water, the total irrigation potential from those water resource is 7.5 Mha with a hydropower potential of 45000 MW. According to yours study, Ethiopia has a goal of increasing irrigation potential from the current potential to 7.5 Mha in its ten years perspective development plan of 2020-2030. The implication shows that, estimation of the irrigation potential of Ethiopia varies from one source to other source.

2.3 The need for irrigation development in Ethiopia

Ethiopia is a water tower countries, but has very high hydrological variability's combined with lack of appropriate soil fertility supervision contribute to lower crop yields, resulting in high food insecurity and dependent country's on food aid (Worklul et al., 2017). In Ethiopia, climate elements such as precipitation, temperature, humidity, sunshine, and winds are affected by geographic location and altitude. The country locates near the equator and an extensively altitude range, has a wide range of climate features suitable for influencing different agricultural production system (Tesema, 2015).

Due to hydrological variability during the crop growing season rainfall is declined by 15 to 20%, while temperature increased, consequently the impact of drought could reduce the available productive cropland. The unbalanced instant between densely populated area and observed decline rainfall results the agricultural sector dominated by subsistence rain-fed system with low productivity in high level of risk leads to dependent country on food aid (Fewnet, 2012). In worldwide, irrigated agriculture represents 20% of the total cultivated land but it contributes 40% of the total food produced (FAO, 2015). Irrigation plays a substantial role in the considerable increment of food production for food security and economic

development of Ethiopia with the efficient use of physical resources like land and water (Haile & Kasa, 2015). Irrigation could shift the agricultural production frontier to in some extent high level in Ethiopia (Makombe et al., 2007). Irrigation has a significant role to enhance farmer's livelihood through different dimensions, household income, employment opportunity and participation in community decision (Mengstie & Kidan, 2016). Another study at Lake Tana basin IWMI (2015) indicates that, on average household income of those that practiced irrigation were 27% higher than those that did not.

2.4 Irrigation potential in Amhara Region

Amhara region is located in the north part of Ethiopia with a total area of 170,752 square kilometer (km^2). The majority of the people living in the highlands are traditionally subsistence grain farmers with surplus production farmers constituting quite some portion of the highland. The Region has four major River basins with small tributaries, which are part of Abbay, Awash, and Tekeze-angereb River basins and Danakil depression with total estimated annual run-off water of 35 Bm^3 . Almost all of the estimated volume of water is lost without any meaningful economic and environmental use. From this four basin, the Region has an estimated of 500,000 ha total potential of irrigable area. While, currently from the total potential of irrigable area less than 10% irrigable area has been developed (Bitew, 2013). The region has an average annual rainfall amount ranges from 600 mm to 1600 mm. Some of the major developed schemes in the region for irrigations are; Kobo-Girana Valley Development program (KGVDP), Koga, Ribb and Megech small to large scale irrigation development projects.

KGVDP is located in north wollo zone of Amhara region. The area has a potential of producing $156.12 \text{ Mm}^3/\text{annum}$ of sub surface water yield and $113 \text{ Mm}^3/\text{annum}$ of

underground water yield, which accounts a total of 269.12 Mm³/annum water yields. The project was proposed to irrigate 5665 ha by using sub surface water source and 3600 ha by using underground water source, which altogether goes to 9265 ha of land (Adinew, 2009).

Koga irrigation project is located in West Gojjam Zone of Amhara region within geographical location of 11.16⁰N to 11.41⁰N latitude and 37.03⁰E to 37.28⁰E longitude. The project is established on koga river basin by constructing earth dam across the Koga River which covers a total watershed area of 237.69974 km². Koga River is a tributary of the Gilgel Abbay River in the head water of Blue Nile Abbay catchment (Banteamlak, 2014). The key purpose of the project is to irrigate 7004 ha of land within 9 rural kebeles. The yield from koga dam is established to be 72.44 Mm³ per annum (MacDonald, 2004).

Ribb dam is established in river Ribb of south Gondar zone of Amhara region east side of the sub basin of Lake Tana. The Ribb River has approximately 130 km long and drainage area of approximately 1790 km² with an annual average discharge of 14.633m³/s. It has a catchment area of about 685 km² on the dam site (Addisu, 2021).

The Megech watershed is located in the north part of the Lake Tana sub basin in Amhara region of Ethiopia. It originates from near the Semen Mountains at an altitude of 4000 m. The total area of the watershed covers 663 km² at the Lake inlet of which 500 km² is gauged. The dam was constructed on a tributary of Megech River with a reservoir surface area of 51 ha and a design capacity of 5.3 Mm³ with a catchment area of 68 km² (Afera et al., 2018). The region has also a future (under detail design) large scale irrigation schemes like Gumara dam, Jema dam and Gilgel Abbay dam irrigation project with irrigation potential of 13776 ha, 7786 ha and 11508 ha respectively (Birlew, 2016).

2.5 Irrigation potential in Abbay Basin

Abbay basin is the most important basin in Ethiopia, since it accounts 25% of the country's population and for over 40% of its agricultural production. The area is located in latitude of 7°42'13"N - 12°44'03"N and longitude of 34°14'43"E - 39°48'20"E. As recent study the total irrigation potential has been estimated at more than 523,000 ha, which is about 19.6% of 2,671,500 ha of the country's economic irrigation potential (FAO, 2016). Yet, Girmachew (2018) on the other hand recognizes, Abbay basin has irrigation potential of 526,000 ha economically feasible lands and it contributes 38% hydropower potential and 40% of the agricultural product at national level.

2.6 Order of land suitability evaluation

Land suitability evaluation is a process of assessing land performance for helping to establish strategies to increase agricultural productivity by identifying inherent and potential capability of land for intended objectives (Pramanic, 2016). Principal parameters such as topography factor (slope), land use/land cover, soil physical properties (depth, texture and drainage) and distance from water source are frequently used for assessment of land suitability evaluations (Zolekar & Bhagat, 2015). As extensively discussed in FAO (1997) land evaluation guidelines, land suitability for agriculture can be classified into two classes, namely suitable and not suitable. These classes are further classified based on their benefits and limitations.

Order S-suitability:

- S1 (highly suitable) - lands not have a substantial limitation to sustained application of a given use'
- S2 (moderately suitable) - lands having limitations in a same extent which in aggregate are moderately severe for a sustained application of a given use.

- S3 (marginally suitable) - lands having limitation which in aggregate are severe for a sustained application of a given use but reduce productivity or benefits.

Order N-suitability:

- N1 (temporarily not suitable) - land having limitation but it may be manageable in time. However, cannot be corrected with existing knowledge at current satisfactory cost.
- N2 (permanently not suitable) - lands having limitation which appears as severe as to prevent any possibility of successful sustained use of the land of a given use.

2.7 Biophysical parameters used for evaluation of land suitability

2.7.1 Slope

Slope is a measure of the rate of change of elevation in the direction of steepest descent and commonly expressed in percent. It is one of the most important factors in the determination of irrigation type and method to be practice, run-off, drainage and erosion. Slope classes range from 0-2% is highly suitable for the development of surface irrigation, while slope classes 2-5%, 5-8% and >8% are moderately suitable, marginally suitable and not suitable respectively for the development of surface irrigation (FAO, 2006).

Table2. 1: Slope range of surface irrigated land

Slope	Percent	Factor of rating
Horizontal	0 – 2	S1
Very flat	2 – 5	S2
Flat	5 – 8	S3
Steep	>8	N

2.7.2 Soil

Both physical and chemical properties of soil like drainage, texture, depth, salinity, alkalinity and others largely affect the suitability of the land for surface irrigation. Its primary influence is in the productive capacity. However, it may also influence production and development costs (Tasisa and Girma, 2019). Soil suitability for crop should be evaluated by examining soil properties for a given area, because not all soil can be irrigated due to various physical properties such as poor internal drainage (Kebede, 2010).

Table 2. 2: Soil suitability factor rating

Factors	Factor rating			
	S1	S2	S3	N
Soil texture	C, SiC, SC	Si - SCL	SL	Coarse sand
Soil depth(cm)	greater than 120	100 to 120	50 to 100	less than 50
Soil drainage	Well drain	Imperfect drain	Poor drain	Very poor drain

Source: FAO (1976, 1991 and 2002).NB: clay(C), silt clay(SiC), sandy clay(SC), sandy loam(SL), sandy clay loam(SCL), silt sandy clay loam(Si-SCL).

2.7.3 Land use land cover

By nature and/or artificial events, on the earth's surface may have unique portion of land in the cover possesses like land use and land cover. Land use and land covers are distinct, yet has closely linked characteristics of the earth's surface, Land use is the way in which human beings employs the land and its resource. It includes Agriculture, urban development, grazing, logging and mining. However, land cover describes the physical state of the land surface. From these categories includes cropland, forest, wetland and roads (Abraha et al., 2005). Land cover and land use is one of the most important factors that influence the suitability of the land for irrigation combined with slope and soil characteristics (Worku and Tripathi, 2015).

Table2. 3: LULC suitability class for surface irrigation

Category	S1	S2	S3	N
Suitability class	Highly suitable	Moderately suitable	Marginally suitable	Not suitable
LULC description	Cultivated land	Grass land and open bush land	Open forest, wood land and dense bush land	Dense forest, urban area and water body

Source: FAO (1976 and 1996). An interactive analysis for land resource evaluation

2.7.4 Water availability

Water has the main limiting factors for crop production in much of the world where the available rainfall is insufficient to meet crop demand. Assessment of irrigation potential should take in to account to estimate how much adequate amount of water potential is available in the basin/catchment or in a particular study area for the intended irrigation method and crop to be grown in the identified irrigable area (Steduto et al., 2012). For surface irrigation, water source should be above the command area to irrigate the entry area by gravity and nearest distance between water source and irrigable command area is very essential to reduce the conveyance system and thereby developing irrigation system to be economical (Kebede, 2010).

2.8 Over - View of GIS application

GIS is a computer software program used for digitally represent and analysis the geographic features present on the earth's surface and events that taking place on it like, land parcel, roads and vegetation's. Its method and procedures have a great role to play in analyzing decision problems (Yared, 2014). As more and more spatial data's are becoming available, several authors have effectively used GIS for multiple purpose. For instance, Meron (2007) has studied on surface irrigation suitability analysis of southern Abbay basin using GIS. The

study was mainly considered some physical catchment characteristics such as land use land cover, slope and soil parameters to investigate suitable land for irrigation with respect to location of available water resource. The combined influence of these factors was determined for irrigation suitability analysis using weighted overlay analysis in Arc GIS.

2.8.1 Mapping

Most GIS users like, Meteorologists, Hydrologists and irrigation Engineers use GIS software for mapping purpose, where things are in editing task as well as for a map based query (to see what data or attribute values are stored) and analyzed (Campbell, 1984). The map represents geographic information's as a collection of layer and other elements in a map view. Maps should contain cosmetics elements like data frame, scale bar, scale text, north arrow, title, descriptive text, and a symbol legend for users to obtain impression information's about the map message (Kebede, 2010).

2.8.2 Watershed delineation

Watershed is an area of a particular basin that drains in a common outlet. For delineating a watershed, it uses automated watershed delineation embedded in Arc SWAT interface. In GIS, Digital elevation model (DEM) data's are essential to delineate a watershed within integration of Arc SWAT model (Winchell et al., 2008).

2.8.3 Weighted overlay analysis

Weighted overlay analysis is a technique for applying a common measurement scale of values to varied and dissimilar imputes to create an integrated analysis. It uses to analysis different factors of geographic problems. For example, finding an optimal site for irrigation requires weighting of factors like slope, soil and land use land cover. It applies divers imputes to have an integrated analysis. Within an individual raster, it has been needed to define the weight

value to the classes based on the relevance in the irrigable land suitability. The weighted overlay function weight the individual impute raster on a defined scale and within weighted overlay tool, the influence assessed to all the impute raster must be gives 100% (Yang, 2003).

2.8.4 GIS as a tool for irrigation potential assessment

Work on GIS began in late 1950s. However, first software comes only in late 1970s from the lab of the Environmental System Research Institute. From past up to know several authors have effectively used GIS to assess irrigation potential and water resource (FAO, 1997; Kebede, 2010; Worqlul et al., 2015; Yonas et al., 2022; Worqlul et al., 2017 & Tasisa, 2020).

FAO (1997) has studied the irrigation potential of Africa by concentrated mainly on quantitative assessment based on physical criteria (land and water), however relied heavily on information collected from the Country. To insure consistency at River and Basin level, River Basin approach had been used, for these purpose GIS facilities were extensively used. Based on this study a physical approach to irrigate potential was understood as setting the global limit for irrigation improvement.

Kebede (2010) conducted a study on surface irrigation analysis of Dale wereda by using GIS techniques. He considered the physical factors (soil, slope and land use land cover) to find suitable land for surface irrigation with respect to River proximity and to determine the combined influence of these factors for irrigation suitability analysis, weighted overlay analysis was used in Arc GIS.

Worqlul et al., (2015) carried out study on assessment of surface water irrigation potential in the Ethiopian highland Lake Tana basin using GIS. The study estimates the irrigable area and crop water requirement during the growing season of the crop in Lake Tana basin. To find the

irrigable area, if all water was stored, they dividing the average daily flow by the crop water requirement. According to this study, to increase the irrigation in the potentially irrigable area, water falling and flowing during the rain monsoon phase needs to be stored for the dry phase.

Worqlul et al., (2017) also conduct a research on assessing potential land suitable for surface irrigation using ground water in Ethiopia. This study is the first of its kind to provide especially explicitly ground water irrigation area suitability map for Ethiopia. The finding indicate that there is modest amount of land suitable for irrigation using ground water and for locational a large portion of suitable land is located in upper Blue Nile, Rift valley, Omo Gibe and Awash River basin.

Tasisa (2020) works a research on Irrigation water potential and land suitability assessment in Kurfa chelle-Girawa watershed which locates in wabe-shebelle basin. It had been carried out to evaluate and estimate suitable irrigable land and water resource in the study area and develop the final suitability map. The main irrigation suitability factor undertaken during the study was slope, soil, land use land cover and Euclidean distance.

Yonas, et al., (2022) has also studied on land suitability assessment for surface irrigation development in Ethiopia highlands of Minch Yekest watershed using geospatial technology. To achieve its objective, the study considers slope, land use, altitude, distance from the water source, soil characteristics and available water storage capacity parameters. According to the finding, most of the watershed was suitable for the aforesaid purposes within the watershed.

2.9 Multi-Criteria Decision Making (MCDM)

MCDM is one of the most widely used methods of overcoming the difficulties in defining relative weights of several criteria involved in decision making on land suitability

(Aldababseh et al., 2017). Due to variability of land topography, climate, water resource availability for irrigation, soil capability and current management practices including land use land cover, assessment of land suitability for agriculture is complex and multidisciplinary (Elsheikh et al., 2013). There have been many MCDM methods that used to assess land suitability like Analytic Hierarchy Process (AHP), Simple Additive Weighting (SAW), Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) and ELimination Et Choix Traduisant la REalite (ELECTRE) methods are some of it (Bizzarri et al 2015).

SAW is a MCDM approach that can be established based on a simple addition of scores that represent the goal achievement under each criterion multiplied by a particular weight (Qin et al., 2008). It is intuitive to decision makers and has ability to compensate among criteria. The main advantage of this method is simple and can be done without the help of complex computer programs, but the estimates produced by SAW do not always reflect the real situations and the result gained may not be logical with the value of one specific criterion largely differing from those of other criteria (Podvezko, 2011).

ELECTRE was developed at the end of 1960s with basic concept of dealing with outranking relations by using pairwise comparisons among alternatives under each one of the criteria separately (Triantaphyllou et al., 1998). It's one of the best advantage is that it takes in to account uncertainty and ambiguity, however its process and out comes can be difficult to explain in layman's term and due to the way preference are uncorrupted, the lowest performance under certain are not displayed (Velasquez and Hester, 2013).

TOPSIS is also one of the MCDM methods that identify alternatives which are close to the ideal solution and farthest to the negative ideal solution in a multi-dimensional computing

space (Qin et al., 2008). Similar to the other MCDM methods TOPSIS has also its own numerous advantages, such as its process is simple, easy to use and programmable, although its use of Euclidian Distance does not consider the correlation of attributes, difficult to weight attributes and keep consistency of judgment especially with addition attribute (Ic, 2012).

AHP method is one of the perfect and easiest methods under MCDM because, it is easy to use and make room for checking and reducing inconsistency. AHP methods have sufficient evidence based on the formula along with comprehensive literature review by the authors to strongly recommend to future researchers (Aziz et al., 2016). Yet due to the approach of pairwise comparisons, it can be subjected to inconsistency in a judgment and ranking criteria (Konidari and Mavrakis, 2007). The AHP method is a powerful and flexible decision process to help people set priorities and can make the best decision with both qualitative and quantitative aspects of decision need to be considered (Weerakoon, 2014).

2.10 Description of SWAT model

SWAT is the acronym for “Soil and Water Assessment Tool” which is developed by the USDA Agricultural Research service (USDA-ARS) and it is a semi-distributed model of watershed scale and continuous time. The primary objective to develop SWAT was to predict the impact of various activities such as land use land cover change, climate change over the years on stream flow of gauged and ungauged watersheds and water quality and quantity parameters. Entirely, SWAT simulation process can be dividing into two major parts which includes the land surface which contains runoff and slope confluence and the water surface which contains concentration of channel (Awasthi and Kumar, 2021). SWAT has been applied in many studies around the world, especially in research related to include hydrology, erosion, soil and climate, land management, temperature and plant growth. Stream processes

considered by the model include water balance, routing, sediment and pesticide dynamics (Gokhan Cuceloglu et al., 2017).

The model was designed to assess long term impact of land management on water balance, sediment transport, and non-point source pollution in River basin. In this model a watershed is dividing in to homogeneous hydrological response units (HRUs), which are a combination of land use, management practice, topography (slope) and soil characteristics. Its hydrological response units are represented as a percentage of the sub-watershed area and may not be contiguous or especially identified within a SWAT simulations. Sub-dividing watershed allows user to analyze hydrologic process in different sub-watershed within a large watershed and under localized land use management practice (Mbungu and Kashaigili, 2017).

SWAT works on a daily time step and is designed to predict the impact of land use and management on hydrology, sediment, and agricultural chemical yields in ungagged watersheds. The model is process based, computationally efficient, and capable of continuous simulation over long time period. The model simulates eight major components that include weather, hydrology, soil temperature and properties, plant growth, nutrients, pesticides, bacteria and pathogens, and land management (Bouslihim et al., 2016). SWAT requires daily value of precipitation, maximum and minimum temperature, solar radiation, relative humidity and wind speed. The occurrence of rain on the given day has a major impact on meteorological data for the day. Meteorological data's such as maximum temperature and minimum temperature, solar radiation and relative humidity are generated based on the availability of rain for the day (Neitsch et al., 2005). Predict of run-off and sediment yields in Ija Galma Waqo spate irrigation project was studied using SWAT model. Given the

complexities of the watershed and the number of interactive processes taking place simultaneously and consecutively at different time and place within a watershed, it is quite remarkable that the simulated results meet with the measurement to the degree that they do. Based on the results obtained in the study, SWAT was assessed to be a reasonable model used for water quality and quantity studies in the Ija Galma Waqo watershed. The result found were sediment yield of Ija Galma Waqo spate irrigation project was quantified and the most sediment yielding part of the basin was identified (Eyob, 2010).

SWAT is a proven to be an effective and flexible tool for a wide range of applications, watershed scales and environmental conditions. Moreover, the semi-distributed structure makes the model computationally efficient and enables to generate especially explicitly output (Gassman, 2014). It is one of the best known and most widely used tools to develop a water quality and quantity model at the watershed scale because the model is an open source tool and detailed online documentation, user groups, video tutorials and a unique literature databases are available (Gyamfi et al., 2016).

Similar to other tools, SWAT tool also has its own shortcoming. For instance, have led to a difficult code and a high number of parameters requiring expertise to run the model and complicating the calibration processes (Arnold 2012a), use of non-interacting HRUs because the HRUs are not linked to each other, routing processes of flows and pollutants and pollutant attenuations within the sub-watershed are lacking (Arnold et al., 2010), moreover the semi-distributed structure impends to generate spatially explicitly outputs at the HRUs level (Gyamfi et al., 2016).

2.11 Weather Generator

Meteorological data is vital in the application of hydrological models such as SWAT model, means that SWAT model requires meteorological data (White et al., 2017). However, observed meteorological data's are often inadequate in terms of completeness, length and special coverage, which accounts for the need to use weather generators model (WXGEN) that solve this problem by generating data with the same statistical properties as the observed data (Vesely, et al., 2019). SWAT includes a weather generator model (Richardson, 1981).

WXGEN depends on rainfall, temperature (minimum and maximum), wind speed, relative humidity and solar radiation data, but it depends strongly on a rainfall data, as a half of the WXGEN required statistics as related to rainfall (Neitsch, et al., 2011). First, weather generator independently generates precipitation for the day and then, once the total amount of rainfall for the day is generated, the distribution of rainfall within the day can be computed. Temperature (maximum and minimum), solar radiation and relative humidity are generating based on the presence or absence of rain for the day. Then finally, wind speed is generated independently (Neitsch et al., 2005).

2.12 Crop water requirement

CWR is the acronym for "crop water requirement" that defined as the total water needed for evapotranspiration from planting to harvest for a given crop in a specific climate regime, which adequate soil water is maintained by rainfall and/or irrigation, so that it does not limit plant growth and crop yields. In ordered to calculate CWR, reference evapotranspiration has to be converted to crop evapotranspiration (ET_c). Modification to the standardized reference is applied through the use of crop coefficient (K_c). The crop coefficient integrates the

vegetation's resistance of transpiration, height, roughness, reflection and canopy cover to calculate individualized crop evapotranspiration (Ganeshbabu et al., 2015).

2.12.1 Crop water requirement determination models

Some model programs were developed by FAO and International Benchmark sites for Agro-technology transfer and as a tool to assist irrigation engineers and other related field individuals or organizations in the accomplishment of the usual calculations for water irrigation studies and mainly in the management and design of irrigation schemes. In real world, CROPWAT, ARCU, WOFORST, DSSAT and other models are in a significant practice used by researchers for the assessment of crop water requirement, crop evapotranspiration and irrigation schedules (Banik et al., 2014). According to this study CROPWAT model is simple and easy to use and also linked to less intense data requirements than other models. Etefa, (2019); conducts a research on determination of crop water requirement and irrigation water requirement in a case study of Somodo watershed. The main concern of his study was to determine the crop water requirement, irrigation water requirement and schedule for the cultivation of Coffee Arabic in sodomo watershed by using CROPWAT8.0 software by dividing the development stage of the crop in to four seasons; initial, development, mid and late seasons and carried out with input of climate, crop and soil data. Finally, the study can respond the basic questions on the irrigation water requirement (how much water to apply) and irrigation schedule (when to apply) for the cultivation of Coffee Arabic in Sodomomo agro-ecology.

Memon and Jamsa (2018) also says CROPWAT is a power full simulation tool developed by land and water division of FAO and designed for particular used by agronomist, irrigation engineers and agro-meteorologists with regard to have a main function of:

- i. To calculate reference evapotranspiration's, crop water requirement and crop irrigation requirement.
- ii. To develop irrigation schedules under various management conditions and water supply scheme.

2.12.2 Reference evapotranspiration estimation methods

Evapotranspiration from the source is termed as reference evapotranspiration denoted as ET_0 . It is one of the very important components of crop water requirement and necessary step in water resource management. Efficient determination of crop water requirement requires a good quantification of evapotranspiration. FAO-56 Penman (PM), Blaney-Criddle (BCM), Thornthwaite (THM), Hargreaves (HGM), Modified Penman (MPM) and Priestley-Taylor (PTM) methods are the most popular and used methods for estimating reference evapotranspiration (Sonowal and Borah, 2015). However, different researchers with different time recommended that FAO-56 Penman Monteith method is a sole standard method for determining reference evapotranspiration in all climates, especially where there was available of data. For instance, Tellen (2017), Zarei et al., (2015) Ali and Abd El-wahed, (2014), Smith et al., (1991) and Roja et al., (2020) are some of it.

Tellen (2017), Conducted a comparative analysis of reference evapotranspiration from the source of rain fed grass in Yaoundé, calculated by six empirical methods against the Penman Monteith method. According to his/her study FAO-56 Penman Monteith method is easy to use in terms of parameters required and that can accurately and consistently capture evapotranspiration losses. As recommend that, this method will guide meteorologists, hydrologists, agronomists and irrigation engineers in the calculation of reference and crop evapotranspiration and estimating crop water demand for rain fed and irrigated agriculture.

Zarei et al., (2015) had been carried out on comparing several methods to estimate reference evapotranspiration in Kowsar research stations. The major comparison methods under taken during this study was FAO-56 Penman Monteith, Blaney-Criddle, Hargreaves-Samani modified 2, Pan Evaporation, Jensen-Haise and Thornthwait. The finding indicates that FAO-56 Penman Monteith method was pronounced as a new standard for reference evapotranspiration and it advised on procedures for calculation of various parameters and it overcomes shortcoming of the previous FAO Penman methods and provides values more consistent with actual crop water use data worldwide.

Ali and Abd El-wahed, (2014) Also conducts on assessment of several reference evapotranspiration estimation methods under coastal Mediterranean conditions. Based on this study, FAO-56 Penman Monteith method was ranked as the best method for all climate conditions. Other researchers, Smith et al., (1991), recommend that Penman Monteith method can be used as the standard method to estimate reference evapotranspiration when compared to other methods.

2.13 Compare the available river flow with irrigation requirement of dominant crops

The total quantitate of water required to compensate the evapotranspiration loss from the cropped field is defined as crop water requirement. The values for crop evapotranspiration and crop water requirement are identical. Crop water requirement refers to the amount of water that needs to be supplied, while crop evapotranspiration refers to the amount of water that is lost through evapotranspiration. The irrigation water requirement represents the difference between the crop water requirement and effective rainfall. For agricultural production, effective rainfall refers to the portion of rainfall that can effectively be used by plants (Mahtsente and Birhanu, 2015).

3. MATERIAL AND METHODS

3.1 Description of the study area

3.1.1 Location of the study area

Teme watershed is one of among other watershed of Abbay sub basins and situated at $10^{\circ} 45'$ N - $11^{\circ} 1'$ N latitude and $37^{\circ} 52'E$ - $38^{\circ} 0'E$ longitude in East gojjam zone, Amhara Region, Ethiopia. The watershed covers a total area of 18,255 ha at altitude of 1682 m to 4043 m above sea level (Figure 3.1).

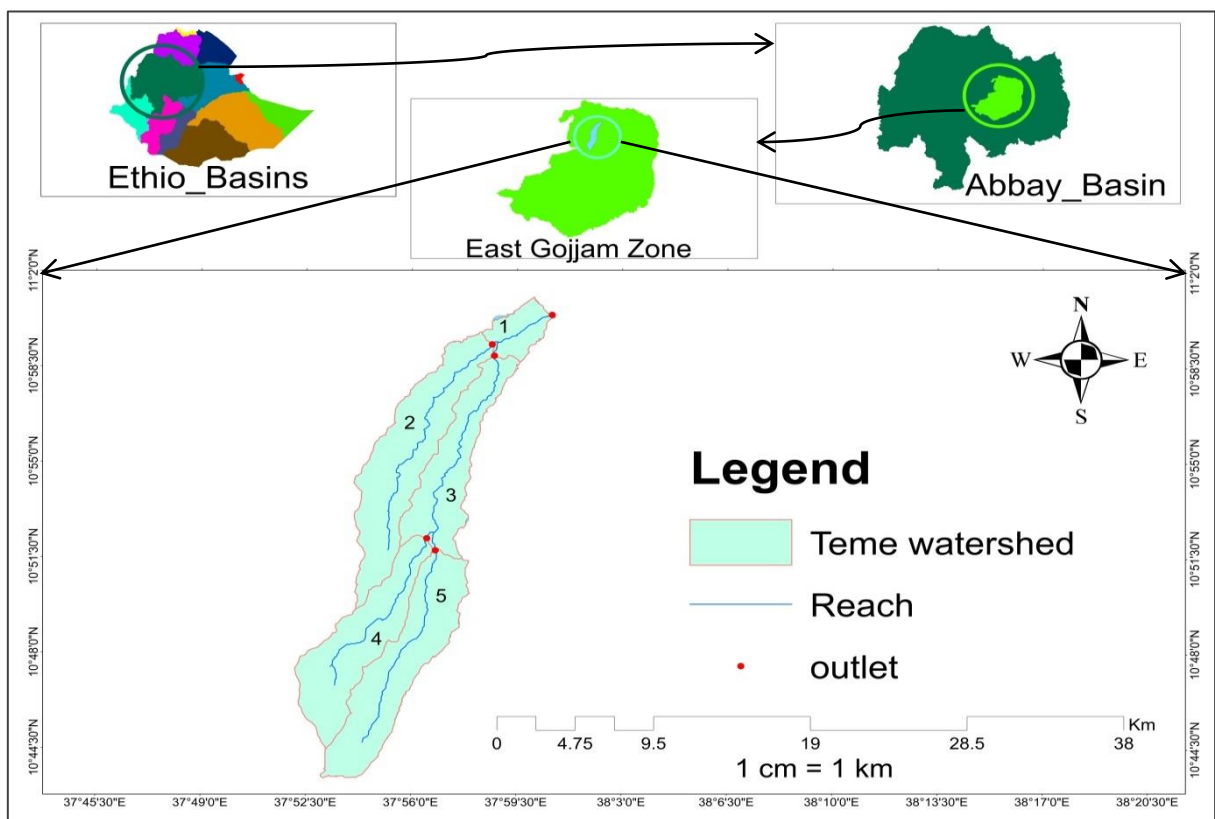


Figure3. 1: Location Map of study area

3.1.2 Topography

Topography is defined as the arrangement of natural and/or artificial physical feature of the land. The topography of the study area covers different topographic features with elevation

ranging from 1682 to 4043 meters above sea level as shown below figure (3.2). On the southern part of the study watershed, there is sloping land which is sloped towards the river feature. Yet, in northern part of the watershed, there is complicated land with higher and lower slopes. On the middle part of the study area, its slope is decrease gradually becomes gently slope.

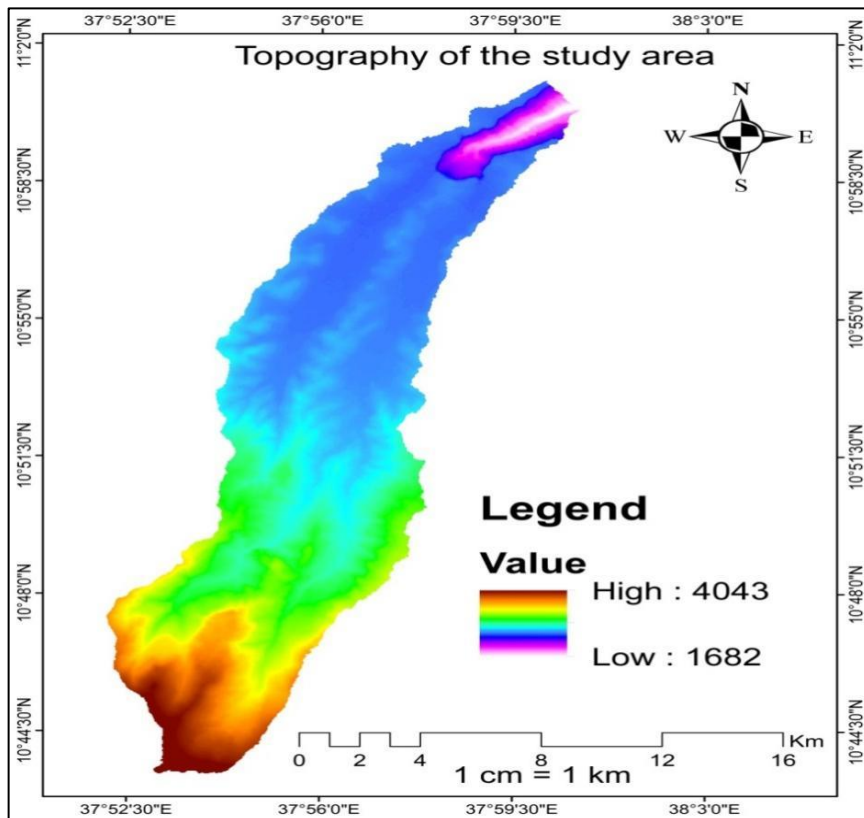


Figure3. 2: Topography of the study area

3.1.3 Climate

Traditionally the country has five climate zones named: Wurch, Dega, Woina dega, Kola and Berha with altitude of greater than 3200 m, 2300-3200 m, 1500- 2300 m, 500- 1500 m and less than 500 m respectively (Alemneh, 2003). The climate zone of the study area includes Wurch, Dega and Woina dega, since its altitude ranges from 1682 to 4043 meters above sea level.

3.1.3.1 Rainfall

In traditional way, the watershed has two rainfall seasons named: Belg rain season (short rain season) from April to June and Kiremt rain season (long rain season) from July to September. The main rain season in the study area is occurring from June to September. Annual minimum and maximum rainfall ranges from 920.96 mm to 1392.41 mm. The highest and the lowest rainfall are recorded in the month of July and January respectively.

3.1.3.2 Temperature

In Teme River watershed, the average temperature range from 8.17°C to 25.91°C. Maximum and Minimum temperature of the study area ranges from 18.08°C to 26.62°C and 7.25°C to 11.77°C respectively. Its highest maximum and lowest minimum temperature is observed in the month of March and January respectively.

3.1.3.3 Relative Humidity

Its relative humidity of the watershed is ranges from 43.79% to 76.78%. The highest humidity is observed in the month of August and lowest humidity is observed in the month of February.

3.1.3.4 Wind speed

The watershed annual wind speed is 1.41 m/s. The maximum and minimum wind speed of the watershed is observed in the month of May and August respectively.

3.1.3.5 Sunshine

Sunshine hours of the watershed is varies from 5.74 hours/day to 9.63 hours/day. The highest sunshine hours are observed in the month of December and the minimum sunshine hours are recorded in the month of July.

3.2 Data collections and analyses

3.2.1 Identification of suitable irrigable site for surface irrigation

For the accomplishment of the studies objective, different data's were utilized. Different data's from their source were collected for the specific purpose of estimating the available surface water, Model calibration and validation, digital representation of the topography, land use classification, slope suitability, soil suitability, water source proximity and finally for finding suitable site for surface irrigation as described below table (3.1).

Table3. 1: Required data and their source with purpose

Data type	Source of data	Scale/period	Description/purpose
DEM	Downloading from Earth explorer - USGS	30m*30m 01/01/2021 to 03/31/2021	For further processing in SWAT2012 model
Landsat8.0 image	Downloading from Earth Explorer - USGS	30m*30m 01/01/2021 to 03/31/2021	LULC identification
Stream flow data	MoiWEE	1997 to 2010	Calibration and validation
FAO/UNESCO soil map of East Africa available in Arc/info format	GIS and Remote Sensing Department, ministry of water resources	1997	Classification of dominant soil groups
Meteorological data	NMSA of Ethiopia	1990 to 2018	Estimation of surface water

The assessment of the available irrigable site for surface irrigation was carried out by considering land suitability evaluation factors such as slope, soil (depth, texture and drainage) LULC and distance from water supply. First, the individual suitability parameters were analyzed by using Arc GIS 10.3 software and finally weighted overlay analysis was done

using MCDM method of AHP process in spatial analysis tool by creating a suitability model to get suitable irrigable site.

3.2.1.1 Slope suitability assessment

Slope is one of the most vital environmental factors that influence potential irrigable land for surface irrigation. Primarily, the factor is influenced by duration and intensity of rainfall, erodibility of soil and farming method. By using 30*30m spatial resolution SRTM DEM of the study area, the slope Map was derived using “spatial analysis tool” in Arc GIS 10.3 Software. SRTM DEM of the study area was downloading from internet by importing the shape file of the study area to United States Geological Survey (USGS) Earth explorer and Configure its coordinate system to UTM projection and WGS 1984 datum. The derived slope was classified based on the classification system of reclassification reclassify tool. Slope suitability classification was ranges from slope between 0-2% (S1), slope between 2-5% (S2), slope between 5-8% (S3) and slope greater than 8% (N) which represents highly suitable, moderately suitable, marginally suitable and not suitable respectively for surface irrigation development (FAO, 2006).

3.2.1.2 Soil suitability assessment

Soil is also one of the key factors in determining the suitability of surface irrigation. Physical characteristics of soil (depth, texture and drainage) of the study area were derived from the FAO website Harmonized world soil database, in Environmental System research Institute (ESRI) shape file format of version 1.21. The dominant soil groups classified in the study area obtained from FAO/UNESCO soil map of East Africa (1997) available in Arc/info format were Eutric Leptosols, Eutric Vertisols, Haplic Alisols and Haplic Luvisols. In this study only the physical properties of this soil group (depth, texture and drainage) were considered for

irrigation suitability analysis. For further (overlay and others), soil vector layer (shape file) was converted in to a raster layer using conversion tool “Polygon to Raster or Feature to Raster module”.

After the rasterized, soil map of the study area was reclassified based on the basic physical parameters of soil (texture, depth, and drainage) of the study area and using overlay tool in Arc GIS 10.3 spatial analysis, weighted overlay analysis of this factors were performed to determine soil suitability for surface irrigation. Then the new values were reselected for each soil factor in order of their irrigation suitability rating based on common evaluation scale 1- 9 available in weighted overlay analysis within 33% for texture, 33% for depth and 34% for drainage weights were given. As a final point soil suitability map of each parameter was developed through factor rating of S1, S2, S3 and N by reclassified the raster layer based on FAO classification guideline.

3.2.1.3 LULC suitability assessment

LULC information of the study area was obtained from Landsat 8.0 image having 1, 2,3,4,5 and 7 bands with 30m*30m spatial resolution. Its classification was generated by using ERDAS imagine software by the support of Google Earth and partial observation within some part of the field for the use of determining suitability of the watershed for surface irrigation practice. The true color composite image was created by combining the spectral bands that mostly are similar to the range of human eye for land use land cover analysis by using ERDAS imagine 2014 software.

The class of LULC of the Teme watershed was ranked based on their importance for surface irrigation potential with evident cost to change for cultivation and environmental impacts

under the watershed. Finally LULC type of watershed was reclassified in to four suitability classes named as, highly suitable, moderately suitable, marginally suitable, and not suitable. To understand the accuracies of the datasets used in this study, the accuracy assessment was performed using ground truth data. The software package performs segmentation and classification then it exports the results as polygons in the ESRI shape file format. Thus, to do classification accuracy assessment the polygons converted to grids of irrigated areas. Then, grid values extracted using extract values to points.

3.2.1.4 Distance from water source (supply)

Distance from water source is one of the most important factors to identify irrigable land by considering topography of the watershed. It was calculated using SRTM DEM of 30m*30m cell size and reclassified using “spatial analysis tool” as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable (N). The reclassified distance was used for weighted overlay analysis combined with other suitability analysis factor.

3.2.1.5 Weighted overlay analysis

To find a suitable land for surface irrigation a suitable model is needed. Its required model with logic was analyzed through MCDM methods (FAO, 1976). Aziz et al., (2016) recommended for future researchers due to, AHP method is suitable for ranking and analyzing a complex decision making problems and also he regards as one of perfect and easiest method because of it is easy to use and make room for checking and reducing the inconsistency in opinions, AHP method was used in this study.

Satty (1977), develop a required model with logic for producing weights under the AHP process with a weighted linear combination and he develops a comparison matrix to compare a suitability parameter one to one with each other. Slope factor, soil factor (texture, depth and

drainage), land use land cover factor and distance factor were used as the input for irrigation suitability model to find the most suitable land for surface irrigation. The pairwise comparison matrix was prepared to express the relative importance and its scale of importance was broken down from a value of “1 to 9” as shown in table below (3.2).

Table3. 2: Pairwise comparison scale and definition (Saaty, 1977)

Intensity of importance	1	3	5	7	9	2, 4, 6 8
Definition	Equally important	somewhat more important	Much more important	Very much More important	absolutely more important	Intermediate value

The complete pairwise comparison matrix contains multiple paths by which the relative important of criteria can be assessed; it’s possible to determine the degree of consistency that has been used in developed ratings.

$$CIR = \frac{CI}{RI} \dots\dots\dots (3.1)$$

$$CI = \frac{\lambda_{max} - n}{n-1} \dots\dots\dots (3.2)$$

Where:

CI = Consistency index

λ_{Max} = Largest or Principal eigenvalue of the matrix

n = Number of elements being compared in the matrix

RI = Random index obtained from table that depend on numbers of elements.

Table3. 3: Random index table (Saaty, 1980)

n	1	2	3	4	5	6	7	8	9	10	11	12
RI	0.00	0.00	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.48

3.2.2 Surface water availability assessment

The available surface water of Teme River watershed was estimated by using Arc SWAT2012 Model using meteorological data of four stations named: “Debrework, Motta, Gindewoin and Yetnora” obtained from National Meteorological Service Agency of Ethiopia, land use land cover data with code, soil data with code, slope and SRTM DEM data of the study area. Stream flow data obtained from the MoIWEE; department of hydrology used for both flow calibration and validation through SWAT CUP Sufi 5.1.2.6 software after sensitivity analysis.

3.2.2.1 Data pre-processing and checking

Data’s needed for specific purpose may contain unnecessary errors due to either instrumental failure or absence of the observer. So, before using the data for desired purpose, the data should be checked and the errors should be removed, unless errors can have negative effects on the reliability confidence and accuracy of the estimating result. For reducing such type of error we need to check the homogeneity and data consistency that is used for a specific purpose. Specifically, analysis of hydrological and meteorological data should have to be extended to prepare input data for estimation of irrigation water requirement and assessment of water resources respectively.

3.2.2.2 Filling missing rainfall data

Some rainfall stations may have short or long breaks in the records because of either failure of measuring device or the recorder reading error. Mostly there are two methods that used to estimate missing rainfall data named as: Arithmetic mean method and Normal ratio methods. If annual rainfall of the index station (gauged stations whose data are used to calculate the missing station data) lies within $\pm 10\%$ of annual rainfalls of interpolation station (stations whose data are missing) then we apply Arithmetic mean method to determine the missing

rainfall record otherwise Normal ratio method was used for this purpose (Singh, 1994). Simple mathematical equation was applied to quantify the total percentage of the missing value from the total data series as follows (Ahmednasir and Nade, 2020).

$$\% \text{ of missing data} = \left[\frac{X_1}{X_2} \right] * 100 \dots\dots\dots (3.3)$$

Where: X₁ is count of missing data, X₂ is whole data set.

In this study Normal ratio method was used because in this region the annual rainfalls among stations differ by more than 10%.

$$PX = \frac{1}{N} \left(\sum \frac{Px}{Pi} * Pg \right) \dots\dots\dots (3.4)$$

Where:

PX = Missing data.

P_x = Annual average precipitation at the gauge with the missing data.

P_i = Annual average values of neighboring station.

P_g = Monthly rainfall data in all stations for the same month of missing station.

N = Total number of gauge under considerations.

However, for one day gap, the average value between the previous and the next day was used and for very short gaps (up to 3 days) mean ten day values for the same time period was used. Other metrological data also filled with the same method and it presents in the appendix table.

3.2.2.3 Homogeneity of rainfall data

Real world has lacking of certain behavior or trends and similarly contain many errors. However, any hydrological design in the real world needs homogeneity of a recorded data for stastical analysis, because uncertainty of the recorded data may lead to poor predictions at the time now and for the future (Nurhamidah et al., 2021). It is desirable to distinguish changes in

the homogeneity of precipitation records within a particular study area. To identify uncertainty about possible change graphical method was used in climatology and hydrology to obtain some understanding about the homogeneity of recorded data as described in figure (3.4) below.

Table3. 4: Mean monthly rainfall data of four meteorological stations (mm)

Stations	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
D.work	11.2	11.4	41.1	41.1	85.4	97.8	256.3	210.4	88.1	45.2	20.2	12.7
Motta	5.2	7.5	32.9	52.4	86.1	121.8	316.6	309.2	172.4	107	33.7	11.2
G.woin	14.5	17.5	58.7	66.1	101.9	146	394.2	310.5	141.3	79.7	35.2	26.7
Yetnora	5.1	12.7	47.5	64	97	145.1	299.6	260.1	135.1	60.8	20.3	7.5

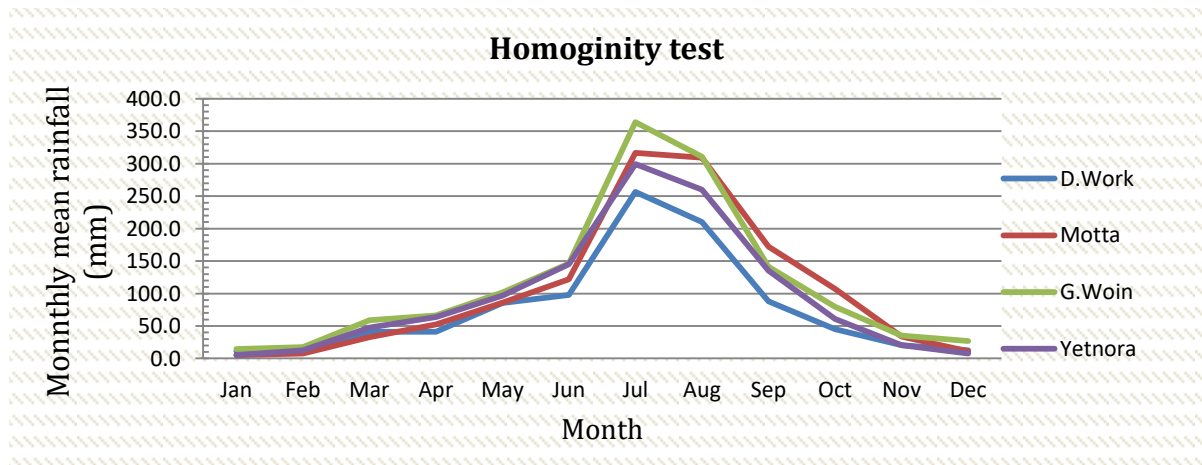


Figure3. 3 : Homogeneity test chart in each meteorological station

3.2.2.4 Consistency of rainfall data

For further application, the analysis of rainfall data is very important and its consistency was checked by graphical method such as double mass curve. To check the degree of consistency, it provides the following value of coefficient of correlation as follows (Buishand, 1982).

$r = 1$, direct linear correlation,

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

$-0.6 < r < 0$, insufficient-reciprocal correlation,

$-1 < r < 0.6$, good reciprocal correlation

and $r = -1$, reciprocal correlation.

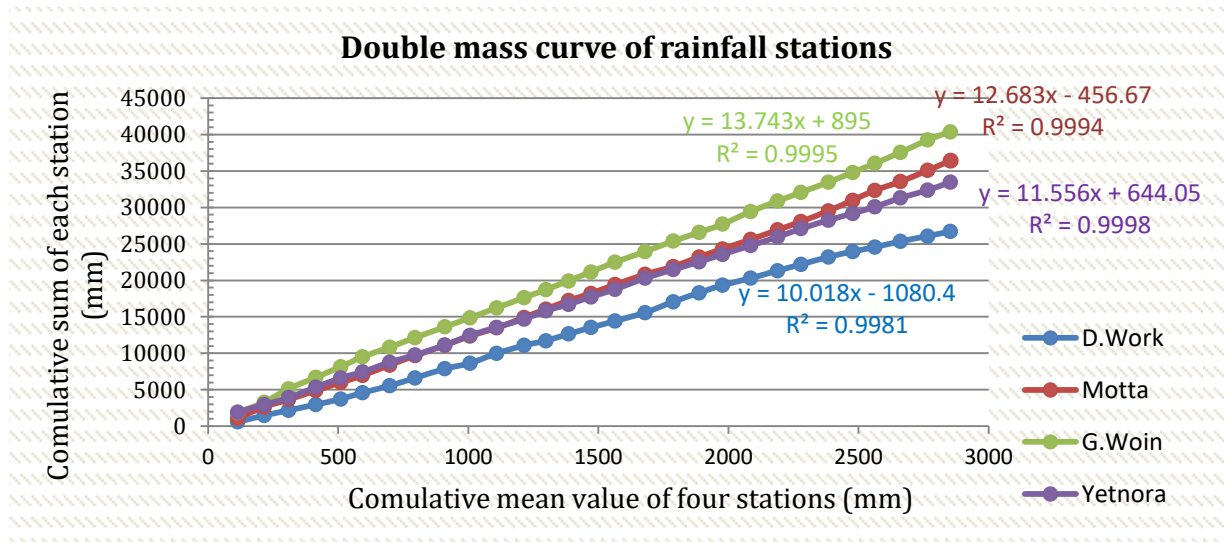


Figure3. 4: Double mass curve for consistency analysis

3.2.2.5 Weather data generation

WXGEN weather generator is mostly used to generate daily climate data for SWAT Model where input climate data are not fully available. Within used meteorological stations (Debrework, Motta, Gindewoin and Yetnora) have both temperature and precipitation data, yet only Motta station was synoptic station used for generating the remaining weather data of others weather generator station. After preparing weather generator parameter and location table automatically, the daily meteorological data with the missing data filled with a missing data identifier of NA and including the corresponding location table prepared according to the SWAT format were loaded in to the model. SWAT weather database Vo1803 were extracted and SWAT takes data of each climatic variable from the nearest weather station measured from the meteorological stations.

3.2.2.6 SWAT Model analysis

Subsequently collecting the entire data which are important for SWAT Model, the Model were run and then read the simulated output of the stream flow. In this study, the model was adjusted to run the simulations of 29 (1990 to 2018) years of data with 2 year warm up period for further analysis. However, instead of directly used of the simulated result, it is necessary to evaluate the ability of the model for sufficiently prediction of the stream flow through sensitivity analysis, model calibration and model validation (Whit and Chaubey, 2005).

3.2.2.7 Model sensitivity analysis, calibration and validation

It is necessary to identify model parameters that exert the highest influence on model calibration or on model predictions. Sensitivity analysis and calibrations are difficult with large number of parameter due to making tedious and time consuming to change all these parameters to calibrate the model. Parameters with small sensitivity value do not significantly affect the model outputs. However, parameters with medium and high sensitivity value significantly affect the model output. So, model parameters that have medium to higher sensitivity value must be selected with care. Two type of sensitivity analysis are generally performed named as “Local”, by changing values one at a time and “Global”, by allowing all parameters values to change (Arnold et al., 2012). In this research Global sensitivity analysis was used to perform the sensitivity of parameters. Global sensitivity analysis use t-stat and p-value to determine sensitivity of each parameter. The t-stat sensitivity analysis identify the sensitivity of parameter by entering its value to absolute and then have large absolute value are more sensitive. Whereas, p-value sensitivity analysis implements after iteration, p-value near to zero has more sensitive.

Calibration is a modification of model parameters by checking the results against observations to ensure similar response over time. Calibration was done with the carefully selected parameter value for model input parameters that have been identified as most sensitive. The parameter values are then adjusted to more closely match the model behavior to that of the watershed. Its process of adjustment can be done with manual or automatic (Abbaspour et al., 2007). While in this study automatic method was used to calibrate the model by observed stream flow data. Calibration should be ongoing at least until the minimum recommended value were embraced by the model, $R^2 > 0.6$, $NSE > 0.5$ and $RVE < \pm 15$ (Santhi et al., 2001).

After calibration, model validation was done for demonstrating the given set of a specific model is capable of making sufficiently accurate simulation, while sufficiently accurate simulation can vary based on project goals. Its procedure comprises running a model by means of parameters that were determining during the calibration process and comparing there prediction to observed data not used in the calibration (Refsgaard, 1997). In general good calibration and validation should involve multiple evaluation skills (Boyle et al., 2000).

3.2.2.8 Model performance evaluation

To assess the performance of SWAT model for better reliability and prediction against the observed flow, the following efficiency criteria were used in calibration and validation period (Moriasi et al., 2007).

A. Coefficient of determination (R^2)

Coefficient of determination (R^2) provides a measure of how a well observed outcomes are replicated by the model. Ranges of R^2 lies between zero and one, which describes how match of the observed dispersion is explained by the prediction. Value of R^2 closer to one indicates that the agreement between the simulated and the measured flow is higher.

$$R^2 = \left[\frac{[\sum_{i=1}^n (Q_s - Q_s \text{ mean})(Q_o - Q_o \text{ mean})]^2}{[[\sum_{i=1}^n (Q_s - Q_s \text{ mean})]^2 [\sum_{i=1}^n (Q_o - Q_o \text{ mean})]^2]} \right] \dots\dots\dots (3.5)$$

Where:

Q_s = Simulated discharge (m^3/s),

Q_o = Observed discharge (m^3/s),

$Q_s \text{ mean}$ = Mean of simulated discharge (m^3/s) and

$Q_o \text{ mean}$ = Mean of observed discharge (m^3/s).

B. Nash-Sutcliffe Efficiency (NSE)

NSE indicates the degree of fitness of observed and simulated data; Value of NSE can range from $-\infty$ to 1. If the value of NSE is zero (0), it indicates that the model prediction are as accurate as the mean of observed data while an efficiency less than zero ($-\infty < NSE < 0$), indicates that the observed mean is a better prediction than the model. Generally if the value of NSE is closer to one indicates that the model performs extremely well.

$$NSE = 1 - \frac{\sum_{i=1}^n (Q_i - P_i)^2}{\sum_{i=1}^n (Q_i - Q_i \text{ mean})^2} \dots\dots\dots (3.6)$$

Where:

Q_i = Observed flow at i^{th} period,

P_i = Simulated flow at i^{th} period and

$Q_i \text{ mean}$ = Mean of observed flow at i^{th} period.

C. Relative Volume Error (RVE)

RVE measures the mean propensity of the simulated data either larger or smaller than their observed counterpart with optimal value of zero and low magnitude value indicates accurate simulation. The value may be either positive or negative with specific designates. Positive

value indicates model underestimation bias and negative value indicates model overestimation bias (Gupta et al., 1999).

$$RVE = \frac{\sum_{i=0}^n(Q_{ob} - Q_{sim})}{\sum_{i=0}^n(Q_{ob})} * 100 \dots\dots\dots (3.7)$$

Where:

RVE = Relative Volume Error (%),

Q_{sim} = Simulated flow (m^3/s),

Q_{ob} = Observed flow (m^3/s) and

n = Number of observation.

3.2.2.9 Transferring discharge of simulated river to site of interest

By using meteorological data, the available water in Teme River watershed was simulated. Discharge of simulated river was used to estimate discharge at site of interest, yet to estimate discharge at site of interest from simulated river discharge, both catchment characteristics such as LULC, soil type and slope of the catchment range should be similar and distance between the catchment should not be more than 50 km and also at least a minimum of 10 years mean monthly river flow at the catchment should be available. The discharge from simulated site was transferred to the site of interest using the following relation (FAO, 1997).

$$Q_{site} = \left(\frac{DA_{site}}{DA_{gauged}} \right)^n * Q_{gauged} \dots\dots\dots (3.8)$$

Where:

Q_{site} = Discharge at site of interest (m^3/s),

DA_{site} = Drainage area at site of interest (km^2),

Q_{gauged} = Discharge at gauged site (m^3/s) and

DA_{gauged} = Drainage area at gauged site (km^2).

The exponent “n” values fluctuate between 0.6 and 1.2. If the drainage area at the site of interest is within 20% of the drainage area at gauged site ($0.6 \leq DA_{\text{site}} \text{ divided by } DA_{\text{gauged}} \leq 1.2$), uses “n” equal to 1 otherwise 0.6 is used.

The discharge was transferred from sub watershed two to sub watershed three. Sub watershed three have similar suitability parameter characteristics such as slope range, soil type and land use land cover with that of sub watershed two as shown below in table (3.5).

Table3. 5: Characteristics of sub watershed two and sub watershed three

Suitability Parameters	Sub watershed two	Sub watershed three
Slope range (%)	0 – 2, 2 – 5 and 5 - 8	0 – 2, 2 – 5 and 5 - 8
Soil type	Eutric Vertisols and Haplic Alisols	Eutric Vertisols and Haplic Alisols
Land use/land cover	Agricultural land, grass land, shrub land, Forest area and build up area.	Agricultural land, grass land, shrub land, forest area and build up area.

3.2.3 Estimation of irrigation water requirement for dominant crops

In order to estimate irrigation water requirement of selected crops (Tomato, Maize and potato) in the potential irrigable site, the climatic station area of influence around the watershed were put in to consideration. The selection of irrigable crops depends on local adaptability (focuses on locally and regionally adapted crops) and market availability information’s of the study area obtained from local observation with local farmer interview. Irrigation water requirement of selected crops were quantifying by applying the CROPWAT 8.0 model and it were carried out with input of climatic (monthly mean of minimum and maximum temperature ($^{\circ}\text{C}$), relative humidity (%), sunshine duration (hours), wind speed at 2m high (m/s) and monthly rainfall), crop (sowing date, crop coefficient etc.) and soil (soil moisture (mm), infiltration

rate (mm/day), rooting depth (m) etc.) data's. The gross irrigation water requirement of the crop at the identified suitable irrigable site were estimated by considering both application and conveyance efficiency of surface irrigation (FAO, 2001). Conveyance efficiency is the efficiency of conveyance of water from the source to the point where it leaves the point of distribution, yet application efficiency is the efficiency of which the water living the distribution point of the irrigation system falls on the soil surface (Machibya, et al., 2004).

$$ET_C = K_C * ET_O \dots\dots\dots (3.9)$$

Where:

ET_C = Standard evapotranspiration (mm/day),

K_C = Crop coefficient and

ET_O = Reference evapotranspiration (mm/day).

Reference evapotranspiration (ET_O)

ET_O expresses the evaporative demands of the atmosphere at specific location and time of the year and does not consider crop and soil factor. In this research four climatic stations such as Debrework, Motta, Gindewoin and Yetnora were taken to compute ET_O . FAO Penman-Monteith method offers the best results with minimum error in relation to a living grass reference and it requires more data required by the model than others (Ali and Abd Ei-wahed, 2014). The equation has the form:-

$$ET_O = \frac{0.408\Delta(Rn-G) + \frac{900\gamma}{T+27.3}U_2(es-ea)}{\Delta + \gamma(1+0.3U_2)} \dots\dots\dots (3.10)$$

Where:

ET_O = Reference evapotranspiration (mm/day),

Rn = Net radiation at the crop surface (MJ/day m²),

G = Soil heat flux density (MJ/day m^2),

T = Mean daily air temperature at 2m height ($^{\circ}C$),

U_2 = Wind speed at 2m height (m/s),

e_s = Saturated vapor pressure (Kpa),

e_a = Sctual vapor pressure (Kpa),

$e_s - e_a$ = Saturation vapor pressure deficit (Kpa),

Δ = Slope vapor pressure curve (Kpa/ $^{\circ}C$) and

γ = Psychometric constant (Kpa/ $^{\circ}C$).

After evaluating reference evapotranspiration (ET_0) need to determine crop water requirement (CWR) of selected crops. Most of the time ET_C and CWR in a local irrigator are identical or indistinguishable, while ET_C refers to the amount of water loss through evapotranspiration and CWR refers the amount of water that is needed to compensate for loss.

$$NIR = ET_C - P_{ef} \dots\dots\dots (3.11)$$

Where:

NIR = Net irrigation requirement of crop and

P_{ef} = Effective rainfall (mm).

Effective rainfall is a portion of rain that falls during the growth period of the crop which is available to meet the consumptive water need of the crop.

$$GIWR = \frac{1}{E} (FWF * A_{crop}) \dots\dots\dots (3.12)$$

Where:

$GIWR$ = Gross irrigation water requirement (m^3 /month)

FWS = Field water supply (l/s/ha)

Acrop = Potential irrigable area to be cultivated with selected crop (ha)

E = Irrigation efficiency (%)

$$GIR = \frac{1}{E}(NIR) \dots\dots\dots (3.13)$$

Where:

GIR = Gross irrigation requirement and

E = Efficiency of irrigation (%).

In Ethiopia, most of the time irrigation efficiency accounts in the range of 40% up to 60% under surface irrigation system (Machibya et al., 2004). In this study the value of irrigation efficiency was taken as average value of the recommended range which is 50%.

3.2.4 Methods of the Study

After collecting of necessary data's for this research and quality checking have been done carefully, identification of suitable land, mapping the suitable land for surface irrigation development, estimation of available flow, determination of irrigation water requirement, Comparing the Gross Irrigation requirements of the selected crops for the identified suitable land with simulated river flow and finally knowing availability of potential irrigable land for surface irrigation development within the watershed were the main task of the this study.

To address objective of this study starting from data preparation up to knowing availability of potential irrigable land for surface irrigation in the watershed, a simple and clear conceptual framework is presented as follows in figure (3.5).

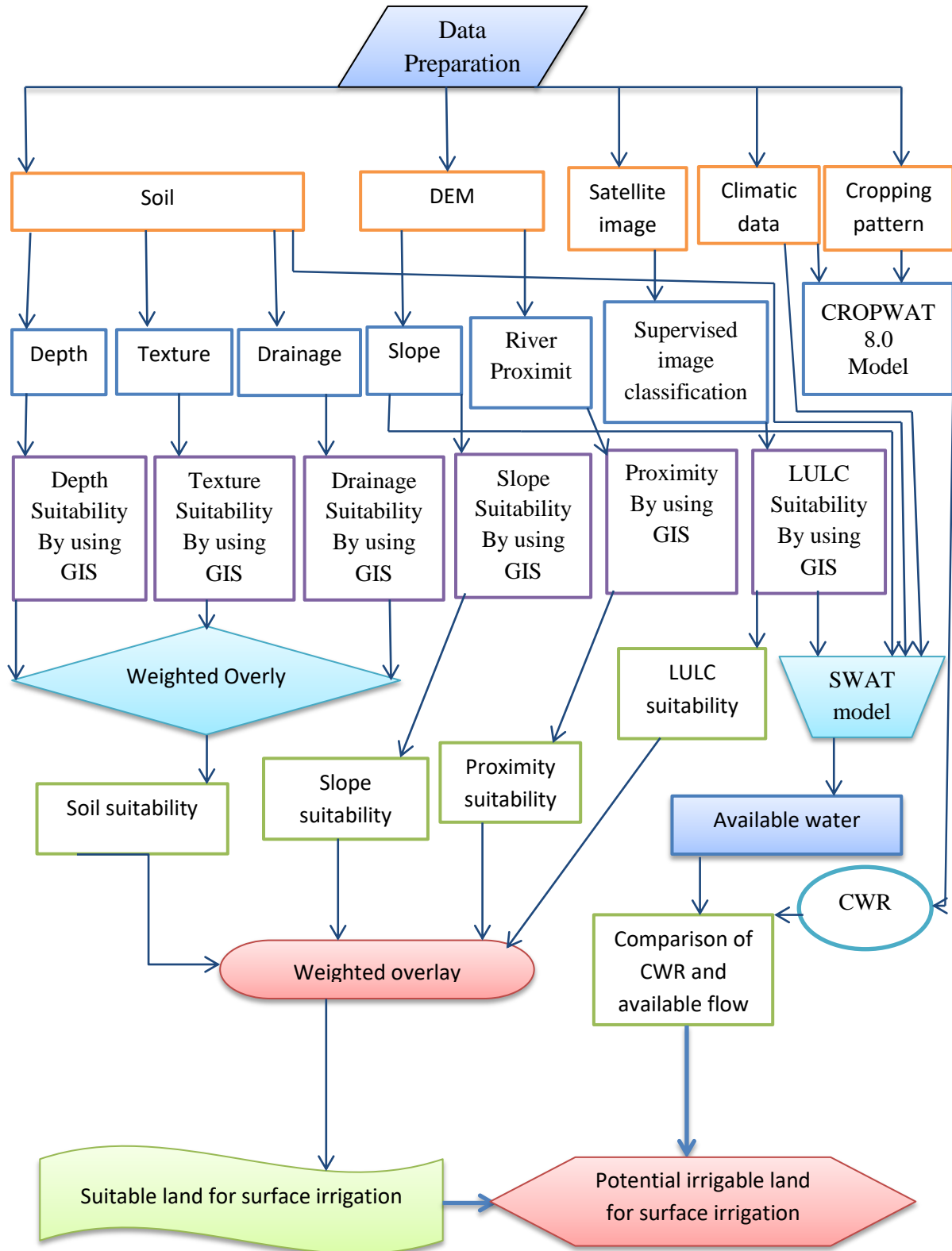


Figure3. 5: Conceptual frame work for surface irrigation potential assessment

4. RESULTS AND DISCUSSION

4.1 Identification of suitable land for surface irrigation

The analysis of surface irrigation suitability was identified by considering land suitability evaluation factors such as slope, soil, LULC and distance from the water source (supply).

4.1.1 Suitability based on slope

Slope map of the study area was classified in to four suitability classes (highly, moderately, marginally and not suitable class). Slopes less than 2% are very suitable whereas slopes greater than 8% are not suitable for surface irrigation (FAO, 1997). Slope of the watershed area was reclassified using “Reclassification tool” of ArcGIS 10.3 software Special Analysis tool by 30m*30m resolution SRTM Digital Elevation Model data clipped from freely available earth explorer USGS within a period of 01/01/2021 to 03/31/2021.

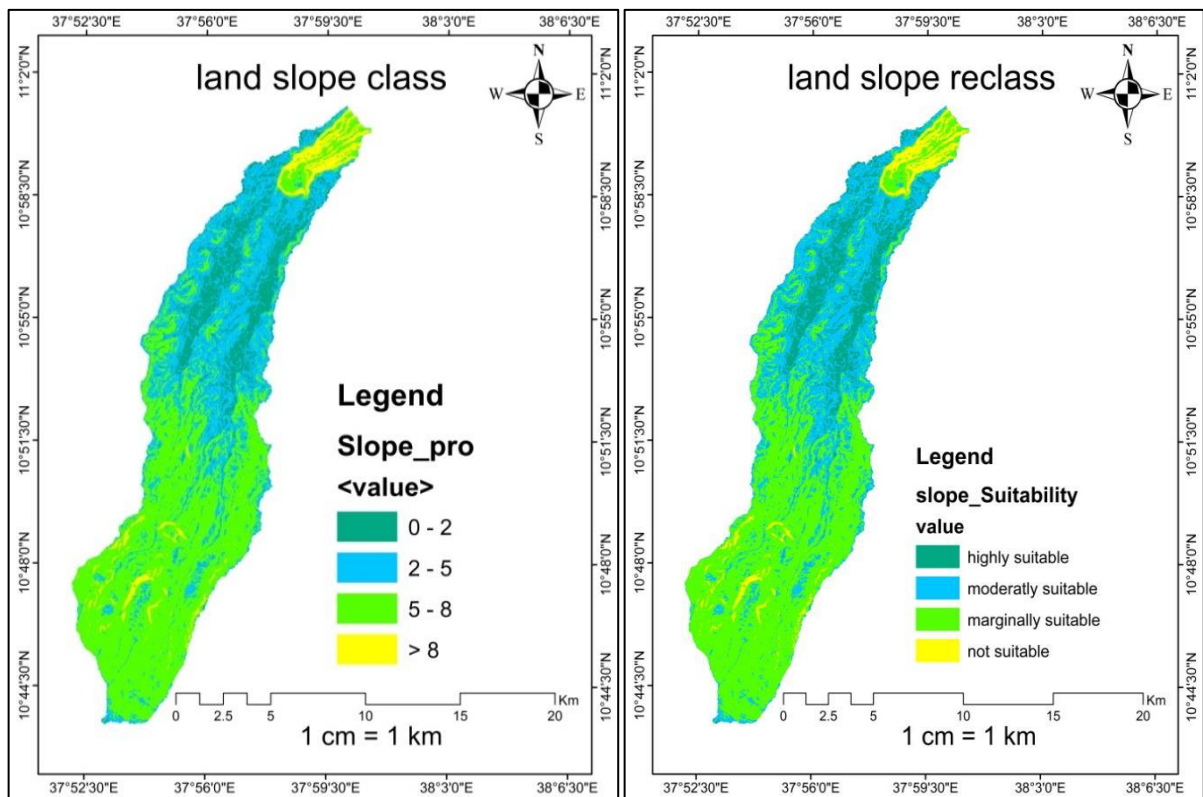


Figure4. 1: Slope class and suitability map of the study area

Table4. 1: Slope suitability class of the study area

Slope range (%)	Area coverage (ha)	Area coverage (%)	Suitability class
0 – 2	2332	12.8	highly suitable
2 – 5	5713	31.3	moderately suitable
5 – 8	9413	51.6	marginally suitable
> 8	797	4.3	not suitable

From the above table exhibited that 44.1% of the land was within the range of highly suitable to moderately suitable with respect to slope suitability and the remaining 55.9% from the total watershed area covers marginally suitable to not suitable for surface irrigation development.

4.1.2 Suitability based on soil

The dominant soil types of Teme watershed were Eutric Leptosols (LPe), Eutric Vertisols (VRe), Haplic Alisols (ALh) and Haplic Luvisols (LUh). From the total area of the study area, the area of each soil type covers 2921 ha, 3103.2 ha, 8762.4 ha and 3468.4 ha respectively.

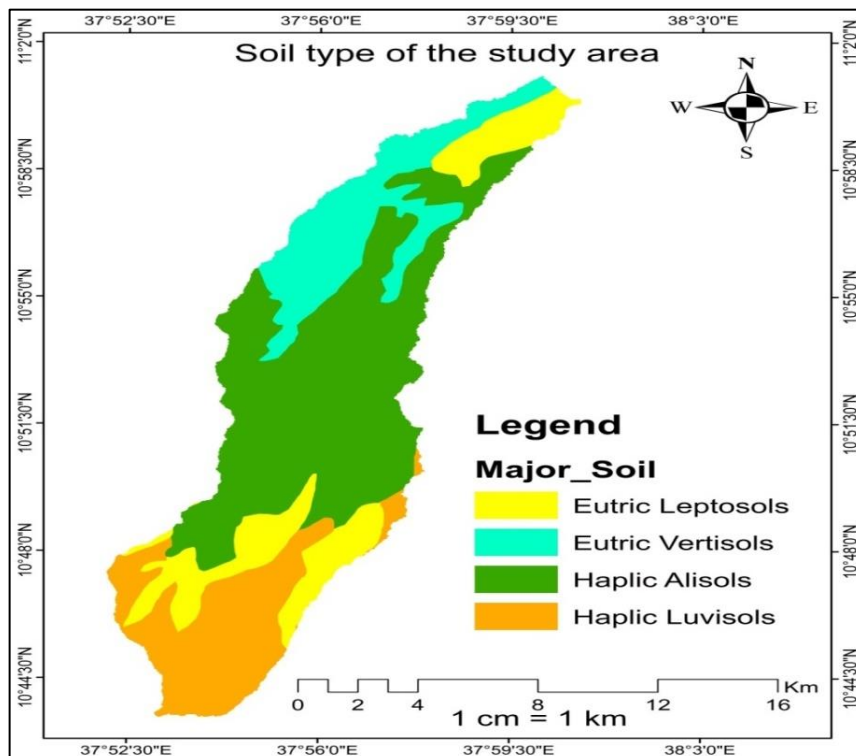


Figure4. 2: Soil type map of the study area

4.1.2.1 Suitability based on soil depth

The soil depth of the study area obtained from harmonized world soil database was varied from place to place, for instance most of the study area of soil depth are categorized as highly and moderately suitable for surface irrigation with soil depth greater than 150 cm and lies between 80 cm and 150 cm respectively, the remaining soil depth is less than 40 cm, which is not suitable. The soil depth map of the study area was analysis on Arc GIS 10.3 and evaluated for surface irrigation in terms of highly suitable, moderately suitable and not suitable classes with area coverage of 48%, 47% and 5% respectively as shown in figure (4.3) below.

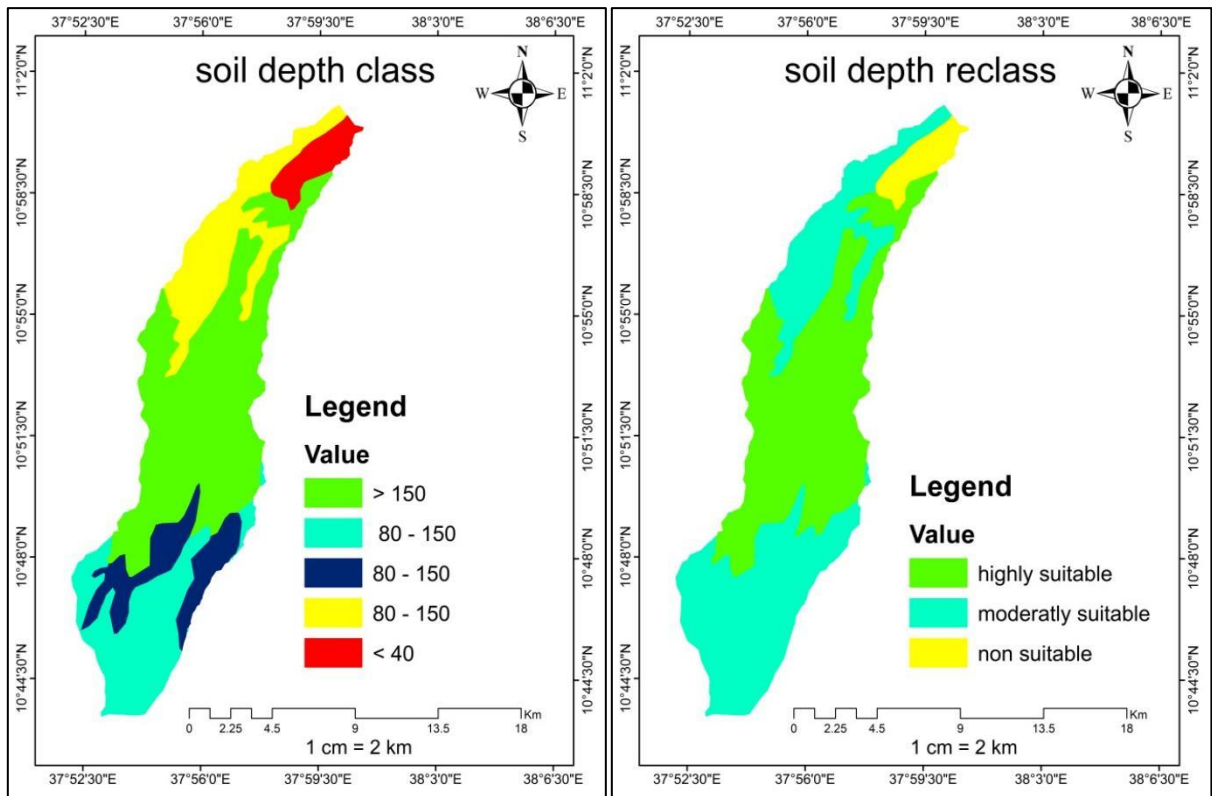


Figure4. 3: Soil depth map and suitability for surface irrigation in the watershed

4.1.2.2 Suitability based on soil drainage

Soil drainage is one of the important parameter of evaluation suitability area for surface irrigation. In current study area, four soil drainage classes which are somewhat excessive

drain; well drain, moderate and somewhat poorly drain classes were identified. The drainage suitability map of the study area shows that somewhat excessive drain soil covers an area of 41 ha, well drain soil 11,822 ha, moderate drain soil 5486 ha and somewhat poorly drain soil covers an area of 906 ha from a total study area of 18,255 ha.

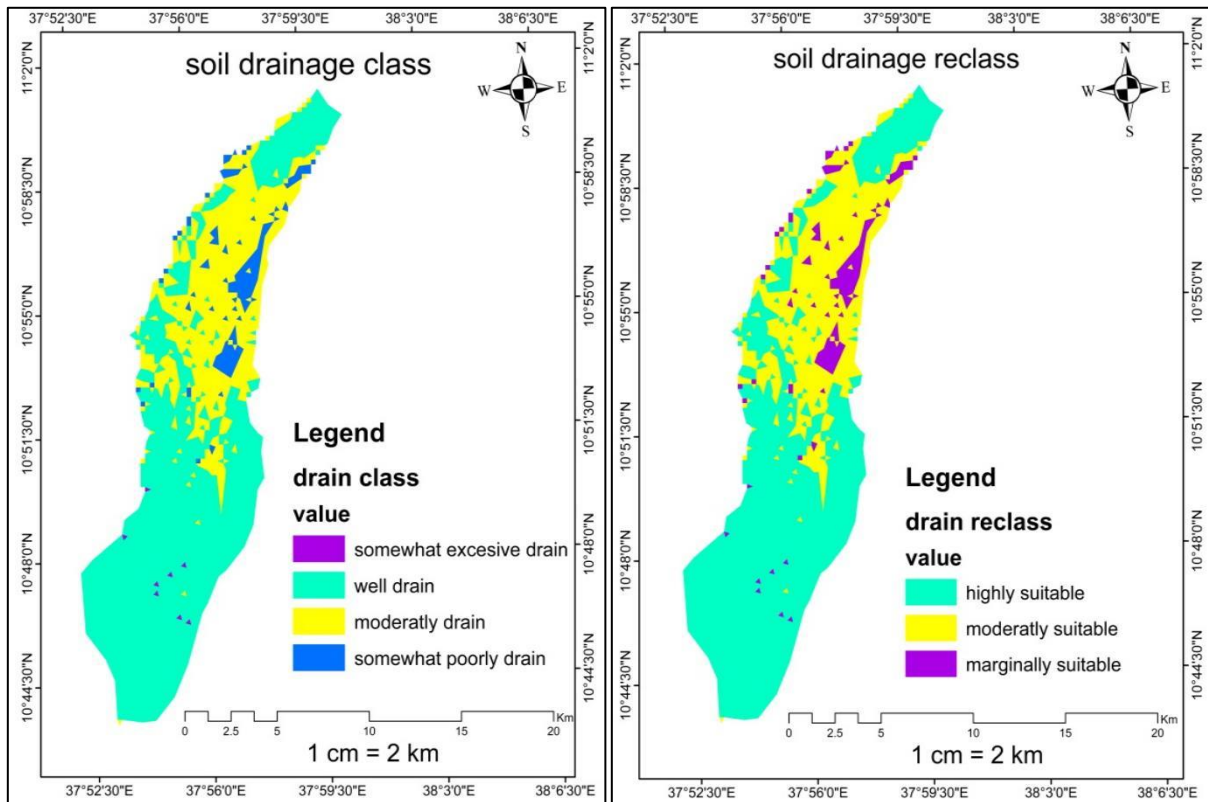


Figure4. 4: Soil drainage and suitability class of the study area

4.1.2.3 Suitability based on soil texture

Soil texture describes the proportion of three size of soil particles (sand, silt & clay) and/or fineness or coarseness of soil (Martin et al., 2017). Depending on this proportion, the soil texture in the study area was classified as sandy loam, sandy clay loam and clay texture soil, while most of the watersheds were dominated by sandy clay loam and clay texture soil. Clay soil is the most active soil for surface irrigation development and categorized as highly suitable, sandy clay loam soils were evaluated as moderately suitable and sandy loam soil

grouped as marginally suitable for surface irrigation development (FAO, 1976). Based on this classification, soil texture of the watershed covers an area of 36% highly suitable, 38.3% moderately suitable and 25.7% marginal suitable for surface irrigation within the study area.

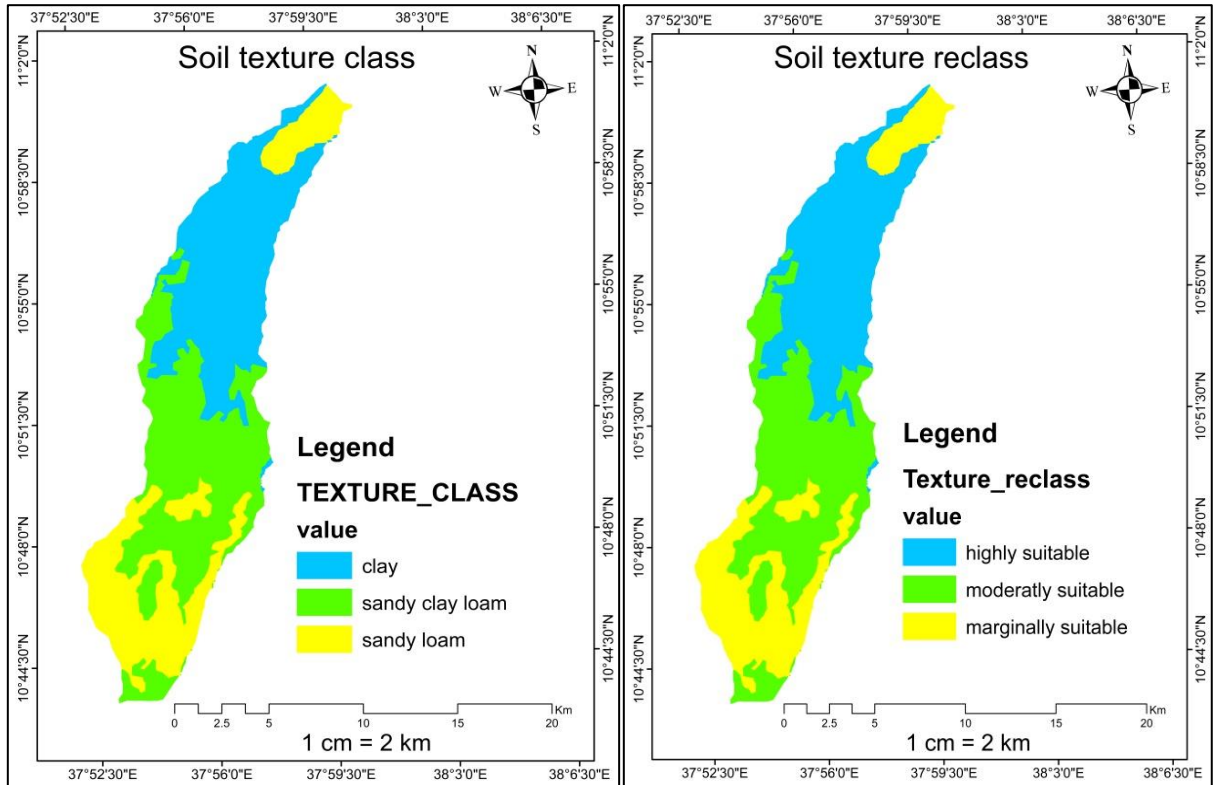


Figure4. 5: Soil texture map and suitability for surface irrigation

4.1.3 Weighted soil suitability

To classify potential suitable soils for surface irrigation development system, three soil suitability parameters (depth, drainage and texture) were used by using Arc GIS 10.3. In this suitability analysis, soil parameters has its own suitability classes; since soil depth has 3 suitable classes (highly, moderately and not) suitable, both soil drainage and soil texture has also 3 suitable classes (highly, moderately and marginally) suitable. In suitability evaluation of soil parameters for overlay analysis was taken 1 by 4 in 1 scale for the analysis. From soil suitability evaluation, result of the analysis pronounces in the table (4.2) and figure (4.6).

Table4. 2: Soil suitability class based on weighed overlay

No	Area coverage (ha)	Area coverage (%)	Suitability class
1	7522	41.2	highly suitable
2	8905	48.8	moderately suitability
3	1828	10.0	marginally suitable

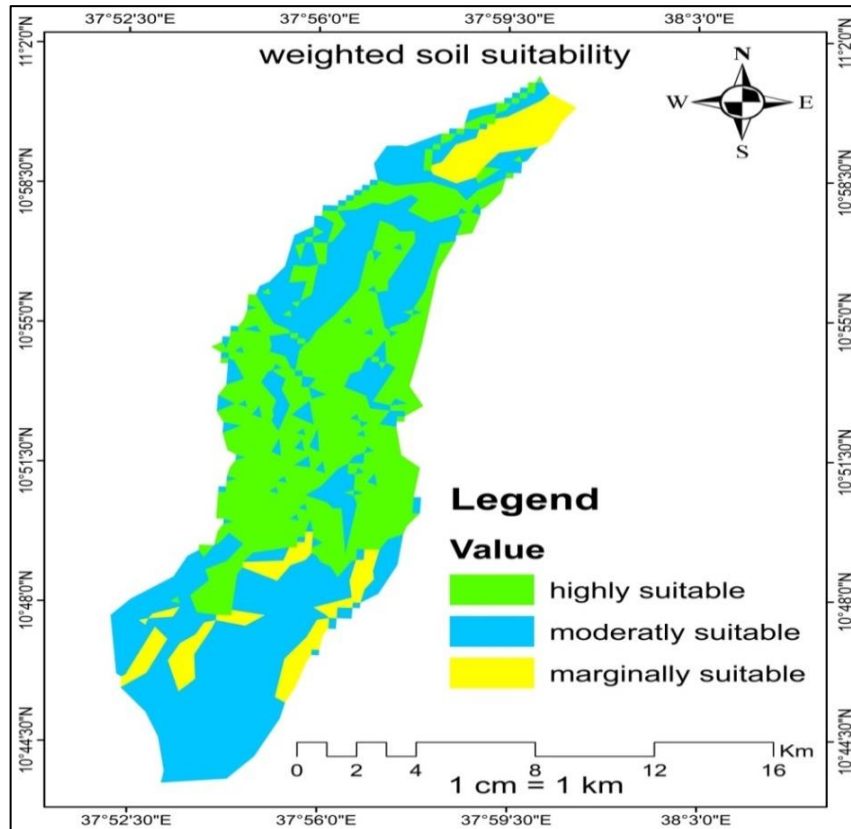


Figure4. 6: Weighted overlay soil suitability map

4.1.4 Land use land cover suitability

In order to identify land use land cover class of Teme River watershed, supervised classification was used for finding accurate image classification by using ERDAS imagine 2014 version software. For LULC suitability identification, satellite image of Landsat8.0 of the period 01/01/2021 to 03/31/2021 were used. From this classification six LULC classes were identified in the watershed. These classifications include agricultural land, shrub land,

grass land, forest area, built up area and barren lands. The accuracy assessment showed that overall accuracy of 86.3% as describes in table (4.3) and in the figure (4.7).

Table4. 3: Confusion Matrix for Teme watershed LULC Classification on year 2021 Map

Classification data	Ground Data in 2021GC						Total	UA (%)
	Agricultural land	Grass land	Shrub land	Forest land	Build up area	Barren land		
Agricultural land	15	1	0	0	0	0	16	93.8
Grass land	1	10	1	0	0	0	12	83.3
Shrub land	0	1	11	0	0	0	12	91.7
Forest land	0	1	1	12	0	1	15	80
Build up area	1	0	1	0	12	0	14	85.7
Barren land	0	0	1	0	1	9	11	81.8
Total	17	13	15	12	13	10	80	
PA (%)	88.2	76.9	73.3	100	92.3	90		OA = 86.3%

Hint, UA= User Accuracy, PA= Producer Accuracy and OA= Overall Accuracy

LULC classes' identification of the study area describes in table (4.4) and in the figure (4.7) below respectively.

Table4. 4: LULC class of the study area

LULC class	Area coverage (ha)	Area coverage (%)	Suitability class
Agricultural land	13068	71	S1
Grass land	417	3	S2
Shrub land	2598	14	S3
Forest land	1508	8	N
Build up area	328	2	N
Barren land	336	2	N

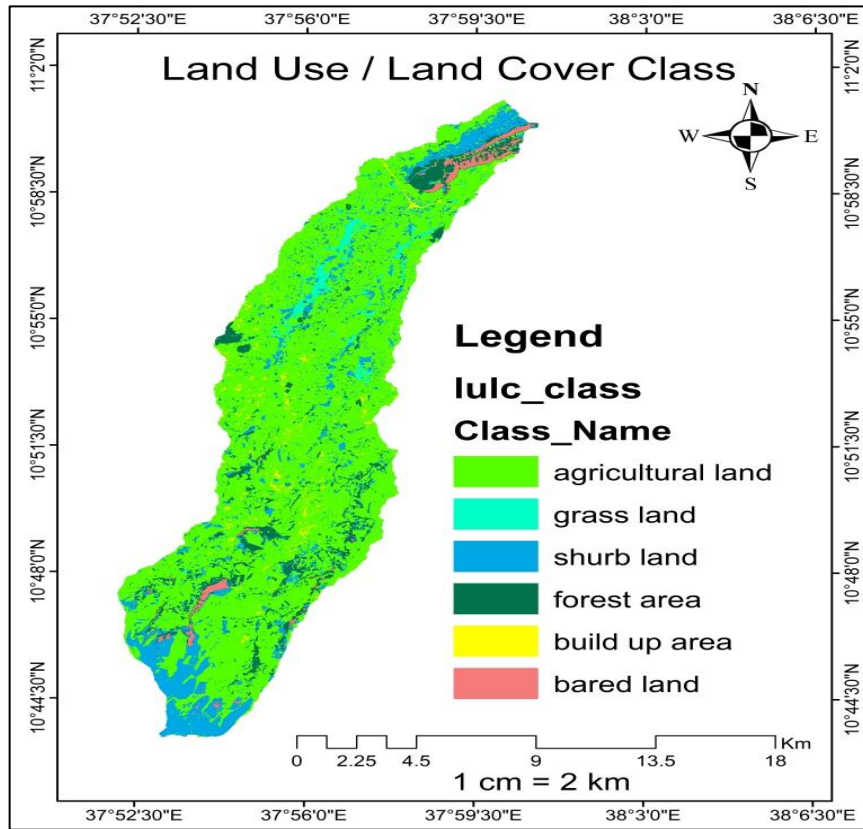


Figure4. 7: LULC class map of the study area

From the above land use land use map of the study area shows that agricultural land was the dominant land use as related to other LULC type of the study area of the total study watershed. The suitability of land use land cover class for surface irrigation improvement was categorized in to four suitability groups which are, highly suitable, moderately suitable, marginally suitable and not suitable as shown in table (4.5) and figure (4.8) below.

Table4. 5: LULC suitability class for surface irrigation development

LULC class	Area (ha)	Area (%)	Suitability class
Agricultural land	13068	71	highly suitable
Grass land	417	3	moderately suitable
Shrub land	2598	14	marginally suitable
Forest, Build up and Barren land	2172	12	not suitable

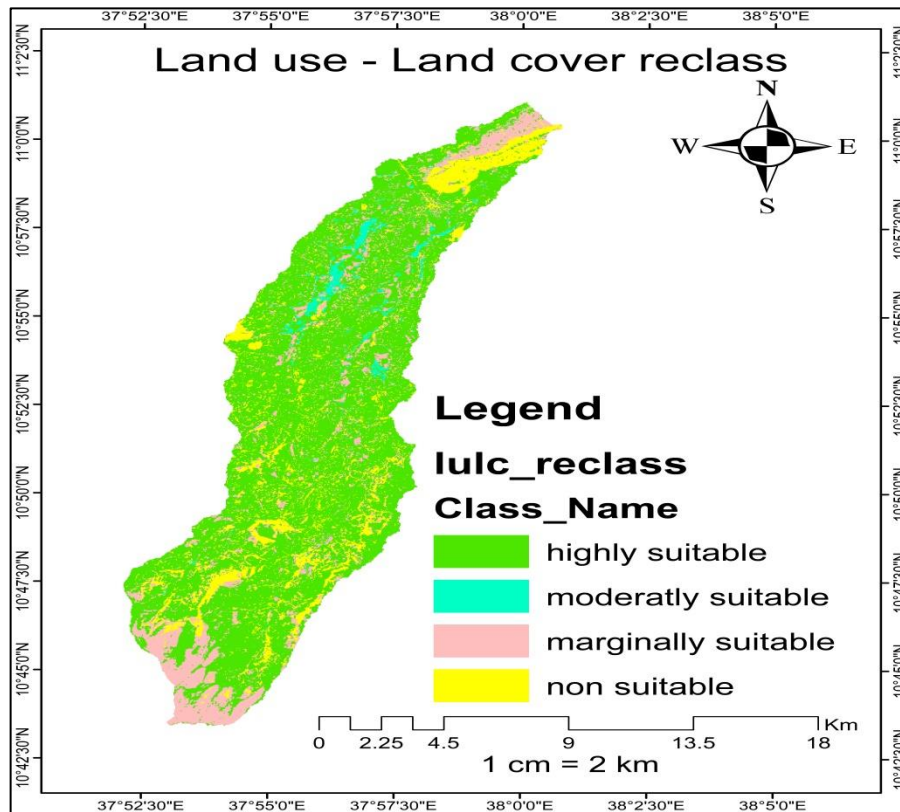


Figure4. 8: LULC suitability classification for surface irrigation development

4.1.5 Distance from the water source (supply)

If the location of command area is near to the river, the area is suitable for surface irrigation system. 89.5% of the distance from the River covers from highly suitable to moderately suitable of the watershed for surface irrigation development system while, 10.5% of the area covers from marginally to not suitable as shown table (4.6) below.

Table4. 6: River proximity suitability for surface irrigation development system

River Proximity (km)	Area (ha)	Area (%)	Suitability class
0–1.5	9144	50.1	highly suitable
1.5–3	7199	39.4	moderately suitable
3–5	1840	10.1	marginally suitable
>5	72.00	0.40	not suitable

Source: Edmealem (2018)

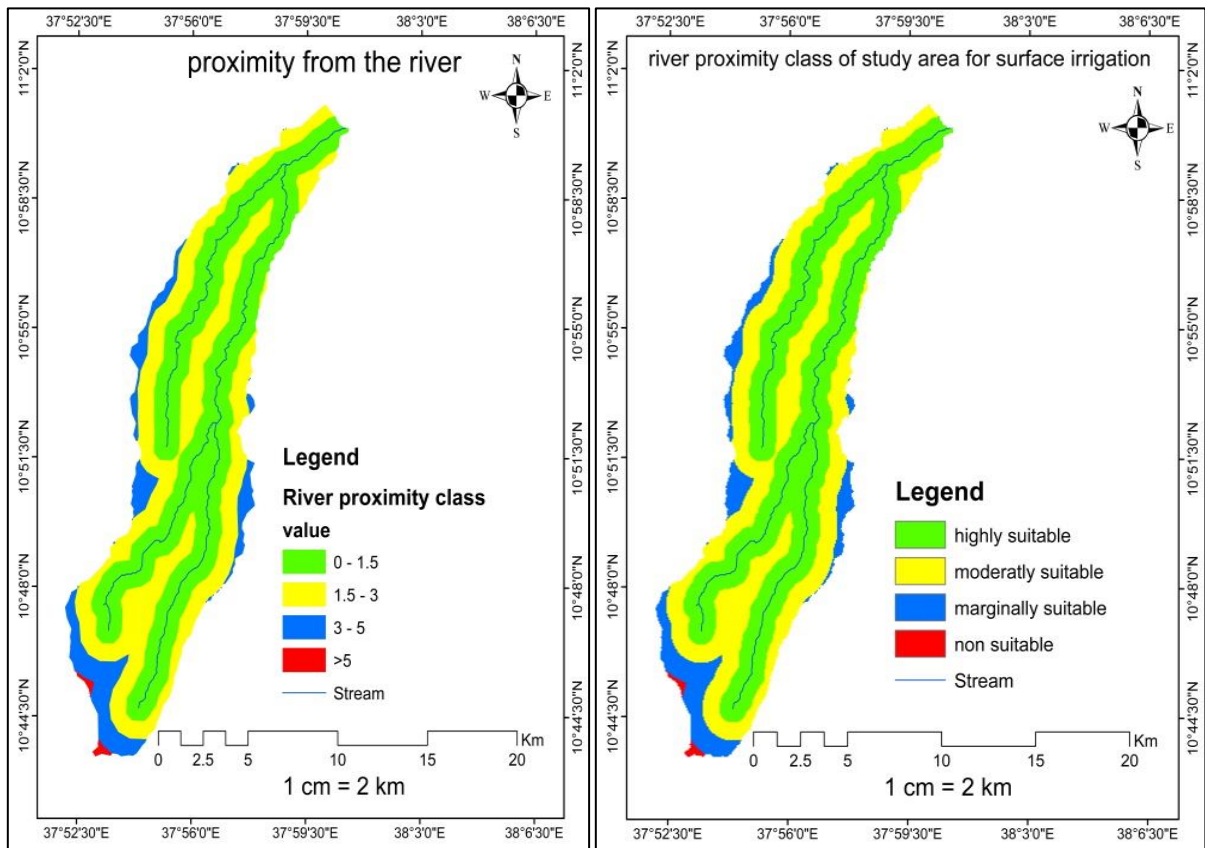


Figure4. 9: River proximity class and suitability for surface irrigation system

4.1.6 Weighted overlay analysis to find suitable land

To identify suitable irrigable site for surface irrigation development, determining weights of decision factor by providing a series of pairwise comparison based on the relative importance among slope, river proximity, soil (texture, depth and drainage) and LULC factors were one of the essential primary work for this study. As (Saaty, 1977), nine point intensity scale of importance (process of deriving priorities) between two factor elements, slope, river proximity, soil, and LULC were judged as very much more important, much more important, somewhat more important and somewhat intermediate important respectively for surface irrigation development in the watershed. The process of determining values for criteria weights calls for a lot of hard thinking on the part of the decision maker. Most of the time, any

surface irrigation is purposeful for flat land slope and for minimum highly investment cost for constructing conveyance structure. So, the river should be near to the command area. Based on the above judgment between two factor elements, the Analytic Hierarchy Process table was described in table (4.7) below.

Table4. 7: Pairwise comparison matrix

Factors	Slope	River proximity	Soil	LULC
Slope	1	2	3	5
River Proximity	0.5	1	2	4
Soil	1/3	0.5	1	3
LULC	1/5	1/4	1/3	1
Sum	2.033	3.75	6.333	13

Hint: - The column factor was compared with the factors in the rows for their significant for surface irrigation development in the study area.

After the pairwise comparison matrix was occupied, the next step is to obtain the criteria weight of each element by averaging the entire row. First normalized pairwise matrix was obtained by dividing individual element of the column to sum of the column and then normalized value in each rows were added and divided by the number of suitability parameters as shown in table (4.8) below.

Table4. 8: Normalized pairwise matrix

Parameters	Slope	River proximity	Soil	LULC	Criteria Weight
Slope	0.4919	0.5333	0.4737	0.3846	0.4709
River proximity	0.2459	0.2666	0.3158	0.3077	0.2840
Soil	0.1638	0.1333	0.1579	0.2307	0.1714
LULC	0.098	0.0666	0.0526	0.0769	0.0736

Finally, after normalized pairwise matrix, calculating of consistency for checking the calculating value was correct or not is crucial. Matrix consistency was calculating by multiplying each value in column with criteria weight as shown in table (4.9) below.

Table4. 9: Matrix consistency

Parameters	Slope	River Proximity	Soil	LULC	SW.V	C.W	SW.V/C.W
Slope	0.4709	0.5681	0.5142	0.3682	1.9214	0.4709	4.0803
River Proximity	0.2355	0.284	0.3428	0.2944	1.1567	0.284	4.0729
Soil	0.157	0.142	0.1714	0.2208	0.6912	0.1714	4.0326
LULC	0.0942	0.071	0.0571	0.0736	0.2959	0.0736	4.0204

Hint:- C.W = Criteria weight, and SW.V = weighted sum value.

The highest eigenvalue (λ_{\max}) was calculated by summing all the ratio value and dividing by the number of suitability parameters (n).

$$\lambda_{\max} = \frac{4.0803 + 4.0729 + 4.0326 + 4.0204}{4} = 4.0516$$

$$CI = \frac{4.0516 - 4}{4 - 1} = \frac{0.0516}{3} = 0.0172 \quad \text{and} \quad CR = \frac{CI}{RI} = \frac{0.0172}{0.9} = 0.0191$$

The value of CR (0.0191) is < 0.1. Since, the pairwise comparison matrix has an acceptable consistency (Chen et al., 2010). From surface irrigation suitability factor (slope, river proximity, soil and LULC), the percentage of influence are described in table (4.10) below.

Table4. 10: Parameter percentage of influence on surface irrigation project development

Parameters	Slope	River proximity	Soil	LULC
Percent of influence	47.09	28.40	17.14	7.36

Surface irrigation suitability analysis for suitable irrigable site identification was obtained by creating irrigation suitability model analysis which involved weighting of suitability parameters (slope, river proximity, soil and LULC). The model for irrigation suitability analysis was described below as identified in figure (4.10).

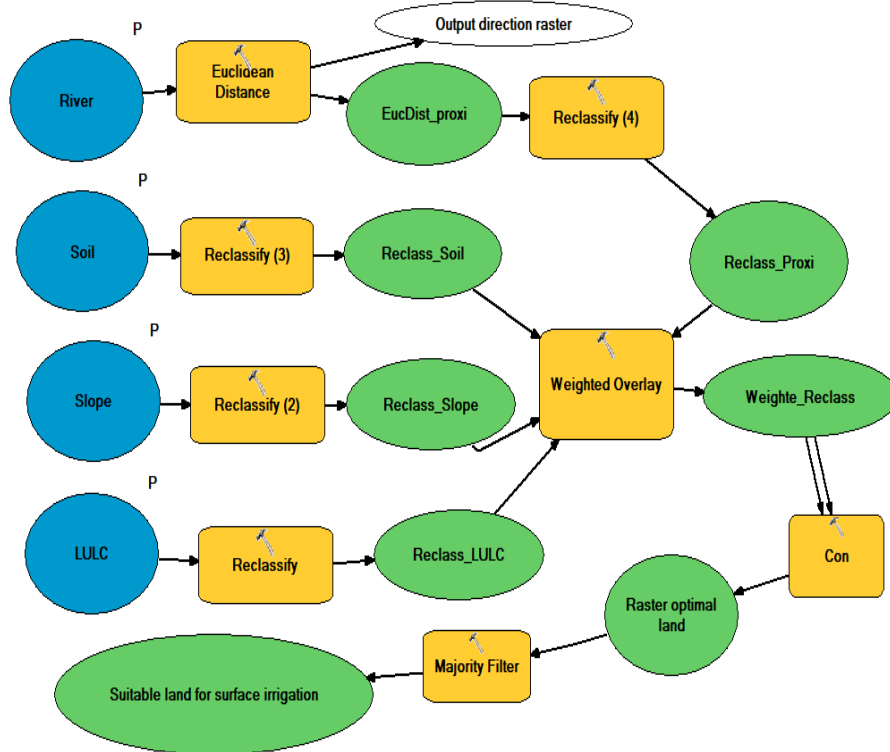


Figure4. 10: Models for weighted overlay analysis

4.2 Mapping the suitable land for surface irrigation development

Suitable land of the watershed site was obtained by weighted overlay analysis of individual suitability parameters which are slope, river proximity, soil and LULC of the watershed by Arc GIS 10.3. The above four suitability parameters identify appropriate irrigable site in the study area as suitable and non-suitable for surface irrigation development. As described below the manually added outlet during the watershed delineation based on the location of surface irrigation suitability site on the map specifies each suitable irrigable land source of water

supply respectively. Because of the irrigation methods were surface irrigation, the suitable irrigable land site were located below the source of water supply as shown Figure (4.11) below.

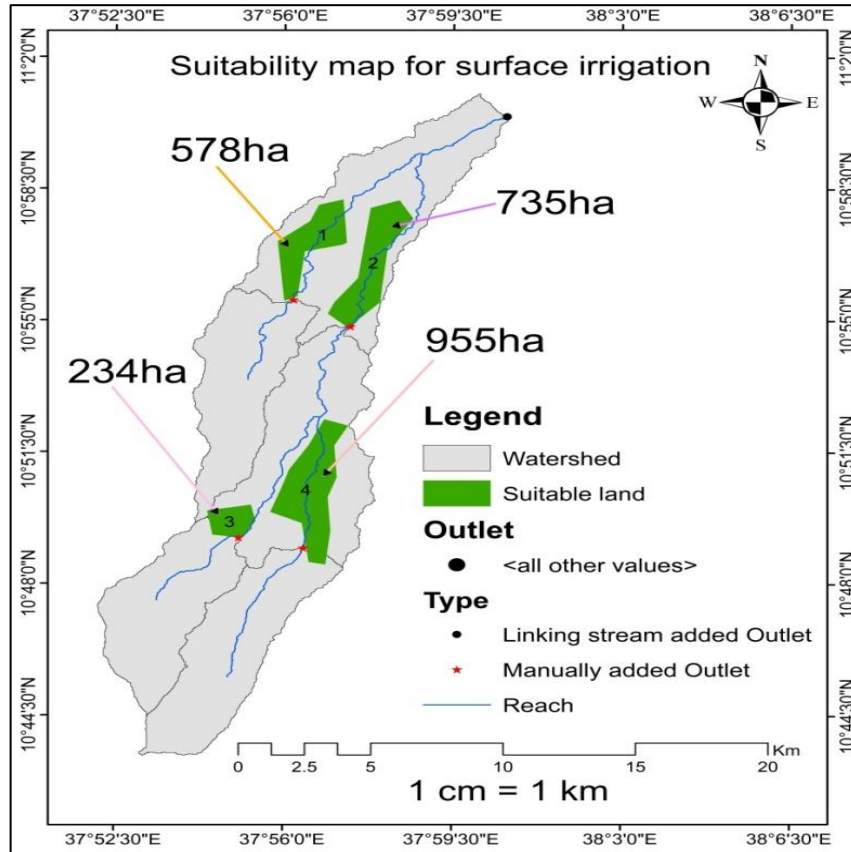


Figure4. 11: Surface irrigation suitable site with location of its water source

Table4. 11: Surface irrigation suitable command area from each sub watershed.

No	Sub watershed	Water source location		Command area (ha)
		Longitude	Latitude	
1	Sub watershed1	383765	1208083	578
2	Sub watershed2	385814	1206633	735
3	Sub watershed3	381747	1196353	234
4	Sub watershed4	384174	1195880	955

4.3 Estimation of available flow

The watershed delineation showed that there are four manually and one linking stream added outlets with five Sub-watersheds in the study area. The areas of the sub-watersheds from sub watershed one to five were 1551 ha, 4756 ha, 3496 ha, 3851 ha and 4601 ha respectively. The added outlet and sub-watershed were shown in the figure (4.12) below.

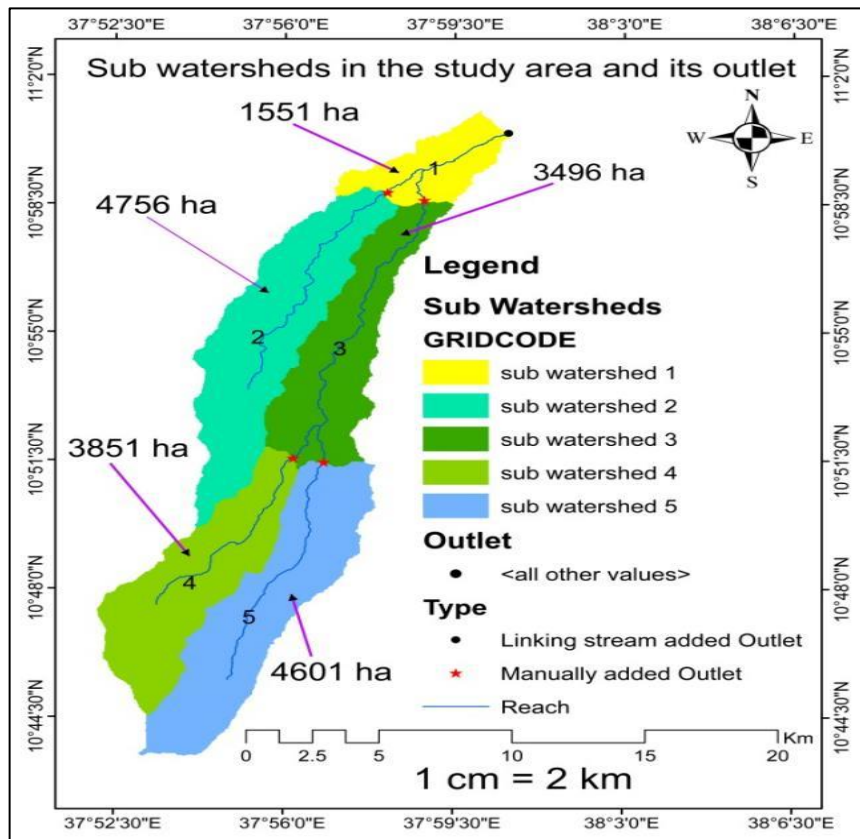


Figure4. 12: Sub watersheds and outlets of the study area for simulation.

The available water in each sub watershed was simulated through Arc SWAT2012 model. The model was run successfully first and the observed flow data were used for model calibration and validation by considering sensitivity parameters through SWAT CUP Sufi 5.1.2.6 software. The assessment of water availability understand the potential of irrigation water supply in each sub watershed of the watershed obtained from SWAT2012 outputs and comparing with the irrigation water requirement for dominant crop of the study area. The

mean monthly simulated stream flow results of each sub watershed of the study area were given in table (4.12) below.

Table4. 12: Mean monthly simulated flow (m³/s) of each Sub watershed

Month	Subwatershed1	Subwatershed2	Subwatershed3	Subwatershed4	Subwatershed5
Jan	0.52	0.24	0.38	0.26	0.22
Feb	0.24	0.22	0.26	0.23	0.21
Mar	0.39	0.26	0.36	0.25	0.26
Apr	0.65	0.26	0.49	0.23	0.26
May	1.29	0.43	0.84	0.37	0.41
Jun	2.19	0.59	1.42	0.49	0.58
Jul	9.89	2.67	6.6	2.3	2.69
Aug	14.02	3.96	9.54	3.27	3.87
Sep	9.96	2.93	6.67	2.21	2.68
Oct	7.66	2.29	5.11	1.67	2.04
Nov	3.71	1.17	2.48	0.78	0.98
Dec	1.59	0.57	1.09	0.42	0.53
Mean	4.34	1.30	2.94	1.04	1.23

4.3.1 Sensitivity analysis

Sensitivity analysis was carried out to identify which model parameters are the most important or sensitive that involves in the process of calibration and validation (Cibin, R. et al, 2010). Based on previous studies done surround the study area and model performance evaluation criteria during trial period, 12 parameters were identified as the most sensitive which are considered in both calibration and validation. About 500, iteration with 12 selected parameters has been done by SWAT sensitivity analysis at the watershed of sub watershed number one (outlet of the watershed found). The model parameters name, their code, t-stat, p-value and their sensitivity rank were shown in table (4.13) below.

Table4. 13: Sensitivity analysis of model parameters in Teme river watershed

Parameter name	Parameter code	t-stat	p-value	Sensitivity rank
Maximum canopy storage	CANMX	-1.93	0.054	1
Initial SCS CN II value	CN2	-1.872	0.062	2
Ground water evaporation coefficient	GW_REVAP	1.729	0.084	3
Soil evaporation compensation factor	ESCO	1.629	0.104	4
Threshold depth of water in the shallow aquifer acquired for evaporation to occur	REVAPMN	-1.324	0.186	5
Ground water delay	GW_DELAY	1.281	0.201	6
Base flow alpha factor	ALPHA_BF	1.222	0.222	7
Threshold depth of water in the shallow aquifer required to return flow to occur	GWQMN	-1.042	0.298	8
Effective hydraulic conductivity in the main channel	CH_K2	-0.804	0.422	9
Available water capacity of soil layer	SOL_AWC	-0.772	0.44	10
Moist bulk density	SOL_BD	-0.275	0.783	11
Depth from soil surface to bottom of layer	SOL_Z	0.213	0.831	12

4.3.2 Model calibration

After identification of sensitive parameters, the mode was calibrated. The mean monthly observed flow data for 9 years (1997-2005) at gauging station were used for calibration. Model efficiency during calibration of the model flow simulation evaluated by R^2 , NSE and PBIAS of stream flow during initial model run was 0.72, 0.68 and -21.1% respectively. After

some adjustment for more identification of efficiency of model, value of R^2 , NSE and PBIAS becomes 0.84, 0.78 and -24.6% respectively.

Table4. 14: List of best fitted parameters with calibrated values for mean monthly flow

Parameter name	Parameter Code	Minimum Value	Maximum Value	Fitted Value
Initial SCS CN II value	CN2	-0.2	0.2	0.08
Base flow alpha factor	ALPHA_BF	0	1	0.485
Ground water delay	GW_DELAY	30	450	258.5
Threshold depth of water in the shallow aquifer required to return flow to occur	GWQMN	0	2	1.272
Effective hydraulic conductivity in the main channel	CH_K2	-0.01	500	65.24
Threshold depth of water in the shallow aquifer acquired for evaporation to occur	REVAPMN	0	500	65.81
Available water capacity of soil layer	SOL_AWC	0	1	0.186
Ground water evaporation coefficient	GW_REVAP	0.02	0.2	0.211
Depth from soil surface to bottom of layer	SOL_Z	0	3500	0.003
Soil evaporation compensation factor	ESCO	0	1	0.742
Maximum canopy storage	CANMX	0	100	86.7
Moist bulk density	SOL_BD	0.9	2.5	1.023

The fit between observed and simulated flow were checked through plotting a time series bar chart as identified in figure (4.13) below.

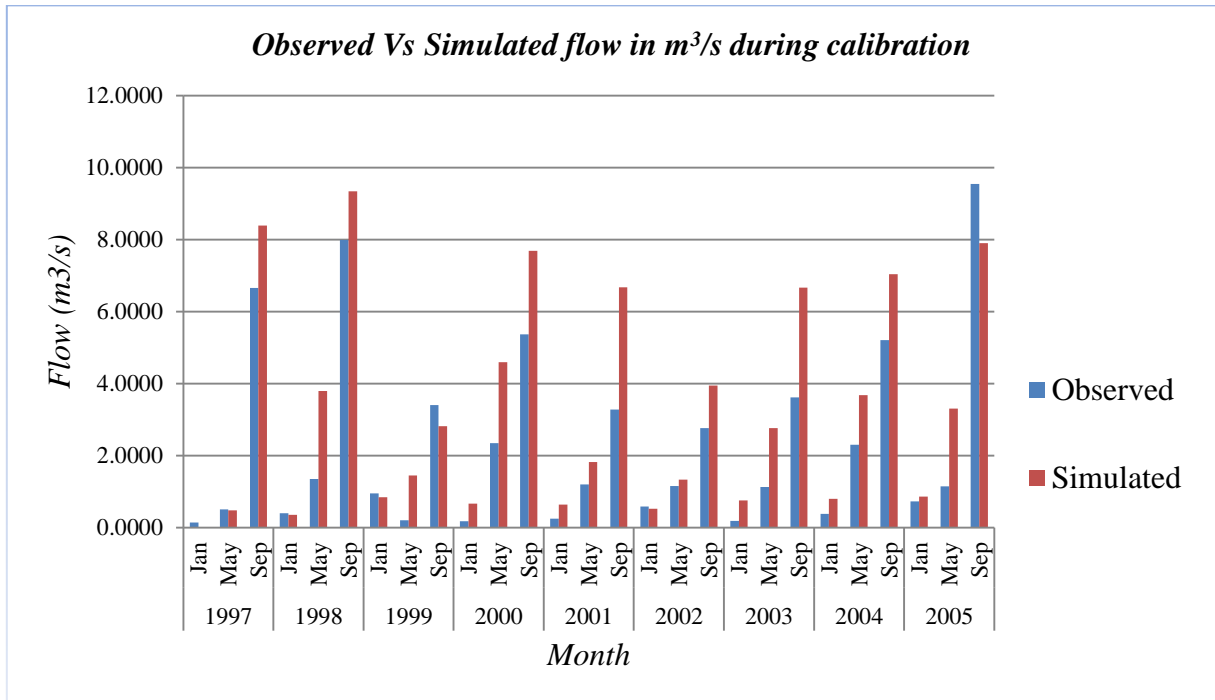


Figure4. 13: Mean monthly observed and simulated flow calibration bar chart (1997-2005)

4.3.3 Model validation

After calibration, the model final best fit parameters of 5 years (2006-2010) observed flow data were used for validation of the model. The validation process was running using a different time series input data without changing any parameter values which have been adjusted during calibration process. During validation period, the observed and simulated flow in monthly estimations were underestimate in some of the year and overestimate in some of other year, yet the model has strong predictive capability with R², NSE and PBIAS value of 0.85, 0.83 and -18.1% respectively. This showed that, statistical model efficiency criteria fulfilled the requirement of R² > 0.6, NSE > 0.5 and RVE < ± 15, which is recommended by SWAT developer (Santhi et al., 2001).

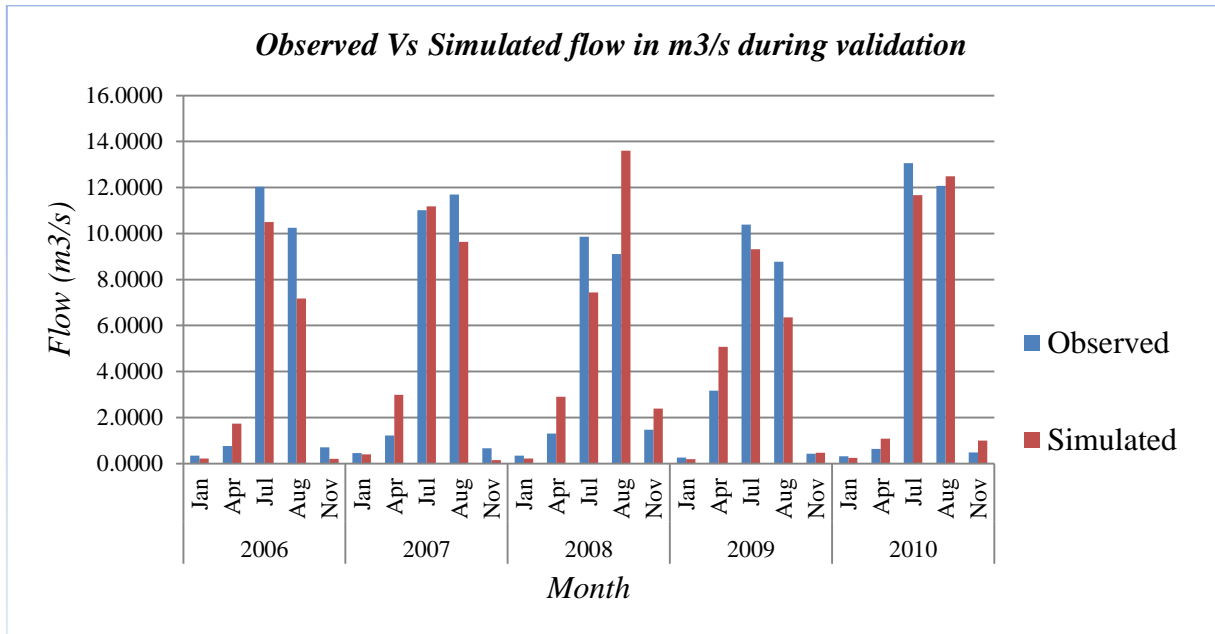


Figure4. 14: Mean monthly observed and simulated flow validation bar chart (2006-2010)

4.4 Irrigation water requirement of the selected crops

As irrigation water requirement information is needed in all aspects of irrigation design and management, irrigation water requirement of the major crops (Tomato, Maize and potato) within suitably identified land of the study area was estimated using the prevailing climatic conditions, the crop and its stage of growth, soil properties (such as water holding capacity), and the extent of root development data by CROPWAT8.0 model. Water within the crop root zone is the source of water for crop evapotranspiration. Thus, it is important to consider the field water balance to determine the irrigation water requirements. The total monthly quantities of water used in irrigation (quantity, or depth of irrigation water in addition to precipitation required to produce the desired crop yield and quality) for each crops were presented below by assuming a single cultivation in a year during the cropping period (Mono-cropping) through surface irrigation method as described in table 4.15, 4.16 and 4.17 respectively below.

Table4. 15: Gross irrigation water requirement for Tomato growing period (Mm³/month)

No	Command area (ha)	Month					
		Jan	Feb	Mar	Apr	May	Total
1	578	0.47	0.83	1.35	1.24	0.36	4.25
2	735	0.59	1.05	1.72	1.58	0.46	5.40
3	234	0.19	0.33	0.55	0.50	0.15	1.72
4	955	0.77	1.36	2.23	2.06	0.60	7.02
Total	2502	2.02	3.57	5.85	5.38	1.57	18.39

Table4. 16: Gross irrigation water requirement for Maize growing period (Mm³/month)

No	Command area (ha)	Month					
		Jan	Feb	Mar	Apr	May	Total
1	578	0.62	1.06	1.48	1.33	0.46	4.95
2	735	0.79	1.35	1.88	1.69	0.59	6.30
3	234	0.25	0.43	0.60	0.54	0.19	2.01
4	955	1.03	1.75	2.45	2.19	0.76	8.18
Total	2502	2.69	4.59	6.41	5.75	2.00	21.44

Table4. 17: Gross irrigation water requirement for Potato growing period (Mm³/month)

No	Command area (ha)	Month					
		Jan	Feb	Mar	Apr	May	Total
1	578	0.55	1.07	1.44	1.20	0.22	4.48
2	735	0.71	1.36	1.83	1.52	0.28	5.70
3	234	0.22	0.43	0.58	0.48	0.10	1.81
4	955	0.92	1.77	2.38	1.98	0.37	7.42
Total	2502	2.40	4.63	6.23	5.18	0.97	19.41

4.5 Transferring discharge of gauged river to site of interest

Discharges at the site of interest were acquired by transferring discharge from the gauged river in the watershed. During transferring period, needs to think characteristics of the gauged river site catchment (LULC, soil type and slop) should be similar to the site of interest catchment and closer to each other. Area ratio method was implemented. Drainage areas of the site of interests were found within 20% of the drainage area of the gauged site (Awulachew et al., 2010).

Table4. 18: Mean monthly discharge (m³/sec) at site of interest

Site of interest	Month											
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
G/Teme	0.17	0.09	0.12	0.18	0.25	0.44	1.94	2.81	2.23	1.77	0.96	0.48

4.6 Irrigation potential of river sub watersheds

Identification of irrigation potential for surface irrigation within the sub watershed of the study area were acquired by comparing irrigation water requirement of the recognized suitable land of the major selected crops (Tomato, Maize and Potato) with the available mean monthly flow in the river sub watershed obtained from simulations based on the method suggested by (FAO, 1997). Result of this analysis concluded that, the flow of the river was not enough to develop the total suitable (irrigable) land through surface irrigation method. The comparison of gross irrigation water requirement of the known suitable land and available mean monthly flow occurred from SWAT 2012 simulation outputs within each sub watershed for surface irrigation development in each selected crop were compared in table (4.19, 4.20 and 4.21) respectively below.

Table4. 19: Comparison of GIR with available stream flow for tomato crop

River name	Command area (ha)	Flow (m ³ /s)	Month				
			Jan	Feb	Mar	Apr	May
Tejatil	578	Available flow	0.20	0.11	0.14	0.21	0.29
		GIR	0.17	0.35	0.51	0.49	0.14
G/Teme	735	Available flow	0.17	0.09	0.12	0.18	0.25
		GIR	0.22	0.44	0.65	0.62	0.18
Tigebahar	234	Available flow	0.23	0.19	0.22	0.20	0.32
		GIR	0.07	0.14	0.21	0.20	0.06
Tiwa	955	Available flow	0.12	0.11	0.18	0.16	0.29
		GIR	0.29	0.57	0.84	0.80	0.23

Table4. 20: Comparison of GIR with available stream flow for maize crop

River name	Command area (ha)	Flow (m ³ /s)	Month				
			Jan	Feb	Mar	Apr	May
Tejatil	578	Available flow	0.20	0.11	0.14	0.21	0.29
		GIR	0.23	0.44	0.55	0.51	0.17
G/Teme	735	Available flow	0.17	0.09	0.12	0.18	0.25
		GIR	0.29	0.56	0.71	0.65	0.22
Tigebahar	234	Available flow	0.23	0.19	0.22	0.20	0.32
		GIR	0.09	0.18	0.22	0.20	0.07
Tiwa	955	Available flow	0.12	0.11	0.18	0.16	0.29
		GIR	0.38	0.72	0.92	0.84	0.28

Table4. 21: Comparison of GIR with available stream flow for potato crop

River name	Command area (ha)	Flow (m ³ /s)	Month				
			Jan	Feb	Mar	Apr	May
Tejatil	578	Available flow	0.20	0.11	0.14	0.21	0.29
		GIR	0.21	0.44	0.53	0.46	0.08
G/Teme	735	Available flow	0.17	0.09	0.12	0.18	0.25
		GIR	0.26	0.56	0.68	0.59	0.10
Tigebahar	234	Available flow	0.23	0.19	0.22	0.20	0.32
		GIR	0.08	0.18	0.21	0.19	0.03
Tiwa	955	Available flow	0.12	0.11	0.18	0.16	0.29
		GIR	0.34	0.72	0.89	0.76	0.13

The available flow simulated for January, February, March and April was (0.20, 0.11, 0.14 and 0.21) m³/s, (0.17, 0.09, 0.12 and 0.18) m³/s and (0.12, 0.11, 0.18 and 0.16) m³/s for Tejatil, G/Teme and Tiwa rivers respectively, Whereas the gross irrigation requirement of Tomato, Maize and Potato from CROPWAT 8.0 was calculated as (0.30, 0.60, 0.88 and 0.84) l/s/ha, (0.40, 0.76, 0.96 and 0.88) l/s/ha and (0.36, 0.76, 0.92 and 0.80) l/s/ha for the month January, February, March and April respectively with irrigation efficiency of 50% in all cases. Critical command area was calculated for growing those crops with the available flow (Michael, 2008). Based on this, critical irrigable land was calculated as 114 ha, 93 ha, and 114 ha for Tejatil, G/Teme and Tiwa rivers for growing Maize crops. For Tigebahar river, the monthly flows were greater than and/or equal to the irrigation water requirement of the selected crops. Therefore the total irrigation potential site of the study area for surface

irrigation was found to be 555 hectares, which accounts 3.04% of the total study area and/or 22.18% of the total suitable land area of the watershed as shown table (4.22) below.

Table4. 22: Surface irrigation potential summery in the study area

River name	Irrigation Potential (ha)		
	Tomato	Maize	Potato
Tejatil	125	114	119
Gilgel Teme	102	93.0	97.0
Tige Bahar	234	234	234
Tiwa	125	114	119
Total potential land	586	555	569

5. SUMMARY, CONCLUSION AND RECOMMENDATIONS

5.1 Summary and Conclusion

The aim of this study was to assess surface irrigation potential using Arc GIS 10.3 technique in terms of land suitability parameters such as land slope, physical property of soil, Euclidian distance and land use land cover of Teme watershed. Specifically, identification of available irrigable land and mapping to it, estimation of available surface water and estimation of crop water requirement for dominant crops within the study area were the key task of these studies.

To achieve the objective of this study, collecting of different data inputs from different sources and used were needed. Data's including meteorological data of four statins obtained from NMSA of Ethiopia, flow data obtained from MoIWEE, Satellite image obtained from downloading from Earth Explorer USGS, soil data with code, DEM data with code and other information's about the crop and cropping pattern collecting from different source were used.

Mainly, for assessment of surface irrigation potential within the study area, four suitability parameters were considered such as, slope, soil (depth, drainage and texture), river proximity and land use land cover of the watershed. Surface irrigation land suitability result shows that 44.1% of slope, 90% of soil, 89.5% of river proximity and 74% of LULC in the study area were in the range of highly suitable to moderately suitable, However the remaining of 55.9% of slope, 10% of soil, 10.5% of river proximity and 26% of LULC were in the range of marginally suitable to not suitable. After weighted these physical parameters using Arc GIS 10.3, the suitable irrigable site were found to be 13.7% of the total study area.

During the assessment of surface irrigation potential within the study area, five sub watersheds were obtained by using Ac GIS 10.3 software watershed delineation system. The area of each sub watershed covers an area of 1551 ha, 4756 ha, 3496 ha, 3851 ha and 4601 ha

from a total area of 18255 ha, obtained through four manually added outlets and one linking stream added outlet for further flow determination using Arc SWAT2012 model.

Soil and water assessment tool (SWAT) model were used for simulating available stream flow within the study area. However, instead of direct used the simulated result it is necessary to evaluate the ability of model for sufficient prediction of the stream flow through sensitivity analysis, model calibration and model validations. The mean monthly observed flow data for the period of 1997 to 2005 and 2006 to 2010 at gauged stations were used for model calibration and validation respectively. The result of model performance and applicability were in acceptable range of coefficient of determination (R^2), PBIAS and Nash-Sutcliffe model efficiency (NSE) during in both calibration and validation period. Since, $R^2 = 0.84$, PBIAS = -24.6% and NSE = 0.78 for calibration and $R^2 = 0.85$, PBIAS = -18.1% and NSE = 0.83 for validation. Crop water requirement of selected crop was carried out through CropWAT8.0 model. From this model, it decided that each selected crop has its own different irrigation water requirement for different month.

The available mean monthly flow of sub watershed obtained from Arc SWAT 2012 model simulation were (4.34, 1.3, 2.94, 1.04, and 1.23) m^3/s respectively from sub watershed one to sub watershed five. The overall available mean monthly flow of Teme River at the outlet was simulated and determined as $4.34m^3/s$. The mean monthly gross irrigation requirements within a crop period from January to April were (0.30, 0.60, 0.88 and 0.84) l/s/ha for Tomato, (0.40, 0.76, 0.96 and 0.88) l/s/ha for maize and (0.36, 0.76, 0.92 and 0.80) l/s/ha for potato.

By comparing the gross irrigation water requirement of the selected crops for the identified suitable land with simulated river *flow*, the total irrigation potential site of the study area for surface irrigation was found to be 555 ha, which accounts 3.04% of the total study area.

5.2 Recommendations

From the viewpoint of this study and conclusion outlined before the following points are recommended for further assessments:-

The present surface irrigation potential assessment in this study was carried out based on only four physical suitability parameters (slope, soil, river proximity and LULC). However other suitability parameters like chemical property of soil, climate conditions, water quality, socioeconomic aspect, environmental aspect and other water sources suitability parameter should be assessed to get more comprehensive and reliable results.

Above have of the land, the study area was not suitable for surface irrigation development based on slope suitability evaluation factor, it shows that land leveling operation and/or soil conservation work should be taken in to consideration for break surface slope and to make it suitable for surface irrigation.

The study was focused on only three dominant crops (Tomato, Maize and Potato) to estimate irrigation water requirement of identified command areas, but the future research should select crops other than the three to evaluate irrigation water requirement and to increase opportunity of productivity.

Only 3.04% of the total study area was potential suitable for surface irrigation due to scarcity of available water within irrigation period. So, further assessment on other irrigation type and water source from ground water and/or harvesting rain water during rainy season by providing a hydraulic structure should be carried out for improving the irrigation potential of identified potential irrigable area.

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APPENDIXES

Table 1: Cumulative mean annual precipitation of each metrological station (mm)

Year	Motta	D.work	G.woin	yetnora	Cumulative mean
1990	1077.80	592.40	1874.10	1926.70	1367.75
1991	2636.68	1463.20	3299.50	2962.04	2590.36
1992	3653.98	2181.80	5133.40	3925.74	3723.73
1993	4887.53	2962.10	6694.30	5349.14	4973.27
1994	5991.50	3730.00	8160.40	6605.74	6121.91
1995	6961.80	4595.00	9520.50	7450.74	7132.01
1996	8385.00	5543.20	10825.90	8764.60	8379.68
1997	9669.50	6613.40	12135.80	9764.08	9545.70
1998	11093.40	7872.68	13618.80	11133.58	10929.62
1999	12361.50	8647.78	14873.90	12460.78	12085.99
2000	13490.40	9982.38	16232.30	13562.31	13316.85
2001	14910.65	11078.28	17628.70	14688.94	14576.64
2002	16057.75	11718.08	18718.90	15832.74	15581.87
2003	17223.55	12652.88	19930.00	16705.84	16628.07
2004	18222.90	13528.18	21157.80	17737.97	17661.71
2005	19417.60	14423.48	22499.45	18779.12	18779.91
2006	20818.80	15584.08	23946.25	20304.92	20163.51
2007	21899.00	17076.18	25392.95	21475.22	21460.84
2008	23223.40	18302.08	26580.65	22543.42	22662.39
2009	24319.07	19330.41	27703.95	23566.82	23730.06
2010	25610.87	20293.54	29440.35	24779.12	25030.97
2011	26921.37	21334.74	30873.75	25961.42	26272.82
2012	28057.87	22180.04	32066.85	27089.72	27348.62
2013	29532.47	23207.44	33465.65	28251.52	28614.27
2014	30988.97	23959.44	34808.40	29185.64	29735.61
2015	32340.57	24552.34	36044.95	30081.34	30754.80
2016	33548.67	25350.84	37555.28	31304.94	31939.93
2017	35090.67	26076.44	39259.48	32370.64	33199.31
2018	36424.77	26707.94	40379.78	33487.34	34249.96

Table 2: Mean monthly rain fall, max and min temperature, humidity, wind and radiation.

Month	PPC(mm)	Tmax(0C)	Tmin(0C)	SLR(hr.)	WND(m/Sec)	HMD (%)
Jan	8.98	24.29	8.23	9.63	1.3	48.86
Feb	12.28	25.34	9.38	9.39	1.44	43.79
Mar	45.04	26.18	10.51	8.76	1.55	45.02
Apr	55.89	25.91	11.02	8.69	1.58	47.07
May	92.61	25.71	11.13	8.69	1.5	53.67
Jun	127.68	24.08	10.74	7.36	1.43	62.83
Jul	316.7	20.92	10.46	5.74	1.39	74.82
Aug	272.54	20.41	10.37	6.14	1.28	76.78
Sep	134.22	21.81	9.88	8.28	1.37	70.55
Oct	73.21	22.86	9.19	9.33	1.36	65.54
Nov	27.35	23.33	8.57	9.35	1.29	57.69
Dec	14.54	23.69	8.17	9.59	1.31	51.87
Mean	98.42	23.71	9.8	8.44	1.41	58.21

Table 3: Mean monthly rainfall data at Motta (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	1.3	32.2	14.4	45.1	20.7	112.6	375.2	178.1	258.8	38.1	1.3	0.0
1991	0.9	5.1	150.4	127.0	170.5	207.7	318.7	276.7	236.3	44.8	1.2	19.6
1992	0.0	2.3	13.6	67.7	62.3	73.3	184.1	324.4	78.2	122.5	56.4	32.5
1993	3.0	13.1	36.7	124.7	143.4	94.3	333.4	154.4	200.5	118.0	12.0	0.0
1994	1.7	16.3	10.0	32.3	103.3	102.9	312.3	301.1	150.3	36.2	29.7	7.9
1995	0.0	7.0	9.0	22.0	77.8	60.2	355.2	238.0	104.5	70.3	4.1	22.2
1996	0.3	2.1	66.4	61.4	110.6	203.7	310.9	365.7	164.0	58.4	70.5	9.2
1997	0.4	0.0	54.4	58.7	139.9	176.5	272.0	184.4	163.7	188.2	43.0	3.3
1998	5.7	1.0	18.2	34.4	119.6	93.4	363.4	368.6	170.7	198.8	49.2	0.9
1999	18.8	0.0	0.0	22.6	52.9	109.9	300.4	371.6	157.2	202.7	5.5	26.5
2000	0.0	0.0	7.6	111.5	8.0	38.4	243.1	267.8	148.2	209.8	63.0	31.5
2001	0.0	15.3	53.2	28.5	83.3	137.5	443.6	327.1	144.3	146.7	37.2	3.6
2002	10.8	0.0	30.8	93.0	26.8	127.9	296.7	288.6	186.1	60.9	7.0	18.5
2003	0.0	11.4	33.6	8.5	8.8	76.5	339.8	354.1	265.3	52.8	14.7	0.3
2004	0.0	7.4	7.0	59.0	14.2	142.0	203.0	269.2	181.3	92.4	23.9	0.0
2005	3.8	4.5	50.7	27.9	20.3	138.5	261.3	226.2	204.5	195.6	61.4	0.0
2006	0.0	2.2	27.9	76.9	106.3	164.1	366.2	339.0	158.0	80.3	52.7	27.6
2007	26.2	12.4	32.4	16.5	116.6	175.5	225.8	295.7	136.4	42.5	0.2	0.0
2008	41.7	0.7	0.0	78.9	145.1	94.2	362.4	279.8	209.7	96.5	15.4	0.0
2009	0.0	13.3	28.1	30.7	9.0	61.8	317.3	338.6	109.4	158.9	28.4	0.2

2010	7.2	0.7	23.3	37.5	64.0	34.1	364.4	450.4	203.4	84.2	22.4	0.2
2011	21.8	0.0	48.0	52.4	93.9	69.4	260.9	408.9	197.0	32.1	126.1	0.0
2012	2.7	0.0	16.3	3.5	37.2	157.7	355.3	322.5	147.9	50.0	23.6	19.8
2013	3.1	0.0	14.5	50.3	77.4	193.0	370.1	381.6	135.6	195.0	54.0	0.0
2014	0.2	4.0	86.5	127.1	239.5	93.9	283.7	292.1	176.8	118.3	26.9	7.5
2015	0.0	0.0	55.7	3.0	165.9	144.4	194.5	341.1	230.5	60.4	61.5	94.6
2016	0.0	0.0	7.0	11.2	88.4	175.4	380.1	273.5	138.3	134.2	0.0	0.0
2017	0.0	47.8	23.8	93.1	152.9	35.4	425.9	380.4	235.9	127.8	19.0	0.0
2018	0.0	18.2	34.3	13.0	38.7	238.1	362.6	367.6	106.0	88.2	67.4	0.0
Mean	5.2	7.5	32.9	52.4	86.1	121.8	316.6	309.2	172.4	107.1	33.7	11.2

Table 4: Mean monthly rainfall data at Gindewoin (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	13.6	44.7	48.3	92.3	67.7	165.8	635.6	504.9	245.9	51.3	1.6	2.4
1991	18.1	11.3	100.9	27.6	55.2	136.8	410.2	410.2	209.0	30.3	14.6	1.2
1992	0.0	77.2	82.3	125.9	110.5	201.0	298.3	439.4	94.3	171.3	143.9	89.8
1993	9.0	14.7	78.6	216.3	154.1	153.9	397.8	223.2	221.9	89.4	2.0	0.0
1994	8.1	33.0	29.8	58.5	112.5	188.5	522.9	284.6	214.6	10.0	3.6	0.0
1995	1.0	15.3	44.6	126.3	266.1	60.1	329.2	301.3	106.9	16.8	23.9	68.6
1996	23.2	1.6	65.9	134.8	96.9	154.4	369.3	292.5	81.2	6.5	67.9	11.2
1997	33.0	0.6	53.0	121.7	103.2	153.0	370.9	170.1	122.5	145.5	31.7	4.7
1998	4.6	26.5	42.0	7.7	216.0	189.7	357.4	270.6	123.2	242.2	3.1	0.0
1999	63.8	0.0	0.3	67.8	26.4	183.2	379.8	256.7	82.8	188.0	0.4	5.9
2000	0.0	0.0	8.8	134.9	32.2	176.7	327.5	282.1	181.9	154.7	39.4	20.2
2001	0.0	38.6	96.3	77.7	144.9	184.3	394.6	327.7	64.8	44.6	5.5	17.4
2002	54.4	16.6	117.0	56.9	16.0	97.3	308.2	288.1	91.1	23.9	8.9	11.8
2003	0.0	67.5	145.2	10.0	15.9	170.0	372.9	272.1	112.2	24.1	2.6	18.6
2004	5.4	21.8	30.9	74.5	23.1	89.0	401.1	297.3	112.1	122.9	35.9	13.8
2005	4.3	1.2	92.7	22.6	56.4	115.6	371.8	335.7	241.2	66.6	33.4	0.2
2006	5.1	13.4	68.0	101.2	94.1	137.1	336.5	374.0	160.6	75.8	12.9	68.1
2007	53.3	31.8	36.2	38.7	132.4	199.0	415.8	252.4	231.5	54.2	1.4	0.0
2008	1.6	0.0	0.8	50.7	144.4	143.9	340.4	241.9	122.3	82.0	49.3	10.4
2009	4.6	17.1	76.9	34.6	39.3	70.4	320.8	355.3	45.9	138.5	3.4	16.5
2010	5.2	3.2	40.4	74.7	149.5	113.3	537.0	386.8	140.4	6.6	31.3	248.0
2011	60.4	0.5	79.9	59.5	84.2	217.4	367.3	274.2	217.8	3.4	68.8	0.0
2012	3.6	0.7	85.3	44.3	65.9	102.8	464.1	259.4	72.0	27.7	62.1	5.2
2013	8.1	0.7	28.2	28.0	100.5	121.4	423.3	371.6	94.2	185.1	35.2	2.5
2014	22.0	25.9	45.2	50.6	228.8	140.1	353.7	230.1	116.4	68.9	59.2	1.9
2015	15.8	12.5	40.2	7.6	65.2	122.7	303.7	209.0	270.6	6.6	148.9	33.8
2016	2.0	9.1	78.3	12.5	57.2	145.0	476.0	363.9	179.5	58.8	87.0	41.3

2017	0.0	9.7	20.7	17.3	49.3	167.2	648.2	518.8	88.3	110.9	25.0	48.8
2018	0.0	12.2	66.0	43.1	246.2	134.9	198.5	211.6	52.3	105.6	18.7	31.2
Mean	14.5	17.5	58.7	66.1	101.9	146.0	394.2	310.5	141.3	79.7	35.2	26.7

Table 5: Mean monthly rainfall data at Debre work (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	1.7	36.5	51.0	48.6	48.2	27.7	171.3	123.0	81.0	2.0	1.4	0.0
1991	19.8	6.5	20.7	0.6	47.2	188.2	340.9	160.3	74.1	3.8	5.1	3.6
1992	10.0	26.2	34.0	49.2	54.2	27.9	140.9	188.9	34.7	77.1	40.1	35.4
1993	1.3	19.3	50.6	74.2	136.7	50.7	190.9	113.4	89.6	47.1	6.5	0.0
1994	0.0	24.9	14.1	23.3	47.3	48.2	283.2	244.1	80.2	2.0	0.6	0.0
1995	0.3	10.2	28.7	33.0	105.2	37.3	234.2	305.0	66.3	6.0	4.2	34.6
1996	42.0	0.0	63.6	137.4	84.3	154.9	191.9	184.2	74.8	0.0	15.1	0.0
1997	38.8	0.0	54.7	73.9	114.3	140.7	230.1	105.7	147.3	151.3	13.6	0.0
1998	23.8	0.0	35.5	10.3	144.2	126.5	305.4	362.4	92.0	147.2	12.0	0.0
1999	8.8	0.0	0.0	26.8	90.3	50.1	252.0	179.4	28.0	136.5	0.0	3.2
2000	0.0	0.0	9.0	114.3	36.4	71.0	373.6	397.9	126.8	107.1	62.5	36.0
2001	0.0	24.0	84.8	25.1	81.2	107.3	310.0	362.7	76.3	19.5	0.0	5.0
2002	15.2	6.8	78.7	4.3	0.0	41.9	252.8	200.2	34.5	0.0	0.0	5.4
2003	15.0	68.0	101.9	7.2	3.0	98.2	252.3	227.8	94.9	34.2	19.4	12.9
2004	7.8	6.3	23.4	63.0	7.6	46.0	252.3	286.8	71.6	92.7	5.4	12.4
2005	19.6	0.0	94.7	46.7	46.9	53.6	299.6	152.5	107.1	54.6	20.0	0.0
2006	1.5	0.0	50.2	35.5	95.1	141.4	321.7	197.0	149.0	53.5	68.3	47.7
2007	8.5	26.6	20.2	24.2	143.3	229.2	343.7	241.4	190.8	52.3	116.5	95.4
2008	47.7	0.0	0.0	27.0	184.9	263.8	319.1	192.9	108.8	56.3	21.5	4.0
2009	7.9	3.2	38.4	29.7	52.3	222.5	298.3	294.5	31.5	34.7	1.2	14.2
2010	9.1	6.3	39.4	84.0	161.7	82.9	283.0	181.3	85.3	2.2	13.0	14.9
2011	21.8	5.0	70.7	33.7	120.9	124.1	292.1	197.7	118.0	3.0	54.2	0.0
2012	0.0	0.0	68.5	37.4	34.0	78.9	260.7	233.6	105.9	8.5	7.8	10.0
2013	11.0	0.0	24.7	39.2	38.1	121.0	324.2	331.2	67.8	65.3	4.9	0.0
2014	6.8	12.5	33.7	47.3	134.1	104.8	167.5	129.5	74.4	11.6	26.8	3.0
2015	0.0	11.5	38.6	3.8	78.9	78.7	119.3	56.4	145.5	0.0	29.0	31.2
2016	6.8	0.0	16.4	38.8	146.5	66.5	218.9	202.9	57.9	40.8	3.0	0.0
2017	0.0	19.8	12.8	18.6	144.0	25.6	211.9	157.9	78.3	56.7	0.0	0.0
2018	0.0	18.1	31.9	33.6	96.1	26.7	191.6	89.8	63.8	45.5	34.1	0.4
Mean	11.2	11.4	41.1	41.1	85.4	97.8	256.3	210.4	88.1	45.2	20.2	12.7

Table 6: Mean monthly rainfall data at Yetnora (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	1.4	74.3	174.1	119.5	35.3	185.7	505.0	480.1	326.7	17.0	7.6	0.0
1991	2.0	10.2	94.0	116.3	56.7	143.1	206.0	242.5	121.2	35.9	0.0	7.4
1992	3.3	30.9	22.3	66.3	44.4	115.3	187.0	220.9	111.4	137.1	23.9	0.9
1993	1.0	16.7	24.3	161.9	127.0	171.0	371.2	280.6	148.5	121.2	0.0	0.0
1994	0.0	6.3	37.7	35.4	126.4	149.2	418.6	338.0	143.7	0.0	1.3	0.0
1995	0.0	3.8	19.7	45.3	91.5	99.2	225.2	242.1	65.2	2.3	6.5	44.2
1996	5.1	0.0	132.6	91.5	135.8	155.9	289.0	231.1	146.7	97.1	15.2	13.9
1997	2.5	0.0	63.6	80.3	92.1	203.0	177.8	184.0	72.7	59.2	54.1	10.2
1998	0.0	0.0	75.1	7.9	185.1	95.5	334.4	368.3	120.2	183.0	0.0	0.0
1999	4.8	0.0	0.0	33.7	96.0	179.5	390.2	259.9	75.6	277.5	2.2	7.8
2000	0.0	0.0	0.0	133.9	32.1	132.4	316.1	324.4	128.1	27.3	1.4	5.8
2001	10.5	9.1	23.4	52.6	35.4	198.8	377.2	225.6	132.5	53.3	3.5	4.9
2002	36.6	6.4	33.3	43.9	13.3	201.7	403.2	314.2	80.5	0.2	0.0	10.5
2003	0.4	30.0	60.1	30.9	0.0	145.2	261.5	222.1	108.9	2.7	9.0	2.3
2004	14.0	9.7	23.7	66.8	8.2	211.0	230.5	223.3	151.3	74.5	7.1	12.0
2005	17.3	0.0	53.6	84.0	58.9	125.1	232.7	243.6	154.2	39.3	32.5	0.0
2006	3.1	13.0	114.3	69.1	92.2	112.5	481.4	300.9	267.4	28.8	7.8	35.3
2007	10.3	22.5	40.2	72.1	129.8	152.1	287.9	227.9	198.9	16.6	0.0	12.0
2008	0.0	0.0	0.0	21.3	101.2	167.7	323.6	180.3	122.9	81.8	69.4	0.0
2009	8.7	11.2	37.8	42.5	18.2	46.4	292.5	321.4	99.3	113.9	5.2	26.3
2010	3.5	23.3	38.8	81.4	190.1	72.1	258.8	281.3	222.1	19.1	20.5	1.3
2011	0.7	0.0	96.8	53.6	178.7	116.2	254.6	262.8	106.6	20.0	92.3	0.0
2012	0.0	0.0	79.0	53.0	38.3	153.3	357.5	233.1	176.4	34.9	2.8	0.0
2013	3.7	0.6	12.6	31.0	143.8	244.4	317.0	288.7	65.6	42.4	12.0	0.0
2014	0.0	45.2	22.4	93.3	112.2	52.8	157.3	180.3	180.4	65.4	24.8	0.0
2015	0.0	6.6	0.0	21.2	124.7	182.7	107.9	212.2	94.2	14.8	108.7	22.7
2016	17.8	15.1	47.5	74.9	278.4	111.1	333.3	209.7	99.6	36.2	0.0	0.0
2017	0.0	9.6	32.4	16.7	227.4	52.3	284.3	230.7	128.0	71.4	12.9	0.0
2018	0.0	24.2	18.1	55.4	41.2	232.2	306.7	212.2	68.6	91.2	66.9	0.0
Mean	5.1	12.7	47.5	64.0	97.0	145.1	299.6	260.1	135.1	60.8	20.3	7.5

Table 7: Mean monthly max-temperature at Motta station ($^{\circ}\text{C}$)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	23.7	24.1	25.6	26.1	26.4	25.2	20.2	20.7	21.0	22.4	23.6	23.5
1991	24.6	25.8	27.9	28.4	27.8	23.2	19.8	19.8	21.4	22.2	23.4	22.5
1992	23.2	24.0	26.6	25.9	26.1	25.5	20.8	18.6	20.8	20.4	20.4	22.2
1993	22.7	23.4	25.5	23.6	24.0	22.8	20.6	21.5	21.4	22.1	23.1	23.7
1994	24.5	27.8	28.4	24.1	23.5	22.4	19.6	19.5	21.1	22.9	23.3	23.7
1995	24.7	25.9	26.6	26.6	25.9	26.4	20.8	20.5	22.1	22.9	23.5	24.2

1996	24.9	25.5	25.6	25.4	23.6	22.1	20.5	20.4	21.8	22.8	22.1	22.9
1997	24.2	25.6	26.0	25.3	25.0	23.4	21.1	21.1	23.0	22.1	22.6	24.2
1998	25.1	26.1	27.3	27.2	26.1	24.8	19.7	20.0	21.6	21.8	22.0	22.6
1999	23.1	26.1	26.4	26.8	26.7	25.2	19.9	20.0	21.4	21.1	22.0	22.5
2000	23.7	24.3	26.8	23.9	26.9	25.2	20.9	20.0	21.2	21.4	22.2	23.1
2001	23.5	25.4	24.7	26.5	25.7	23.4	20.7	20.2	21.7	23.0	23.0	23.6
2002	23.7	25.8	26.2	27.0	27.6	24.7	22.3	20.6	21.4	23.1	23.5	24.0
2003	24.8	26.0	26.1	27.3	28.3	25.3	20.6	20.5	21.2	22.1	23.3	23.3
2004	24.8	24.2	26.6	26.0	27.2	23.5	21.7	20.9	21.6	21.9	23.1	23.6
2005	24.1	27.0	26.4	26.9	26.4	25.7	20.6	21.0	21.5	21.9	22.2	23.0
2006	24.5	25.6	25.3	25.2	25.2	24.3	21.3	20.7	21.6	23.1	23.0	23.4
2007	24.2	25.5	27.3	26.6	26.7	23.1	20.6	21.2	22.0	22.6	23.7	23.8
2008	24.6	24.7	27.8	26.0	24.9	23.7	21.4	21.2	22.1	22.5	22.7	23.5
2009	24.5	25.8	26.8	27.3	27.6	27.2	21.3	21.4	22.8	22.3	23.5	23.7
2010	24.5	26.1	26.5	26.7	25.9	25.8	21.1	20.4	21.8	22.8	23.3	23.0
2011	23.8	26.0	25.0	26.7	25.6	24.4	21.6	20.9	22.0	23.7	23.7	23.7
2012	24.7	25.0	26.6	26.8	27.1	24.8	20.9	20.7	22.0	23.4	23.4	23.7
2013	24.6	26.8	27.3	28.0	26.1	23.8	20.8	20.1	22.2	22.4	23.1	23.4
2014	24.4	25.4	25.9	25.9	24.0	24.4	22.1	20.6	22.0	22.8	23.5	27.1
2015	24.4	26.7	27.1	27.8	26.1	24.7	23.8	22.4	22.8	24.7	24.1	24.3
2016	25.2	25.9	29.0	28.1	25.5	25.3	21.7	21.5	22.7	23.1	23.2	24.1
2017	24.9	25.9	28.1	27.5	25.2	26.8	22.9	21.7	23.3	23.9	24.4	24.7
2018	24.9	25.8	26.7	26.3	26.8	23.0	21.1	20.9	22.7	22.7	21.9	23.7
Mean	24.3	25.6	26.6	26.4	26.0	24.5	21.0	20.7	21.9	22.5	23.0	23.6

Table 8: Mean monthly min-temperature at Motta station ($^{\circ}\text{C}$)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	7.0	8.3	9.6	10.9	11.5	10.6	10.9	11.2	10.8	8.9	8.5	7.1
1991	9.1	9.3	10.3	10.6	10.9	11.5	11.4	11.3	10.1	8.4	8.0	7.3
1992	7.7	8.2	11.5	11.8	12.4	11.2	11.4	11.6	9.8	10.2	8.3	7.8
1993	6.6	7.6	10.2	11.6	11.6	11.7	11.4	11.0	9.9	9.3	8.4	7.0
1994	7.5	9.3	9.5	9.8	9.3	11.0	11.3	10.8	10.0	8.5	8.7	7.1
1995	6.7	8.6	9.3	12.3	12.1	10.9	11.7	11.3	10.8	10.5	9.5	9.6
1996	10.3	9.1	10.9	12.1	11.2	11.1	10.2	9.8	8.7	7.3	7.3	5.6
1997	5.4	8.4	10.0	10.5	11.1	10.7	10.8	10.5	9.1	9.7	9.7	7.3
1998	7.0	7.5	11.2	12.8	12.6	11.2	11.6	11.8	11.2	11.1	7.9	6.2
1999	7.2	9.4	7.8	11.7	10.1	8.8	9.5	9.5	8.5	8.7	5.3	5.9
2000	5.5	6.6	8.7	9.6	10.0	9.2	10.0	9.7	8.9	8.8	7.5	6.7
2001	4.2	6.6	8.5	10.6	10.8	10.3	10.5	11.0	9.5	9.3	6.9	7.1
2002	7.0	8.5	10.0	11.8	11.9	10.3	10.7	10.9	10.0	8.5	7.8	6.5

2003	6.7	10.5	12.1	12.6	13.4	12.2	11.6	11.6	11.1	8.8	8.2	7.5
2004	8.6	9.5	12.5	12.8	11.8	11.0	11.2	11.3	10.2	8.9	9.5	7.7
2005	7.2	10.4	11.6	13.0	8.9	9.6	11.8	11.8	11.2	10.5	8.6	6.7
2006	8.6	10.6	11.3	11.7	11.8	11.3	12.0	11.7	10.7	10.5	9.1	8.0
2007	7.5	8.6	10.8	11.7	12.6	11.1	11.5	11.3	10.5	7.7	7.0	5.8
2008	7.5	7.6	10.4	11.9	10.7	13.0	13.9	14.1	14.1	14.6	14.3	12.8
2009	6.9	11.0	11.0	12.2	10.9	10.4	10.8	10.4	8.5	8.0	6.1	6.4
2010	6.2	9.8	11.0	13.3	12.9	12.2	11.8	11.9	11.3	9.7	9.0	8.0
2011	7.7	8.7	10.1	12.3	11.5	11.4	11.5	11.7	10.9	9.2	9.3	7.4
2012	7.1	8.9	10.9	11.0	12.1	11.6	11.4	10.8	10.3	9.1	8.5	7.5
2013	7.5	9.6	11.8	11.6	12.0	11.8	11.6	12.1	11.8	10.4	10.7	10.2
2014	8.6	11.4	10.6	11.9	11.8	11.1	11.4	10.6	11.1	10.5	8.5	12.3
2015	7.7	10.2	12.3	13.1	11.9	11.6	10.8	11.2	10.2	9.6	9.2	9.1
2016	6.6	8.4	12.1	12.1	11.4	11.0	11.3	11.2	10.2	9.3	6.5	7.1
2017	6.8	10.7	10.9	12.8	12.6	11.6	11.6	11.9	11.2	10.9	8.8	7.1
2018	7.6	11.0	10.3	11.3	12.6	11.7	11.7	11.7	10.2	10.0	9.5	8.3
Mean	7.2	9.1	10.6	11.8	11.5	11.1	11.3	11.2	10.4	9.5	8.5	7.7

Table 9: Mean monthly max-temperature at Ginde woin station ($^{\circ}\text{C}$)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	24.2	22.2	24.6	25.3	25.5	23.4	19.2	20.2	20.6	22.4	24.0	24.8
1991	25.2	26.1	26.0	26.6	27.0	24.6	19.8	20.4	21.2	22.2	23.8	23.3
1992	23.6	24.4	25.8	26.3	25.5	24.1	21.2	20.1	20.3	21.1	21.7	23.5
1993	23.7	23.6	26.5	25.2	25.5	24.3	23.2	22.4	21.3	23.5	24.0	23.7
1994	24.0	25.1	27.1	27.7	26.8	23.5	19.9	19.8	20.9	22.0	22.9	23.8
1995	24.9	24.3	24.7	23.3	25.3	22.9	22.2	19.9	21.4	22.5	23.8	24.5
1996	24.8	25.8	25.0	24.8	25.5	24.2	22.2	21.3	23.5	23.9	23.8	24.5
1997	26.1	26.7	26.4	25.6	26.3	24.3	22.1	21.4	22.4	23.2	23.3	23.6
1998	27.3	27.5	27.7	26.3	27.1	24.4	21.9	21.4	21.4	22.5	22.9	22.7
1999	23.5	26.3	27.4	27.7	26.8	25.7	22.5	20.8	21.7	21.7	22.1	22.3
2000	21.1	22.6	23.7	23.0	23.2	23.2	22.4	20.8	22.3	22.7	28.0	25.7
2001	24.9	25.9	25.1	26.4	26.2	22.7	22.3	20.4	22.1	23.8	24.2	24.5
2002	24.6	26.1	26.5	26.6	28.1	24.4	21.0	20.9	21.7	23.4	24.1	24.9
2003	26.1	26.4	26.2	26.5	28.5	24.9	20.4	20.4	21.3	23.1	24.0	24.4
2004	26.0	26.1	26.5	25.7	28.6	24.7	20.8	21.1	22.2	22.0	23.8	23.2
2005	24.0	27.2	26.6	27.1	25.4	24.2	21.3	20.8	22.6	24.3	24.0	24.0
2006	24.1	25.8	25.4	24.8	25.2	23.7	21.0	20.0	20.4	22.8	22.7	22.8
2007	23.6	24.9	26.8	25.5	26.4	22.9	19.9	20.3	22.1	22.5	22.8	23.6
2008	24.2	25.2	26.8	26.2	25.3	24.8	23.0	21.1	21.7	22.6	22.5	23.7
2009	24.7	25.1	26.0	25.9	26.1	25.9	23.5	22.6	23.2	23.1	23.8	24.6
2010	24.5	25.2	25.2	24.7	24.6	24.7	23.3	22.4	22.8	24.1	23.8	23.6

2011	23.6	24.4	24.2	24.4	23.8	25.2	22.6	22.0	22.4	22.6	22.7	24.2
2012	24.2	23.9	25.8	25.4	26.2	25.7	21.8	21.6	22.3	23.5	24.3	24.1
2013	25.1	27.0	27.4	28.2	27.2	25.2	21.5	20.7	22.5	23.2	23.9	23.6
2014	25.0	25.1	25.4	24.0	23.3	22.7	20.7	20.4	20.8	21.9	23.1	22.5
2015	23.4	24.0	24.9	24.9	23.2	23.2	22.7	21.1	22.4	22.4	23.1	23.2
2016	23.5	24.3	25.9	24.9	24.3	23.6	21.5	20.3	21.8	22.8	23.3	23.0
2017	23.7	23.7	24.6	24.9	25.4	25.2	22.5	23.0	23.9	23.7	24.3	24.5
2018	24.9	24.7	24.9	25.0	25.3	24.3	22.8	23.7	24.8	24.1	23.8	24.3
Mean	24.4	25.2	25.8	25.6	25.8	24.2	21.7	21.1	22.0	22.9	23.6	23.8

Table 10: Mean monthly min-temperature at Ginde woin station ($^{\circ}\text{C}$)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	6.7	9.0	9.7	10.5	10.4	8.3	7.5	6.5	7.1	7.1	7.1	6.7
1991	7.2	7.9	7.2	10.9	7.7	6.1	6.0	6.6	6.8	5.8	5.7	5.7
1992	6.2	7.8	10.0	11.2	12.5	10.3	11.0	10.2	10.3	7.8	6.0	7.2
1993	7.9	9.3	10.0	9.5	11.2	10.3	11.1	10.6	6.2	8.4	9.0	9.3
1994	8.9	10.7	11.0	10.9	9.8	10.4	11.1	10.5	9.0	9.3	9.4	10.7
1995	11.1	10.8	11.5	12.2	12.4	11.1	11.1	11.0	10.6	8.5	7.4	6.5
1996	10.7	11.6	12.8	13.0	11.8	11.3	11.4	11.9	11.3	9.9	7.8	8.4
1997	10.6	10.3	12.0	13.5	12.1	12.1	11.1	11.7	11.3	10.6	8.2	7.9
1998	10.4	9.0	12.4	14.0	12.8	13.0	11.2	11.5	11.4	11.7	8.6	7.4
1999	7.6	8.3	9.6	11.3	12.2	10.8	10.6	10.7	10.6	9.9	10.4	10.1
2000	8.9	9.3	9.5	8.9	10.7	10.2	9.5	10.4	9.3	9.9	9.3	6.5
2001	7.6	8.5	9.7	11.3	11.6	11.0	10.9	11.5	10.6	9.9	7.9	8.6
2002	9.2	11.9	11.6	10.9	12.7	11.3	9.9	11.2	10.1	11.4	12.8	10.8
2003	10.8	10.8	11.0	11.6	13.9	12.0	10.2	10.1	10.2	10.1	9.0	7.5
2004	9.7	9.8	11.2	12.2	12.2	10.7	10.0	10.9	10.7	7.8	7.7	8.4
2005	9.4	10.8	11.5	11.5	10.7	9.4	10.5	10.8	11.3	8.6	7.8	6.5
2006	8.8	9.8	8.3	8.2	8.5	8.1	7.4	6.9	7.2	7.8	7.9	7.8
2007	7.8	8.6	8.9	7.4	8.4	7.8	6.8	7.1	7.9	7.2	7.5	7.0
2008	7.6	8.5	9.9	8.9	8.1	7.3	6.0	5.7	6.0	6.2	5.4	5.5
2009	6.1	7.4	8.8	8.8	9.0	8.5	5.3	4.5	4.8	4.5	4.9	5.5
2010	5.6	6.0	5.9	5.3	5.7	6.7	5.0	4.2	5.4	5.1	5.5	5.6
2011	5.7	7.3	7.4	7.3	6.3	11.9	10.9	10.7	5.6	5.6	6.0	14.4
2012	6.7	8.2	14.1	18.3	18.8	17.1	16.8	17.2	17.4	16.8	17.7	17.3
2013	18.6	19.9	20.4	12.6	12.1	11.9	10.1	10.3	10.6	10.2	9.6	9.5
2014	10.5	10.2	11.2	11.8	11.5	11.3	10.8	10.1	10.2	10.5	10.0	9.7
2015	11.0	10.9	11.0	11.8	11.5	11.1	10.9	10.4	10.4	10.9	9.3	10.5
2016	10.4	11.1	11.5	11.9	11.6	11.4	10.6	9.5	10.4	11.1	11.0	10.8
2017	11.4	11.2	11.4	12.1	11.7	10.8	10.8	10.3	10.8	11.0	11.4	11.3
2018	11.5	11.5	11.5	11.9	11.7	10.9	9.9	10.6	11.3	11.0	10.5	10.6

Mean	9.1	9.9	10.7	11.0	11.0	10.4	9.8	9.8	9.5	9.1	8.6	8.7
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Table 11: Mean monthly max-temperature at Debre work station ($^{\circ}\text{C}$)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	23.4	23.0	24.5	25.1	26.1	26.0	22.5	21.8	21.8	23.8	25.0	25.0
1991	25.0	25.5	25.8	26.0	26.0	25.1	21.8	20.7	21.9	23.9	24.4	24.5
1992	23.1	24.6	26.0	26.7	24.7	25.7	21.7	20.2	21.7	22.3	22.0	22.9
1993	24.9	24.9	27.0	24.0	23.8	24.6	21.5	21.3	22.3	24.0	24.9	24.7
1994	25.4	26.3	26.9	27.0	26.2	24.9	22.0	21.7	23.4	24.6	25.0	25.1
1995	24.9	24.9	25.9	25.2	26.2	26.2	23.2	22.2	24.5	26.0	25.9	24.7
1996	24.8	26.7	26.6	26.0	25.8	24.3	22.7	22.4	23.6	26.2	23.2	25.5
1997	24.1	25.2	24.8	26.5	25.8	25.2	22.9	23.6	23.4	23.2	23.3	24.4
1998	23.2	25.1	26.5	27.0	25.9	26.1	20.6	19.8	21.5	23.4	23.4	23.4
1999	22.3	25.7	26.6	26.7	26.0	25.5	22.2	20.7	21.9	21.8	23.1	23.9
2000	25.6	26.4	28.3	25.6	26.2	26.0	21.6	20.9	23.0	23.9	23.8	23.9
2001	24.5	27.3	25.5	26.8	27.6	24.4	20.8	20.4	22.3	23.6	23.8	24.7
2002	23.7	25.9	26.6	27.0	27.4	25.1	22.2	21.5	22.6	23.1	24.6	24.2
2003	25.1	26.3	26.0	27.7	28.2	25.8	21.9	20.8	22.5	23.4	23.4	23.4
2004	25.1	25.5	26.2	25.6	27.4	24.3	22.0	20.9	21.8	22.7	24.6	24.6
2005	24.5	27.7	27.5	26.5	25.6	25.0	22.0	21.1	21.4	22.0	23.3	24.6
2006	26.3	27.4	26.6	25.1	25.1	24.5	21.9	21.4	21.4	21.8	22.8	23.6
2007	24.0	24.3	25.4	23.8	24.6	23.9	21.8	21.6	21.4	21.6	22.2	22.4
2008	23.8	24.3	24.8	23.8	25.1	25.0	21.3	20.7	21.8	22.1	21.5	22.9
2009	23.6	24.7	25.8	26.0	26.4	26.2	20.7	21.7	22.3	22.7	21.9	22.2
2010	23.3	25.2	25.8	25.8	25.2	25.0	22.1	21.8	22.7	23.3	22.4	21.5
2011	22.8	25.6	23.9	26.0	24.3	24.0	21.7	20.4	21.4	22.3	22.0	22.6
2012	23.7	24.8	24.3	25.5	26.4	24.7	21.0	20.9	21.7	23.0	24.4	24.0
2013	24.9	26.1	26.5	27.8	27.0	24.0	21.3	20.1	22.7	22.5	23.5	23.5
2014	24.6	25.5	25.7	25.7	24.5	24.5	22.0	21.1	21.9	22.5	23.0	22.9
2015	24.2	25.8	25.8	26.9	25.3	23.8	23.4	21.7	23.0	24.7	23.6	23.5
2016	24.3	26.3	27.6	26.4	24.9	24.3	21.1	20.9	22.9	23.6	23.4	23.1
2017	24.2	24.5	25.9	26.3	24.8	25.4	22.4	22.2	23.0	22.9	22.8	23.0
2018	23.3	24.2	25.2	25.7	25.4	25.7	22.4	21.1	22.1	22.3	23.1	26.6
Mean	24.2	25.5	26.0	26.0	25.8	25.0	21.9	21.2	22.3	23.2	23.5	23.8

Table 12: Mean monthly min-temperature at Debre work station ($^{\circ}\text{C}$)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	4.2	4.3	4.0	4.9	5.3	5.2	4.7	4.4	3.9	4.3	6.1	8.2
1991	9.6	10.3	10.5	11.6	11.2	11.3	9.8	8.6	9.3	9.4	5.9	5.5

1992	6.3	6.7	8.0	11.6	11.2	11.7	9.6	8.6	9.1	8.8	6.7	6.7
1993	7.5	7.9	9.2	11.6	11.2	12.0	9.3	8.7	8.8	8.2	7.5	7.9
1994	8.7	9.2	10.3	10.7	11.6	11.2	11.3	11.3	11.0	8.7	9.0	8.9
1995	10.1	9.7	9.5	11.1	11.7	11.8	11.4	11.3	10.8	9.6	9.4	9.5
1996	10.3	11.1	11.0	11.0	10.7	11.1	10.7	10.8	10.6	9.6	10.1	10.4
1997	9.5	10.1	10.1	11.5	11.3	11.3	10.1	10.1	10.2	9.9	10.4	8.8
1998	9.2	10.6	11.4	12.1	11.8	11.5	11.1	10.9	11.2	11.2	10.7	7.2
1999	8.9	9.6	10.4	11.4	11.0	10.5	10.0	10.5	9.9	10.1	9.5	8.4
2000	9.1	8.4	10.2	10.0	10.3	10.8	8.3	6.4	6.6	7.1	10.6	10.1
2001	8.3	8.9	8.9	10.0	8.0	7.4	10.5	10.6	9.9	6.7	6.4	7.4
2002	7.3	8.6	10.1	11.1	9.8	10.8	11.2	10.3	9.7	7.7	5.2	6.3
2003	6.3	8.9	9.4	10.7	11.5	9.5	8.1	9.2	9.1	6.5	6.2	6.6
2004	8.4	8.0	8.7	6.7	7.0	10.8	10.8	10.9	10.3	9.8	8.1	8.4
2005	7.5	8.5	9.7	9.6	11.2	11.0	10.1	10.8	10.0	8.8	10.0	5.9
2006	8.3	7.9	10.2	10.7	11.3	11.2	10.9	11.0	10.5	10.0	10.3	7.5
2007	7.9	9.6	9.8	11.9	11.5	11.3	11.7	11.2	11.1	11.3	12.0	10.7
2008	9.5	9.7	10.1	12.3	11.9	11.8	11.5	11.5	10.7	12.0	13.7	12.2
2009	11.0	8.5	12.4	12.7	11.4	12.2	11.3	10.8	9.4	8.9	6.3	8.4
2010	8.0	10.3	11.7	12.4	13.0	12.0	11.4	11.1	10.0	8.3	7.9	8.2
2011	8.0	6.8	9.2	11.3	11.3	11.7	11.2	11.3	10.3	6.6	8.8	6.2
2012	6.7	9.6	10.4	11.2	11.6	11.7	11.0	11.1	10.0	7.5	8.3	5.8
2013	7.6	9.5	11.0	11.1	11.8	11.7	10.8	10.9	9.7	8.5	8.0	6.0
2014	8.5	9.4	11.6	11.1	12.0	11.7	12.0	10.9	10.1	9.2	7.9	6.5
2015	6.4	9.2	9.0	11.6	11.8	11.5	10.9	10.8	9.6	7.8	9.9	8.8
2016	8.7	10.1	11.5	12.7	12.1	12.1	11.2	11.2	10.8	9.7	6.1	6.8
2017	5.5	10.1	10.7	11.2	12.1	11.6	11.3	11.0	10.5	9.9	9.2	7.4
2018	7.9	8.5	7.3	8.1	8.7	8.4	8.0	9.4	10.6	9.8	10.1	10.9
Mean	8.1	9.0	9.9	10.8	10.9	10.9	10.4	10.2	9.8	8.8	8.6	8.0

Table 13: Mean monthly max-temperature at Yetnora station ($^{\circ}\text{C}$)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	23.4	23.3	24.3	24.7	25.3	23.2	19.8	19.8	20.9	22.6	23.7	24.0
1991	24.8	25.1	24.7	24.4	25.1	23.1	18.3	18.6	20.9	22.1	23.7	22.8
1992	23.2	23.8	26.1	26.3	25.6	23.4	19.6	18.1	20.4	21.2	21.9	23.0
1993	24.1	24.7	25.2	25.6	25.5	23.7	19.4	18.3	20.4	22.1	23.3	23.4
1994	23.9	24.6	25.4	26.0	25.6	24.0	19.7	18.2	20.2	22.1	23.2	23.7
1995	24.5	24.9	26.1	25.4	26.1	23.0	19.1	17.9	21.0	23.3	23.5	23.6
1996	24.2	25.4	25.5	25.2	24.5	20.4	19.4	19.2	21.8	23.3	23.5	24.0
1997	23.8	25.3	24.9	24.4	24.7	21.5	18.5	19.9	22.3	23.1	22.8	24.7
1998	24.3	24.4	24.9	26.1	25.7	24.8	20.2	18.3	19.9	23.0	24.4	24.5

1999	25.5	26.3	27.5	25.8	27.6	24.2	19.6	19.0	22.0	24.0	24.2	23.7
2000	24.4	23.0	26.2	24.2	25.7	20.2	17.7	16.2	21.4	24.9	23.3	23.6
2001	24.5	25.2	26.7	25.4	26.4	22.9	18.5	18.2	21.2	23.3	23.6	23.4
2002	24.2	25.2	26.8	25.1	25.3	21.3	18.3	17.9	20.9	23.1	23.0	23.2
2003	24.2	25.5	26.9	25.3	25.2	21.6	18.5	18.3	20.8	22.6	22.9	23.2
2004	24.1	24.7	27.0	25.3	25.0	21.3	18.5	18.3	20.7	22.4	22.7	23.1
2005	24.0	25.8	27.0	25.7	25.4	22.5	18.3	18.5	20.9	22.4	22.6	23.1
2006	24.0	25.3	26.5	25.6	25.3	21.6	19.4	18.4	20.1	23.0	23.1	23.2
2007	24.1	25.2	26.6	24.9	25.1	21.2	18.6	18.7	20.2	22.1	23.5	23.1
2008	24.0	25.6	27.6	25.8	24.2	21.1	18.5	18.4	21.0	22.0	21.6	22.9
2009	23.9	25.5	26.5	26.7	27.1	26.2	18.0	18.9	21.2	22.3	23.4	23.4
2010	23.8	24.2	25.5	24.7	23.7	23.5	19.0	18.9	21.0	23.1	23.1	23.0
2011	22.9	25.9	25.1	26.2	25.4	22.4	19.8	19.2	21.0	23.3	22.8	23.3
2012	24.7	25.2	26.8	25.8	26.4	24.1	18.7	18.7	20.4	22.7	23.8	24.1
2013	24.9	26.6	27.2	27.3	25.0	21.2	18.3	18.5	21.2	22.0	23.8	23.3
2014	24.8	24.9	26.7	26.1	24.2	23.9	20.3	19.5	20.5	22.3	23.7	23.3
2015	24.6	26.4	26.6	27.3	25.1	22.6	20.8	20.2	22.1	24.2	24.0	23.6
2016	24.7	25.4	28.1	26.2	22.6	22.1	19.4	19.5	21.8	23.3	23.8	23.6
2017	24.5	25.4	27.0	26.9	24.5	24.0	18.6	18.7	20.9	22.8	23.1	23.5
2018	23.8	25.7	26.3	25.6	26.1	21.0	19.4	19.4	22.0	22.7	22.2	24.2
Mean	24.2	25.1	26.3	25.6	25.3	22.6	19.0	18.7	21.0	22.8	23.3	23.5

Table 14: Mean monthly min-temperature at Yetnora station ($^{\circ}\text{C}$)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1990	7.5	9.6	9.7	10.3	10.0	9.7	10.9	10.9	10.4	7.3	7.6	6.7
1991	8.7	8.4	10.2	10.7	10.6	9.9	9.9	12.4	9.3	8.5	6.8	7.0
1992	8.6	9.2	10.7	11.3	11.7	10.2	10.3	10.7	9.5	9.0	7.3	6.6
1993	7.4	9.1	10.4	10.9	10.5	10.1	10.1	10.2	9.9	8.6	7.4	8.3
1994	8.0	9.4	10.4	10.8	10.5	10.1	10.0	10.0	9.8	8.7	7.6	8.2
1995	8.0	9.4	10.4	10.8	10.5	10.1	10.0	10.0	9.8	8.7	7.6	8.2
1996	9.3	8.7	10.9	11.5	11.0	10.9	9.7	10.1	10.2	9.2	8.1	7.2
1997	8.3	10.3	10.6	10.8	10.5	10.0	9.6	9.5	9.6	9.4	8.5	7.9
1998	9.5	9.4	9.3	10.6	10.2	10.1	8.8	8.3	9.1	9.6	8.1	7.6
1999	9.2	8.9	10.9	10.2	10.4	9.0	7.8	8.4	9.1	9.8	10.1	9.4
2000	9.4	8.6	10.4	8.5	10.0	8.5	9.7	8.8	9.9	9.7	9.6	9.3
2001	9.2	9.1	10.8	9.4	10.5	9.4	9.3	8.9	9.4	9.8	10.1	9.8
2002	9.1	9.2	10.7	9.1	10.6	9.7	10.1	9.2	9.5	9.8	10.0	10.0
2003	9.1	9.3	10.8	9.2	10.7	10.0	10.3	9.4	9.4	9.8	10.1	10.2
2004	9.1	9.0	10.8	9.0	10.8	10.4	11.1	9.6	9.5	9.8	9.8	10.0
2005	8.9	9.6	11.0	9.5	11.1	10.6	10.5	9.7	9.1	9.9	10.6	10.8

2006	8.9	9.6	10.9	9.0	11.2	12.1	13.0	10.4	9.6	9.9	9.3	10.0
2007	8.6	10.2	11.3	9.1	11.6	10.8	10.8	10.2	8.6	10.0	12.3	13.2
2008	8.5	9.3	11.1	9.5	12.1	11.6	11.4	11.4	9.9	10.2	8.3	7.4
2009	8.4	11.5	11.8	11.8	11.9	11.7	11.6	11.6	10.9	9.6	6.7	9.9
2010	8.3	10.8	12.0	6.6	12.3	11.3	10.5	10.7	10.7	8.7	7.6	7.6
2011	8.1	7.2	10.1	11.1	10.9	9.5	8.0	9.5	9.7	7.1	7.2	4.6
2012	6.6	7.2	8.5	10.4	9.6	10.5	10.2	10.8	10.1	7.7	7.4	7.5
2013	7.9	10.3	12.0	11.7	11.7	11.4	11.3	11.4	10.7	9.7	8.5	6.2
2014	9.7	10.7	11.9	12.4	11.9	11.4	10.9	10.7	11.0	10.1	8.9	7.5
2015	8.1	10.6	11.6	12.6	12.4	12.3	11.7	11.9	11.1	10.4	9.9	9.7
2016	9.2	10.7	13.0	12.0	12.5	11.4	11.8	11.4	10.3	8.6	6.8	6.2
2017	6.0	11.1	12.2	13.0	12.0	11.2	11.1	11.5	10.7	9.8	6.3	5.0
2018	8.2	10.1	10.3	11.4	11.7	11.0	10.8	10.8	9.7	9.0	8.1	7.1
Mean	8.5	9.5	10.8	10.5	11.1	10.5	10.4	10.3	9.9	9.3	8.5	8.2

Table 15: ET_o and other climatic data for Motta metrological station

Monthly ET_o Penman-Monteith - untitled

Country: Ethiopia Station:

Altitude: 2417 m. Latitude: 11.08 °N Longitude: 37.89 °E

Month	Min Temp °C	Max Temp °C	Humidity %	Wind km/day	Sun hours	Rad MJ/m ² /day	ET_o mm/day
January	8.3	24.3	49	113	9.6	21.1	3.93
February	9.4	25.3	44	125	9.4	22.3	4.44
March	10.5	26.2	45	134	8.8	22.6	4.79
April	11.0	25.9	47	136	8.7	22.9	4.88
May	11.1	25.7	54	130	8.7	22.5	4.70
June	10.7	24.1	63	124	7.4	20.2	4.12
July	10.5	20.9	75	120	5.7	17.8	3.38
August	10.4	20.4	77	120	6.1	18.7	3.39
September	9.9	21.8	71	118	8.3	21.9	3.93
October	9.2	22.9	66	118	9.3	22.4	4.02
November	8.6	23.3	58	111	9.4	21.0	3.81
December	8.1	23.7	52	113	9.9	20.9	3.79
Average	9.8	23.7	58	122	8.4	21.2	4.10

Table 16: Irrigation water requirement of tomato (mm/dec)

Crop Water Requirements							
ETo station			Crop				
Rain station			Tomato				
			Planting date				
			01/01				
Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	1	Init	0.40	1.55	15.5	3.3	12.2
Jan	2	Init	0.40	1.57	15.7	2.6	13.1
Jan	3	Deve	0.40	1.65	18.1	3.1	15.0
Feb	1	Deve	0.51	2.20	22.0	2.8	19.1
Feb	2	Deve	0.69	3.06	30.6	2.8	27.9
Feb	3	Deve	0.85	3.87	30.9	6.5	24.5
Mar	1	Deve	1.01	4.71	47.1	11.3	35.8
Mar	2	Mid	1.11	5.29	52.9	14.9	38.0
Mar	3	Mid	1.11	5.33	58.6	15.6	43.0
Apr	1	Mid	1.11	5.36	53.6	15.4	38.2
Apr	2	Mid	1.11	5.40	54.0	16.1	37.9
Apr	3	Late	1.06	5.11	51.1	19.5	31.6
May	1	Late	0.98	4.66	46.6	23.3	23.3
May	2	Late	0.92	4.31	21.6	13.2	8.3
					518.4	150.3	368.1

Table 17: Irrigation water requirement of maize (mm/dec)

Crop Water Requirements							
ETo station			Crop				
Rain station			Maize				
			Planting date				
			01/01				
Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	1	Init	0.50	1.94	19.4	3.3	16.1
Jan	2	Init	0.50	1.96	19.6	2.6	17.0
Jan	3	Deve	0.53	2.18	24.0	3.1	20.9
Feb	1	Deve	0.69	2.94	29.4	2.8	26.6
Feb	2	Deve	0.85	3.79	37.9	2.8	35.1
Feb	3	Deve	1.00	4.56	36.5	6.5	30.0
Mar	1	Mid	1.13	5.29	52.9	11.3	41.7
Mar	2	Mid	1.16	5.54	55.4	14.9	40.6
Mar	3	Mid	1.16	5.58	61.4	15.6	45.8
Apr	1	Mid	1.16	5.62	56.2	15.4	40.8
Apr	2	Mid	1.16	5.66	56.6	16.1	40.4
Apr	3	Late	1.10	5.31	53.1	19.5	33.6
May	1	Late	1.00	4.76	47.6	23.3	24.3
May	2	Late	0.90	4.22	42.2	26.5	15.7
					592.2	163.6	428.6

Table 18: Irrigation water requirement of potato (mm/dec)

Crop Water Requirements							
ETo station				Crop		Potato	
Rain station		Motta		Planting date		01/01	
Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	1	Init	0.45	1.75	17.5	3.3	14.2
Jan	2	Init	0.45	1.77	17.7	2.6	15.1
Jan	3	Deve	0.49	2.00	21.9	3.1	18.9
Feb	1	Deve	0.67	2.87	28.7	2.8	25.9
Feb	2	Deve	0.87	3.84	38.4	2.8	35.6
Feb	3	Deve	1.04	4.73	37.9	6.5	31.4
Mar	1	Mid	1.13	5.26	52.6	11.3	41.3
Mar	2	Mid	1.13	5.39	53.9	14.9	39.0
Mar	3	Mid	1.13	5.43	59.7	15.6	44.1
Apr	1	Mid	1.13	5.46	54.6	15.4	39.3
Apr	2	Late	1.08	5.25	52.5	16.1	36.4
Apr	3	Late	0.98	4.75	47.5	19.5	28.0
May	1	Late	0.89	4.25	42.5	23.3	19.2
					525.5	137.1	388.4

Table 19: Net Irrigation Requirement of the selected crops from CROPWAT8.0

	Jan	Feb	Mar	Apr	May	Jun
Precipitation deficit						
1. Tomato	40.4	71.5	116.9	107.7	31.6	0.0
Net scheme irr.req.						
in mm/day	1.3	2.6	3.8	3.6	1.0	0.0
in mm/month	40.4	71.5	116.9	107.7	31.6	0.0
in l/s/h	0.15	0.30	0.44	0.42	0.12	0.00
Irrigated area	100.0	100.0	100.0	100.0	100.0	0.0
(% of total area)						
Irr.req. for actual area	0.15	0.30	0.44	0.42	0.12	0.00
(l/s/h)						

	Jan	Feb	Mar	Apr	May	Jun
Precipitation deficit						
1. Maize	54.0	91.7	128.1	114.9	40.0	0.0
Net scheme irr.req.						
in mm/day	1.7	3.3	4.1	3.8	1.3	0.0
in mm/month	54.0	91.7	128.1	114.9	40.0	0.0
in l/s/h	0.20	0.38	0.48	0.44	0.15	0.00
Irrigated area	100.0	100.0	100.0	100.0	100.0	0.0
(% of total area)						
Irr.req. for actual area	0.20	0.38	0.48	0.44	0.15	0.00
(l/s/h)						

	Jan	Feb	Mar	Apr	May	Jun
Precipitation deficit						
1. Potato	48.1	92.9	124.5	103.7	19.2	0.0
Net scheme irr.req.						
in mm/day	1.6	3.3	4.0	3.5	0.6	0.0
in mm/month	48.1	92.9	124.5	103.7	19.2	0.0
in l/s/h	0.18	0.38	0.46	0.40	0.07	0.00
Irrigated area	100.0	100.0	100.0	100.0	100.0	0.0
(% of total area)						
Irr.req. for actual area	0.18	0.38	0.46	0.40	0.07	0.00
(l/s/h)						

Table 20: Observed Monthly flow of Teme River at gauging station (m³/s) (1997-2010).

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Grand Total
1997	0.14	0.39	0.32	0.58	0.51	2.9	10.2	9.66	6.63	3.19	2.26	0.62	3.12
1998	0.4	0.14	0.23	0.96	1.36	2.49	11.8	13.7	6.99	5.14	1.48	0.31	3.75
1999	0.95	0.38	0.23	1.13	0.2	0.54	7.48	12.5	3.41	4.14	0.67	0.24	2.66
2000	0.18	0.44	0.14	1.46	2.34	0.81	10	9.29	2.37	3.3	1.57	0.58	2.71
2001	0.25	0.13	0.52	0.14	1.2	2.54	10.6	11.5	3.28	1.16	0.54	0.2	2.68
2002	0.58	0.17	0.94	0.13	1.06	1.33	9.73	10.3	2.76	1.39	0.15	0.97	2.46
2003	0.09	0.05	0.17	1.07	0.03	5.26	11.6	9.87	3.62	1.14	1.25	0.31	2.87
2004	0.38	0.74	0.13	0.23	2.3	2.19	13	9.12	5.21	3.62	1.61	1.46	3.33
2005	0.73	0.38	0.96	0.73	1.05	2.6	13.1	16.3	9.55	5.68	2.7	1.52	4.6
2006	0.24	0.37	0.21	0.46	1.05	1.96	14	10.3	9.09	4.06	0.7	0.42	3.57
2007	0.36	0.19	0.19	0.21	2.17	5.9	17	16.7	7.38	3.15	0.66	0.49	4.53
2008	0.25	0.08	0.18	0.3	1.36	1.72	9.86	9.1	3.02	3.67	1.47	0.43	2.62
2009	0.26	0.13	0.21	0.16	4.06	1.97	13.4	8.78	6.15	2.04	0.43	0.34	3.16
2010	0.21	0.11	0.22	0.14	1.04	1.93	14.1	14.1	6.58	2.41	0.48	0.42	3.47
Grand Total	0.36	0.26	0.33	0.55	1.41	2.44	11.9	13.5	5.43	3.15	1.14	0.59	3.25