Assessment of Water and Land Resources Potential for Surface Irrigation Development Using GIS: A Case Study of Akaki River Catchment

By: Neddi Johar Mamo

A Thesis Submitted to the Department of Water Resources Engineering
School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Water Resources Engineering (Specialization in Irrigation Engineering)

Office of Graduate Studies
Adama Science and Technology University

February, 2022

Adama, Ethiopia

Assessment of Water and Land Resources Potential for Surface Irrigation Development Using GIS: A Case Study of Akaki River Catchment

By: Neddi Johar Mamo
Advisor: Dr. Boja Mekonnen

A Thesis Submitted to the Department of Water Resources Engineering
School of Civil Engineering and Architecture

Presented in Partial Fulfillment of the Requirement for the Degree of Master's in Water Resources Engineering (Specialization in Irrigation Engineering)

Office of Graduate Studies
Adama Science and Technology University (ASTU)

February, 2022
Adama, Ethiopia

DECLARATION

I hereby declare that this Master Thesis entitled "Assessment of Water and Land Resources Potential for Surface Irrigation Development Using GIS: A Case Study of Akaki River catchment" is my original work. That is, it has not been submitted for the award of any academic degree, diploma or certificate in any other university. All sources of materials that are used for this thesis have been duly acknowledged through citation.

Neddi Johar Mamo ________________ ________________

ADVISOR RECOMMENDATION

I, the advisor of this thesis, here by certify that I have read the revised version of the thesis entitled "Assessment of Water and Land Resources Potential for Surface Irrigation Development Using GIS: A Case Study of Akaki River catchment" prepared under my guidance by Neddi Johar Mamo, Id.No pge/18835/11 submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Water Resources Engineering (Specialization in Irrigation Engineering). Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Boja Mekonnen (Ph.D) ____________ ________________

APPROVAL PAGE OF M.SC THESIS

I, the advisors of the thesis entitled **"Assessment of Water and Land Resources Potential for Surface Irrigation Development Using GIS: A Case Study of Akaki River catchment"** and developed by Neddi Johar Mamo, hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Boja Mekonnen (Ph.D) __________________ _________________

We, the undersigned, members of the Board of Examiners of the thesis by Neddi Johar Mamo have read and evaluated the thesis entitled "Assessment of Water and Land Resources Potential for Surface Irrigation Development Using GIS: A Case Study of Akaki River catchment" and examined the candidate during open defense. This is, therefore, to certify that the thesis is accepted for partial fulfillment of the requirement of the degree of Master of Science in Water Resources Engineering (Specialization in Irrigation Engineering).

Chairperson	Signature	Date
Internal Examiner	Signature	Date
External Examiner	Signature	Date

Final approval and acceptance of the thesis is contingent upon submission of its final copy to the Office of Postgraduate Studies (OPGS) through the Department Graduate Council (DGC) and School Graduate Committee (SGC).

Department Head	Signature	Date
School Dean	Signature	Date
Office of Postgraduate Studies, Dean	Signature	Date

ACKNOWLEDGEMENTS

First of all, I would like to thank 'Almighty Allah' who made it possible, to begin and finish this work successfully.

I acknowledge, with great thanks, my dear advisor, Boja Mekonnen (Ph.D) for his professional assistance, genuine, close friendship, advice, constructive comments and valuable criticism all the way from the time of proposal to the completion of the study. And I would like to acknowledgment Adama Science and Technology University for providing such opportunity.

I gratefully acknowledge all officers who have given me data for my study such as Ministry of Water, Irrigation and Energy Department of GIS, Water Authority and National Meteorological Services Agency.

I am also thankful to my mother Jemila Arus for her prayer support during my study. My deepest thank is to my beloved wife Jemila Jarso for her unconditional love, inspiration and always encouraging me, support me, and give me strength to go through my study. I would also like to thank Mr. Salih Abdela, Fatuma Jarso and other member of their family for their ultimate support and concern for my success and well-being successful from the beginning to the end.

TABLE OF CONTENTS

CONTENTS **PAGES**

LIST OF TABLES

TABLES **PAGES**

LIST OF FIGURES

FIGURE **PAGE**

LIST OF TABLES AND FIGURES IN THE APPENDIX

LIST OF FIGURES IN THE APPENDIX

LIST OF ACRONOMY AND ABBREVIATION

AA	Addis Ababa
AAWSA	Addis Ababa Water and Sewerage Authority
AAU	Addis Ababa University
BCM	Billion Cubic Meter
CA	Comprehensive Assessment of Water Management for Agriculture
C	Clay
CWR	Crop Water Requirement
DEM	Digital Elevation Model
DFID	Department for International Development
E	East Direction
EMA	Ethiopian Mapping Agency
ENVI	Environment for Visualizing Images
ESRI	Environmental Systems Research Institute
ESP	Exchangeable Sodium Percentage
FDRE	Federal Democratic Republic of Ethiopia
FAO	Food and Agriculture Organization of the United Nations
GDP	Gross Domestic Product
GIS	Geographic Information System
GIWR	Gross Irrigation Water Requirement
GLCN	Global Land Cover Network
GPS	Global Positioning System
HRU	Hydrological Response Units
IFAD	International Fund for Agricultural Development
ITCZ	Inter-Tropical Convergence Zone
IWMI	International Water Management Institute
IWR	Irrigation Water Requirement
L	Loam
LULC	Land Use Land Cover
Mha	Million hectare

Mm^3	Million Cubic Meter
MoA	Ministry of Agriculture
MoWIE	Ministry of Water Irrigation and Energy
Mt.	Mountain
NASA	National Aeronautics and Space Administration
NIWR	Net Irrigation Water Requirement
NGA	National Geospatial Intelligence Agency
NMSA	National Meteorological Services Agency
RAM	Readily Available Moisture
RS	Remote Sensing
RWH	Rain Water Harvesting
SL	Sandy loam
SiCL	Silty Clay Loam
SWAT	Soil and Water Assessment Tool
TAM	Total Available Moisture
TIN	Triangulated Irregular Network
USGS	United State Geological Survey

ABSTRACT

Investigating available land and water resources for irrigation is essential for the development of irrigated agriculture. An assessment of the land and surface water resources potential of Akaki catchment was conducted to alleviate lack of required information in relation to potential irrigable area, available water and irrigation water demand for dominant crops which can help for the planning of irrigation development. This study was initiated with the objective of evaluate the water and land resources potential of Akaki river catchment for irrigation development and generating geo-referenced map of the resources by using Geographic Information System. To meet the main objective of the study, land suitability, available water potential and irrigation water demands were evaluated. The most determinant factors of surface irrigation were land use land cover, slope and soil suitability were assessed. Potentially suitable sites for surface irrigation development was evaluated for each selected vegetable crops (potato, tomato, cabbage and pepper). Soil suitability was examined in terms of soil depth, texture and drainage for surface irrigation using GIS model and reference evapotranspiration, net effective rainfall, net and gross irrigation requirement for each of the crop was estimated using CROPWAT software. The maximum potentially suitable area of the Akaki catchment is nearly 67.06% (114,939ha), out of which 6.56% (10,570ha) is highly suitable, 28.07% (45,191ha) moderately suitable, about 36.75% (59,178ha) is marginally suitable and the rest 28.62% (46.081ha) is not suitable. The annual average flow of the river was estimated as 26.585Mm^3 which has a capacity to irrigate 37,169.61ha of land from total available land potential. The total gross water requirement for all crops (potato, tomato, cabbage and pepper) for available land potential was found as 7.413Mm^3. It is evident from the finding that the total potential irrigable land of 114,939 ha required 28.469Mm^3 gross irrigation water for the selected crops. This is showed that irrigation water demand is greater than the available stream flow. To curve the problem of shortage of water, it is recommended to implement irrigation water management, using technology, water harvesting structures and exploring water from ground to fully develop the identified irrigation potential in the study area.

Key Words: Surface Irrigation, Land Suitability, GIS, Surface water availability

CHAPTER 1. INTRODUCTION

1.1. Background and Justification

Irrigation has been much appreciated for its significant contribution to global agricultural production and food security over the past 50 years. Currently, more than 40% of global agricultural products are produced on irrigated land, which constitutes close to 20% of the total global arable land (FAO, 2018). In recent years, there are a large number of irrigation schemes that have been developed in different parts of Ethiopia by the government and support of different funding agencies. However, due to different environmental and management factors most of these irrigation schemes are not being exploited fully and irrigation in general is not contributing its share to the overall economic development of the country as required (MOA, 2011). Hence, the irrigation subsector has to be given top priority in the overall development plans of the country with the ultimate objective of enhancing agricultural production and sustain crop production and alleviate food insecurity problems (MOA, 2011).

Ethiopia is prosperous with natural resources like land and water that helps the Socio-economic development of the country. The country has about 124.4 BCM river water, 70 BCM lake water, and 30 BCM groundwater resources (Birhanu et al., 2014). Ethiopia has an area of 113 Mha land and 5.3 Mha potential irrigable land, of which 3.7 Mha can be developed using surface water resources and 1.6 Mha using groundwater and rainwater management (Awulachew and Ayana, 2011). However, only 12.1% of the potentially irrigable land is currently under irrigation (Awulachew et al., 2010). Compared to the global average per capita irrigated area in Ethiopia is very low (Awulachew et al., 2007). Therefore, inevitably more area needs to be brought under irrigation in order to achieve sustainable food security. Further, future water demands for different uses will increase due to population growth. To develop sustainable agricultural water management, one has to know the limitations and suitability of the potential land for irrigation and the availability of water around the area. The best suitable uses for land depend on the physical characteristics of the soil such as texture, structure, rooting depth, stoniness, rockiness, organic matter and nutrient content, drainage conditions and slope (Negash and Seleshi, 2004).

Ethiopia is a water abundant country in the world but this much water is not successfully apply for irrigation and not contributing its share to the growth of the agriculture sector accordingly.

About 15 to 17% of Government expenditures are committed to the agriculture sector which directly supports 80% of the population's livelihoods, 47% of gross domestic product (GDP) and over 83.9% of export value (FDRE, 2011). But the country has the potential for its development both regarding vast suitable land and availability of freshwater resources adequate for irrigation purpose (MOA, 2011).

Irrigation development could improve agricultural productivity and enhance socio-economic development of the community. Thus, utilization of water resources in irrigated agriculture provides supplementary and full season irrigation to overcome the effects of rainfall variability and unreliability. Irrigation agriculture enhances production and improves the food supply, income of rural population and open employment opportunities for the poor. It also supports national economy by producing industrial crops that are used as raw materials for value adding industries and exportable crops.

Assessing available water and land for irrigation are important for planning of efficient utilization of the resources. In the watershed, stream flows from some of the rivers are not known and potential irrigable areas have not been identified. More than 90% of the world uses surface irrigation, even if local irrigators have least knowledge of how to operate and maintain the system (Saymen, 2005). Furthermore, these systems can be developed at the farm level with minimal capital investment. The major capital investment on surface system is mainly associated with land grading. But if the topography is not too undulating, these costs are not high. Hence, surface irrigation development requires favorable topography and information on land and water resources for proper planning (FAO, 2018).

This study concentrates on identifying surface irrigation potential and suitability of the Akaki river catchment using Geographical Information System (GIS) software. Geographical Information System (GIS) is computer based system designed tool applied to geographical data for integration, collection, storing, retrieving, transforming and displaying spatial data for solving complex planning and management problems (Rajinder et al., 2014).

In the past, several studies have been made to assess the irrigation potential and water resources by using GIS tool (You et al., 2011). Land and water resource potential for irrigation in Africa on the basis of river basins of countries was assessed by FAO (2007). It was one of the first GIS based studies of its kind at a continental level. It proposed natural resource based approach to assess irrigation potential. Its main limitations were in the sensitivity of criteria for defining land suitability for irrigation and in water allocation scenarios needed for computation of irrigation potential. The irrigation potential of Africa was also studied by FAO (2011), taking in to consideration the above limitations. It concentrated mainly on quantitative assessment based on physical criteria (land and water), but relied heavily on information collected from the countries. A river basin approach had been used to insure consistency at river and basin level. Geographic Information System (GIS) facilities were extensively used for this purpose. In this study, a physical approach to irrigation potential was understood as setting the global limit for irrigation development. Irrigation suitability analysis in Ethiopia, a case of Abaya Chamo Lake Basin was studied by Negash (2004). It was a Geographical Information System (GIS) based and had taken into consideration soil, slope, land use and water resource availability in perennial rivers in the basin to identify potential irrigable land.

Hailegebriel (2007) conducted a study on Irrigation potential evaluation and crop suitability analysis using GIS and Remote sensing techniques in Beles sub basin, Beneshangul Gumuz Region. The study considered slope, soil, land cover/use, water resources and climate factors in evaluating surface irrigation suitability. pair wise combination and weighted linear combination techniques used to weight and standardized the factors, which used to develop irrigation suitability map and evaluate suitability of land for the crops.

Meron (2007) carried out similar work on surface irrigation suitability analysis of southern Abay Basin by implementing GIS techniques. As its being the most limiting factor for the realization of, especially for surface irrigation method, the slope layer was used as the base map for the overlaying analysis. The suitable land identified categorized according to the different climatic zones.

1.2. Statement of the Problem

It is unquestionable that Ethiopia is blessed with untapped natural resources. Among these natural resources, water takes the lion's share. Despite the fact that the country is endowed with abundant water resources, the country frequently suffered severe drought in the past, in turn, the people of this (once a source of great civilization) country led their lives under destitution for several decades. The Ethiopian government is working aggressively to tap the water resources of the country. The water policy clearly dictates how to make use of the water resources. The policy takes into account Integrated Water Resource Management approach. Due to growing food insecurity coupled with the population explosion and the degradation of the environment, It becomes more and more clear that riparian countries were utilize their water resources sustainably and without causing harm to each other (particularly to downstream users). This shared responsibility is the binding tie for the cooperation of both upstream and downstream riparian counties.

In this regard, due to unreliable climatic conditions and the high demographic pressure, Ethiopia is embarking to develop its land and water resources potential. High emphasis was put on using the available irrigation potential for alleviating the prevalent food insecurity and the dependency syndrome on food aid. In this respect, the study was carried out to assess the potential of irrigation development in the Akaki River. There are development of irrigated agriculture around Akaki river but there are no studies investigating the land and water resources potential of the river. Therefore, it is essential to understand the land and water resources potential of the catchment for better management and utilization of the resources

Various studies (Awlachew et al., 2007; You et al., 2011) have indicated that the country has a large potential of arable land. However, less than 5% of this potential is irrigated, due to lack of water storage facilities and infrastructure systems (e.g., pumps, water conveyance structures, etc.). Recently, the agriculture sector has received a particular emphasis to transition towards a more comprehensive agricultural production system known as Agriculture Development Led Industrialization. Use of irrigation could substantially transform the agriculture sector, which is currently dominated by single cropping rain fed crops (Awlachew&Ayana, 2011).

Now a day's Ethiopia tries to exploit its river catchment potential for irrigation and develop strong water resources management techniques. Akaki River is one of the tributaries of awash in Ethiopia with a potential for surface water irrigation. The main problems of the study area are lack of required information in relation to potential irrigable area, available water and irrigation water demand for dominant crops which can help for the planning of irrigation development. In addition to this, there is a gap on concise and dynamic potential surface water irrigation management of the Akaki River. Better understanding of the River catchment characteristics is necessary in Akaki River, which is possible with knowing full potential of the available surface water irrigation and land resources and predicting the total surface water irrigation in the Akaki river catchment. Increasing the practice of irrigation practice in the study area is combined with changing land use practices, growth, and climate change and variability, significant problem to the potential surface water irrigation of Akaki River catchment.

There are small-scale irrigation activities taking place throughout the year in the Akaki River catchment. But there is no study available which analyses the land suitability for irrigated agriculture and potential water yield in the Akaki River catchment. Also, the extent and geographical locations of potentially irrigable lands using surface irrigation methods have not been identified. This study will assist in decision making for regional agricultural development, including a selection of suitable irrigation methods and other important measures in order to increase agricultural production in the area, and introduce improved technologies for water saving and management.

1.3. Objectives

1.3.1. General Objective

The main objective of this study was to assess the water and land resources potential of Akaki River catchments for sustainable development of surface irrigation using Geographical Information System (GIS).

1.3.2. Specific Objectives

The specific objectives of the study includes:

- To identify land suitability for surface irrigation development of Akaki river.
- To assess surface water availability for irrigation development.
- To estimate total irrigation water requirement of the Akaki river catchment

1.4. Research Questions

- How much irrigable area could be found in Akaki river catchment?
- How much surface water potential was available?
- Could the available water satisfy the water demand?

1.5. Significance of the Study

One of the present day issues of the Government of Ethiopia is to increase the national economy through Agriculture led Industrialization. The knowledge of identify suitable land resources and surface water availability in the area has a great role in use of resources in a sustainable way and for its most likely use to enhance livelihood of the community and economy of the country. Irrigation potential assessment will contribute in making appropriate land use decisions, which are vital to achieving optimum productivity of the land and to ensure environmental sustainability. Irrigated agriculture has a great role in achieving food security and improves the life style of the people in the area. This study helps as to identify and assess surface irrigation potential under particular study area of Akaki River. Akaki River uses as irrigation water sources for farmers found along the river catchment. The development of irrigated agriculture around Akaki river catchment needs a systematic cost benefit analysis and the realization of profitability for market oriented production and the attainment of sustainable development.

Despite its success and growing importance of per-urban and urban small traditional irrigation, it is still affected to numerous constraints. Among them are uncertainty about land tenure and poor water use efficiency. Most of the farm land found along the river bed exposed to flood hazard, water logged and are not utilized for crop production during the rainy season. Therefore, this study, help as to identify and assess surface irrigation potential under particular study area of Akaki river catchment.

1.6. Scope and Limitation of the Study

This study was initiated to assess the water and land resources potential of the Akaki river for surface irrigation development and providing geo-referenced map of these resources using Geographical Information System (GIS).The study focused on the availability of water, Irrigation demand and potentials of irrigable land for surface irrigation at the watershed level in the Akaki River by implementing a digital elevation model (DEM) on Arc GIS without considering chemical property of the soil and water quality. So the present work only investigates soil physical property, land use/cover and land slope for determining land suitability for surface irrigation. And also assess available water for surface irrigation to compare with irrigation water demand for selected crops.

1.7. Thesis structure

The whole thesis is divided into five chapters. The first chapter provides general introduction about the research work including introduction of the research, research statement, research objectives and significance of the research. The second chapter deals with literature review in which the related works with respect to the research work are presented. The third chapter discuss about the chosen study area is given, and description about the methodology and the materials/data used. Fourth chapter presents the findings of this research work and a detailed discussion on the results obtained. And also the fifth chapters were including the conclusion which drawn based on the results obtained along with recommendations.

CHAPTER 2. LITERATURE REVIEW

2.1. Water Resources Potential of Ethiopia

Until recently, the water potential of the country was not accurately known and even today this is still an argumentative issue. If water is in short supply during some part of the irrigation season, crop production will suffer, returns will decline and part of the scheme's investment will lay idle or invaluable (FAO, 2001). Quantifying the amount of water available for irrigation and the economic efficiency of the water where to transport to the exact locations of irrigation is important in the decision to expand its use.

2.1.1. Surface Water Resources: River Basins, Lakes and Reservoirs

Ethiopia manages its surface water through 12 basins which are part of four transboundary basins: the Nile, Rift Valley, Shebelle-Juba and North East Coast (FOA, 2016). The country has nearly 122-124 BCM of annual surface run-off water contributed from the 12 river basins (Berhanu et al, 2020). The western Abay (Blue Nile), Baro Akobo, Mereb and Setit-Tekeze/Atbara Basins are part of the Nile Basin, which generates 70% of the country's renewable surface water, mostly through the Abay Basin and The eastern Wabi Shebelle and Genale Dawa Basins are part of the Shebelle Juba Basin and contain eight percent of Ethiopia's surface water (Berhanu et al., 2014). Collectively, these basins provide 86% of the Nile's annual flow (Abtew et al., 2019). The central and northeastern Afar Denakil, Awash, Omo Gibe, and Rift Valley Basins account for over 20% of surface water resources and are part of the Rift Valley Basin, which spans much of East Africa. Water supply is concentrated in the southern Omo Gibe and Rift Valley Basins. 4% of the national supply is in the Awash Basin and water availability is negligible in the northern most Afar Denakil Basin. The Awash Basin has limited supply and high demand, with low average annual precipitation (FOA, 2020). The North East Coast Basin encompasses the Ogaden and Aysha, but they are considered dry basins with rivers that only flows after rainfall (FOA, 2016).

Ethiopia has 22 lakes. Lake Tana (Abay Basin) is the largest and is a critical water source for the Nile River. According to Awulachew S. et al., (2007), Ethiopia has 11 fresh and 9 saline lakes, 4 crater lakes and over 12 major swamps or wetlands. Majority of the lakes are found in the Rift Valley Basin. The total surface area of these natural and artificial lakes in Ethiopia is about 7,500 km^2. Most of the lakes except Ziway, Tana, Langano, Abbaya and Chamo have no surface water outlets.

2.1.2. Groundwater Resources System

Groundwater is highly variable and aquifer systems are complex. Aquifers can be broadly characterized as volcanic, basement, sedimentary rock or alluvial. Volcanic aquifers are the most common and are located in highland areas throughout central and western Ethiopia. As compared to surface water resources, Ethiopia has lower ground water potential. However, by many countries standard, the total exploitable groundwater potential is high. According to African Groundwater Atlas, Annual renewable resources of Ethiopia are estimated at around 36 BCM with estimates of total ground water storage varying from 1,000 to 10,000 BCM. Tadesse, (2004) estimated that at least 13.2 billion m^3 infiltrates into the groundwater system of which 50% could be extractable.

2.2. Potential Irrigable Land of Ethiopia

Irrigable land means the area of the country which is importantly the percentage of the cultivable land from the total area covered. Ethiopia has vast cultivable land (30 to 70 Mha), but currently estimates shows that 15 Mha is under cultivation. From this cultivation land 4 to 5% is irrigated with existing equipped irrigation schemes covering about 640,000 ha across the country (Awulachew et al., 2010). However, the study estimates that total irrigable land potential in Ethiopia is 5.3 Mha assuming use of existing technologies, including 1.6 Mha through rain water harvesting (RWH) and groundwater. This means that there are potential opportunities to vastly increase the amount of irrigated land. Ethiopia indeed has significant irrigation potential assessed both from available land and water resources potential, irrespective of the lack of accurate estimates of potentially irrigable land and developed area under irrigation.

2.3. Irrigation Potential of Awash Basin

Awash River basin is one of the major twelve basins in Ethiopia. It originates from West of Addis Ababa in the central Ethiopian Highland with an elevation up to 3000m a.s.l which has a total catchment area of 115,560 km^2 and total length of 1200 km (FAO and MoWIE, 2013). The Awash River is known by population density and intensively utilized river basin in Ethiopia due to its strategic location, access roads, and available land and water resources (Zemede, 2011).

Irrigation potential of the Awash basin is estimated to be 206,000 ha and The current irrigated area of the basin was 165,031 ha in 2012 is expected to increase to about 338,300 ha by the end of 2030. These will be occurs under small scale irrigation schemes about 198,631 ha and 139,627 ha were under medium and large scale irrigation (FAO and MoWIE, 2013). Akaki river catchment is the one among other sub catchment tributary to awash sub basin. Livelihood of most inhabitants in the sub basin depends on agricultural activities.

2.4. Irrigation Land Suitability Evaluation Criteria

Land suitability evaluation according to FAO standards has been applied in many parts of the world, particularly in the developing countries (FAO, 2007 b). In Ethiopia, a number of investigations were conducted to evaluate land suitability for crops and irrigation (Worqlul et al., 2017). These studies are inadequate to made decision on proper utilization of resources in Akaki watershed, because locally adapted evidence from the combination of topographic, soil, climatic and management factors is needed for proper management decision where the productivity of the land in the study area is limited.

Land evaluation is the process of the assessment of land performance when using the land for specified purpose. The assessment require implementation and understanding of survey and studies of land forms, soil, climate, vegetation and other aspects in order to compare favorable kinds of land use in terms applicable to the objective of the evaluation (FAO, 2007 a).

Land evaluation is primarily the analysis of data about the land (its soils, climate, and vegetation) in terms of realistic alternatives for improving the use of that land. For irrigation, land suitability analysis, particular attention is given to the physical properties of the soil, to the distance from available water sources and to the terrain conditions in relation to methods of irrigation considered (FAO, 2007).

Land evaluation parameter used to address the suitability of the selected irrigation method such as surface and sprinkler irrigation method were soil depth, soil texture, electric conductivity, pH, drainage and slope factors and rated based on. In addition to these factors, land cover land use types are considered as limiting factors in evaluating suitability of land for irrigation (Haile, 2007). Determining the suitability of land for surface irrigation requires thorough evaluation of soil properties and topography (slope) of the land within field (Fasin et al., 2008). Since all kinds of rural land are involved by different land cover/use types, its suitability evaluation for surface irrigation also provides guidance in cases of conflict between rural land use and urban or industrial expansion, by indicating which areas of land covers /uses are most suitable for irrigation (FAO, 1993).

Suitability of land for surface irrigation method and for the given land utilization types were assessed by considering slop, land use land cover, soil depth soil texture pH and drainage using GIS techniques (Meron, 2007).

Land suitability orders: It indicates whether land is assessed as suitable or not suitable for the use of under consideration. There are two major orders, namely suitable and not suitable by the symbols.(FAO, 1996)

- **Order S (suitable)**: It implies land expected to yield benefits which justify the inputs, without unacceptable risk of damage to land resources.
- **Order N (not suitable)**: Land which has qualities that appears to preclude sustained use of the kind under consideration.

Land suitability classes: It reflects the degree of suitability. The classes are numbered consecutively in the sequence of decreasing degree of suitability within the order.

- **Class S1 (Highly Suitable):** Land has no significant limitations to sustain application of a given use or only minor limitations that will not significantly reduce productivity and will not raise inputs above an acceptable level.
- **Class S2 (Moderately suitable)**: Land has limitation which in aggregate is moderately severe for sustained application of a given use; the limitations will reduce productivity or benefits and increase required inputs to the extent that the overall advantages to be gained from the use, although still attractive, will be appreciably inferior to the expected on class S1 land.
- **Class S3 (Marginally suitable)**:-Land is having limitations which in the aggregates are severe for sustained application of a given use and will so reduce productivity or benefits, or increase required inputs, that this expenditure will be only marginally justified.
- **Class N1 Currently (Not suitable)**:-Land has limitation which may be surmounting time but cannot be corrected with existing knowledge of current acceptable cost.
- **Class N2 (permanently not suitable)**: Land has limitation which appears severe as to preclude any possibilities of successful sustained use of the land in the given manner.

2.5. Factors used to map land suitability for surface irrigation

Factors that affect the suitability of an area for surface irrigation will be identified based on literature and expert opinion (Worqlul et al., 2017). The factors (sub models) are soil properties, land use land cover (LULC) and slope (S) to find suitable land for surface irrigation.

2.5.1. Slope

Slope is the inclination or gradient of a surface and is commonly expressed in percentage. Slope is important for soil formation and management because of its influence on runoff, drainage, erosion and choice of irrigation types. The slope gradient of the land has great influence on selection of the irrigation methods. According to FAO standard guidelines for the evaluation of slope gradient, slopes which are less than 2%, are very suitable for surface irrigation. Slope measures the rate of change of elevation in the direction of steepest descent; slope is the means by which gravity induces the flow of water and other materials, so it is of greater significance in gradational process of land escape evolution and soil development (FAO, 1999).

Table 2 1: Slope ranges from irrigated land

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

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

2.5.2. Soil Type

The assessment of soils for irrigation involves using properties that are permanent in nature that cannot be changed or modified. Therefore type of soil is the major determinant factor for applying the amount of water to the crop root zone. Even though salinity and alkalinity hazards possibly improved by soil adjustments or management practices, they could be considered as limiting factors in evaluating the soils for irrigation (FAO, 1997). According to this fact, some types of soils are not suitable for surface irrigation due to salinity and alkalinity development rather it is suitable for sprinkler irrigation system.

Fasina et al., (2008) states soil properties include drainage, texture, depth, salinity, and alkalinity are the most determinant factors for selection of irrigation method. There may be physical property factor like infiltration, poor internal drainage which causes salt buildup. The evaluation of physical and chemical soil properties to predict its performance for specific use is an essential part of land evaluation. But in these research chemical properties of the soil is not done due to material shortage. Accordingly, some soils considered not suitable for surface irrigation could be suitable for sprinkler irrigation or micro irrigation and selected land utilization types. Identifying soil type means identifying method of irrigation depending on soil properties in addition to slope of the watershed.

2.5.3. Land Use Land Cover

Land use land cover is often used interchangeably. However, they are actually quite different. The (GLCN, 2006) defines land cover as the observed (bio) physical cover, as seen from the ground or through remote sensing, including vegetation (natural or planted) and human construction (buildings, roads, etc.) which cover the earth's surface. Water, ice, bare rock or sand surfaces also count as land cover. However, the definition of land use establishes a direct link between land cover and the actions of people in their environment. Thus, a land use can be defined as a series of activities undertaken to produce one or more goods or services. A given land use may take place on one, or more than one, pieces of land and several land uses may occur on the same piece of land. Definitions of land cover or land use in this way provide a basis for identifying the possible land suitability for irrigation with precise and quantitative economic evaluation. Therefore, matching of existing land use land cover with topographic and soil characteristics to evaluate land suitability for irrigation with land suitability classes, present possible lands for new agricultural production (Jaruntorn et al., 2004).

2.6. Previous Studies on Land Evaluation for Surface Irrigation development

Land suitability assessment plays an important role in maintaining and developing land use on a spatial basis (Diallo et al., 2016). However, the evaluation of irrigation suitability for new as well as the existing irrigation schemes is very important.

Land suitability evaluation of a given watershed is vital to predict potential and limitation of the land for irrigation (Pan J., 2012). Land evaluation on its soil properties and slop suitability are necessary and important steps in surface irrigation planning (Dagnenet S., 2013) and suggests a parametric evaluation approach for surface irrigation suitability evaluation which is concern on soil physical properties (soil texture, soil depth and drainage), soil chemical properties (salinity or alkalinity status such as calcium carbonate content and gypsum content of the soil) and slope. Any land can be classified as suitable (S), or not suitable (N) orders for surface irrigation.

Suitability of lands for surface irrigation using groundwater of Ethiopia was evaluated using GIS based Multi-criteria techniques in order to enhance the country's agricultural industries. physical land features (land use land cover, slope and soil) climate (rainfall and evapotranspiration) and market access (proximity to roads and access market) Key factors that significantly affect irrigation suitability was included. These factors were weighted using a pair wise comparison matrix then reclassified and overlaid to identify suitable areas for groundwater irrigation.

Suitable sites for surface irrigation along the Erer watershed of the East Hararghe was determined using GIS based multi-criteria land suitability evaluation method considering fifteen factors; namely, soil ph, soil type, soil drainage, soil depth, AWSC, impermeable layer, ECE, CEC, phase, organic carbon texture classes, obstacle to root, land use land cover, slope and distance from the river outlets. Each factors was standardized to a common measurement scale and represent numeric range giving higher values to more suitable and lower values to less suitable attributes.

physical land features (land use land cover, soil and slope), and proximity to water sources was considered to evaluate Land suitability for surface irrigation using Spatial Information Technology in Omo Gibe River Basin, Southern Ethiopia (Gebre et al., 2020). The result obtained reveled that, study area has poor drainage condition and suggests appropriate drainage provision should be taken into consideration in further development and the river basin is not suited for surface irrigation.

Morphometric parameters of Gudina Wacho watershed was analyzed for surface irrigation development using GIS by Gebre et al., (2021). The result of the analysis indicates that the watershed is elongated in shape, high runoff discharge and permeable subsoil circumstances. This revealed the watershed is good for surface irrigation on its hydrological status and topographic shape.

2.7. Estimation of Crop and Irrigation Water Demand

To grow a certain crop on a plot of land has to be supplied with water from time to time. The land is expected to receive water from rainfall on the land surface to grow a certain crop or a combination of crops. But, the distribution of rainfall is rather uncertain both in time and space. Hence, for proper crop growth, the uncertain rainfall has to be supplemented by artificially applying water to the field by irrigation. After knowing of irrigation is important to supplement the rainfall variability, the water resource engineer has to be design enough water source for irrigation and find out the methods by which estimation may be made for crop and irrigation water demand. The most important of crop and irrigation water demand computation is that knowing of the total quantity of water required from its sowing time up to harvest. Under the same condition different crops require different amount of water and the quantities of water used by a particular crop is differ in the entire life span (initial, development, mid-season, late season stage) of the crop period. Initially during seeding, sprouting and early growth a crop uses water at a relatively slow rate. The rate will increase with growth of crop reaching the maximum in most crops as it approaches flowering and then decline towards maturity (MOA, 2011).

The Hargraves method is recommended to be adapted for areas where measured data on daily maximum and minimum temperature and rainfall data's are available. These methods are important specially when there are no full climatic data of meteorological stations. The reference crop ET (ET_O) is usually calculated by using CROPWAT8.0 software implementing through FAO (1992).

The values of decade or monthly Reference Crop Evapo-transpiration (ET_O) are converted into daily values using four distribution models (the default is a polynomial curve fitting). The model calculates the Crop Water Requirements (CWR) using the equation:

$$CWR = ETo \times Kc \times Cutivatedarea \qquad (2.1)$$

For crop water requirements and scheduling purposes, the monthly total rainfall has to be distributed into equivalent daily values.

2.8. Software and Model Used for Assessing Water and Land Resources potential

2.8.1. CROPWAT

CROPWAT is a decision support system developed by the land and water development division of FAO for planning and management of irrigation and it is a computer program for the calculation of crop water requirements and irrigation requirements based on soil, climate (FOA, 2009). In addition, the program allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns. CROPWAT 8.0 can also be used to evaluate farmers' irrigation practices and to estimate crop performance under both rain fed and irrigated conditions. Procedures for calculation of the crop water requirements and irrigation requirements are based on methodologies presented in FAO (2001). The development of irrigation schedules and evaluation of rain fed and irrigation practices are based on a daily soil-water balance using various options for water supply and irrigation management conditions.

2.8.2. Geographical Information System (GIS)

A GIS is computer software used for capturing, storing, querying, analyzing, and displaying geographically referenced data (Yared, 2014).The data are manipulated and analyzed to obtain information useful for a particular application such as land-use suitability analysis (Malczewski, 2003).

According to Prakash (2003), the ultimate aim of GIS is to provide support for spatial decisions making process.

The main application of GIS is mapping where things are and editing tasks as well as for a map based query and analysis (Abebe, 2019). A map is the most common view for users to work with geographic information. It's the primary application in any GIS to work with geographic information. The map represents geographic information as a collection of layers and other elements in a map view. Common map elements include the data frame containing map layers for a given extent plus a scale bar, north arrow, title, descriptive text, and a symbol legend.

2.8.3. ERDAS Imagine 2014 Software

Earth Resources Data Analysis System (ERDAS), it is a remote sensing application with raster graphics editor capabilities designed by ERDAS, Inc. for geospatial applications. Prior to the ERDAS IMAGINE Suite, Earth Resources Data Analysis System (ERDAS), Inc. developed various different products to process satellite imagery from the Advanced Very High Resolution Radiometer (AVHRR), Land sat, Multiple Spectral Scanner (MSS) and Land sat TM and SPOT imagery into land cover land use maps, map deforestation. The latest version ERDAS IMAGINE is aimed primarily at geospatial raster data processing and allows the user to prepare, display and enhance digital images for mapping use in Geographic Information Systems (GIS) or in Computer Aided Design (CAD) software. It is a toolbox allowing the user to perform numerous operations on an image and generate an answer to specific geographical questions. By manipulating imagery data values and positions, it is possible to see features that would not normally be visible and to locate geo-positions of features that would otherwise be graphed. The level of brightness or reflectance of light from the surfaces in the image can be helpful to vegetation analysis, prospecting for minerals etc. Other usage examples include linear feature extraction, generation of processing work flows (spatial models in ERDAS IMAGINE), import/export of data for a wide variety of formats, mosaicking of imagery, stereo and automatic feature extraction of map data from imagery.

2.8.4. Digital Elevation Model (DEM) and Its Application

DEMs are point elevation data stored in digital computer files. These data consists of x, y grid locations and point elevation or z variables. They are generated in a variety of ways for a different map resolutions or scales. Under an agreement with the National Aeronautics and Space Administration (NASA) and the Department of Defense's National Geospatial intelligence Agency (NGA), the US Geological Survey (USGS) distribute elevation data from the Shuttle Radar Topographic Mission (SRTM). Shuttle Radar Topography Mission (SRTM) obtains elevation data on a near-global scale with a radar system that flew on board a space shuttle. For most parts of the world, this data set provides a dramatic improvement in the availability of high quality and high-resolution elevation data (Jarvis et al., 2004). Digital Elevation Models (DEM) is a commonly used digital elevation source and an important part of using for watershed characterization. Many agencies provide DEM data with 90m, 30m and 10m resolutions. The point elevation data are very useful as an input to the GIS. This data is used to yield important derivative products such as slope, aspect, flow accumulation, flow direction and curvature in process of watershed delineation.

A DEM is convenient for representing the continuously varying topographic features of the surface of the Earth, and it is a common data source for terrain analysis and other spatial applications. The utility of the DEM is evidenced by the widespread availability of digital topographic data and by increasing list of uses and products from DEM (Thompson et al., 2001). Digital elevation models (DEMs) are widely used to describe terrain surfaces. Traditionally, DEMs can be generated from such datasets as topographic maps, stereo aerial photography, satellite imagery or field survey. The drawbacks of using these kinds of ways for DEM generation are either their limitations of accuracy or their labor intensity (Liu et al., 2005). Catenary soil development occurs in many landscapes in response to the way water moves through and over the landscape. Terrain attributes can characterize these flow paths and the interaction with the soil attributes (Dobos et al., 2001)

The application potential of a DEM is, however, dependent upon its data storage structure. DEMs are generally stored in one of the following three data structures: two-dimensional arrays (grids), triangulated irregular networks (TIN), or as contours. Grid structures consist of a matrix of square grid cells (known as raster cells) with an average elevation value that is representative for the area that comprises each cell. TINs represent the elevation surface as interconnected triangles with location and elevation values stored for each triangle vertex. Contour-based DEMs consist of digitized contour lines with associated elevation values for each contour (Duke, 2003).

The size of a grid cell is commonly referred to as the grid cell's resolution, with a smaller grid cell indicating a higher resolution. Smaller grid cell sizes allow better representation of complex topography and these high resolution DEMs are better able to refine characteristics of complex topography. This has led many DEM users to seek the highest DEM resolutions possible, increasing the costs associated with both data acquisition and processing (Wechsler, 2006).With the advent of technology, the digital elevation models (DEMs) are generated and the influential landscape attributes namely slope, elevation and others that govern the soil properties can be derived with ease. One of the latest and good happenings is making the access to the digital elevation model at 30 m resolution acquired by the sensor ASTER free (Nages wara and Tripathi, 2009).

The spatial delineation of soil-landscape units in a quantitative manner is a promising benefit of the use of digital data sources. Although it sounds simple and evident to use DEM and DEM derived terrain variables for soil-landscape unit identification, the application of these data sources and the tools of the raster and Grid based GIS is still far behind its potential. There is a lack of appropriate procedures for translating the analog standards of the commonly used terrain characterization protocols into quantitative procedures (Dobos et al., 2002).

CHAPTER 3. MATERIALS AND METHODS

3.1. Study Area

3.1.1. Location

The Akaki catchment is located in central Ethiopia along the western margin of the main Ethiopian rift valley. The catchment is situated at the northwestern Awash River basin between 8°46′-9°14′N and 38°34′-39°04′E, covering an area of about 1610.2 km^2. The entire catchment is bounded to the north by the Intoto ridge system, to the west by Menagesha Mountain and the Wechecha volcanic range, to the southwest by mountain Furi, to the south by mountain Bilbilo and Guji, to the southeast by the Gara Bushu hills and to the east by the mount Yerer volcanic center (Demlie and Wohnlich, 2006).

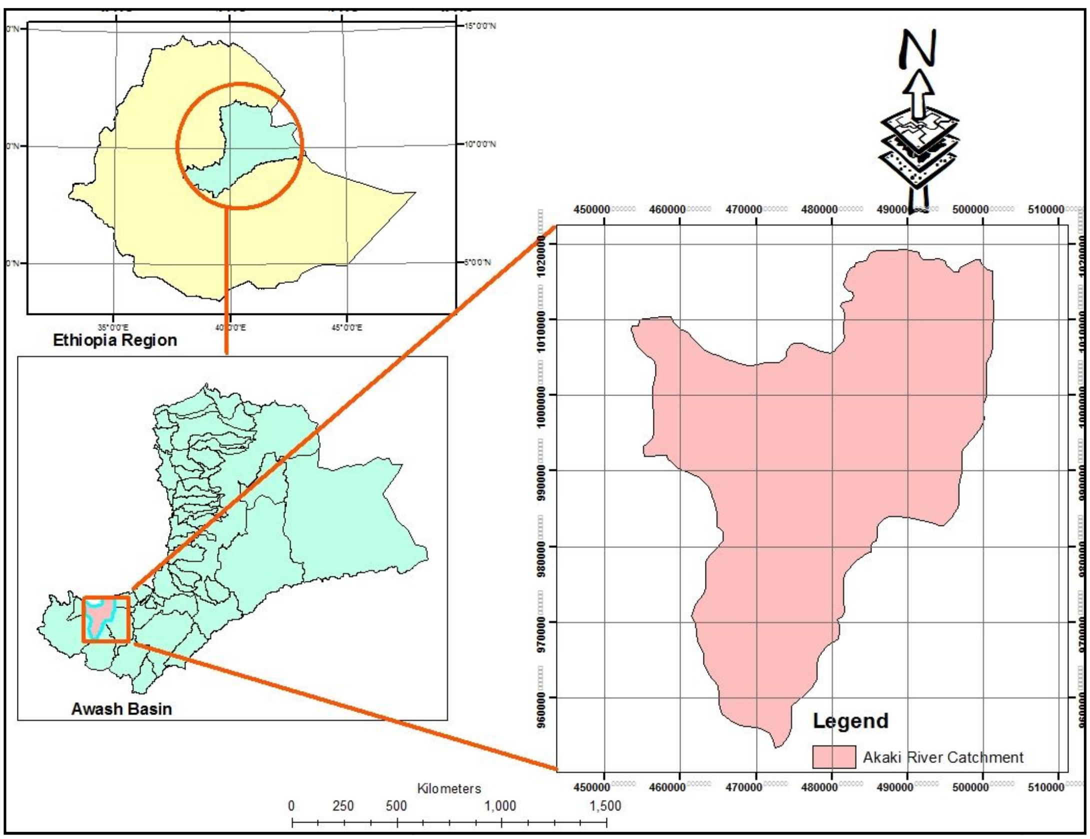


Figure 3.1: Map of the study area

3.1.2. Topography

The topography of a watershed like elevation, slope, aspect, etc. is the most determinant factor influencing surface irrigation practice. The study area found at the southern flank of Entoto ridge (3199m a.s.l.) and expanded in all directions. This ridge marks the northern boundary of the city following the east-west trending major fault (Ambo Kassam). Other prominent volcanic features surrounding the city are Mt. Wochacha in the west (3385m a.s.l.), Mt. Furi (2839m a.s.l.) in the southwest and Mt. Yerer (3100 a.s.l.) in the southeast. (AAWSA, AAU, 2003). The topography of Akaki river catchment is undulating and form plateau in the northern, western and southwestern parts of the Addis Ababa city, while gentle morphology and flat land areas characterize the southern and southeastern parts of the city (JICA and Region 14 Administration, 1998).

According to the extracted elevation of 14 the project area from DEM, the watershed is located along elevation range from 2060ma.s.l around Addis Ababa Bishoftu Road Bridge to 3227 m.a.s.l on Entoto Mountain. Elevation map of catchment is shown below in the Figure 3.3

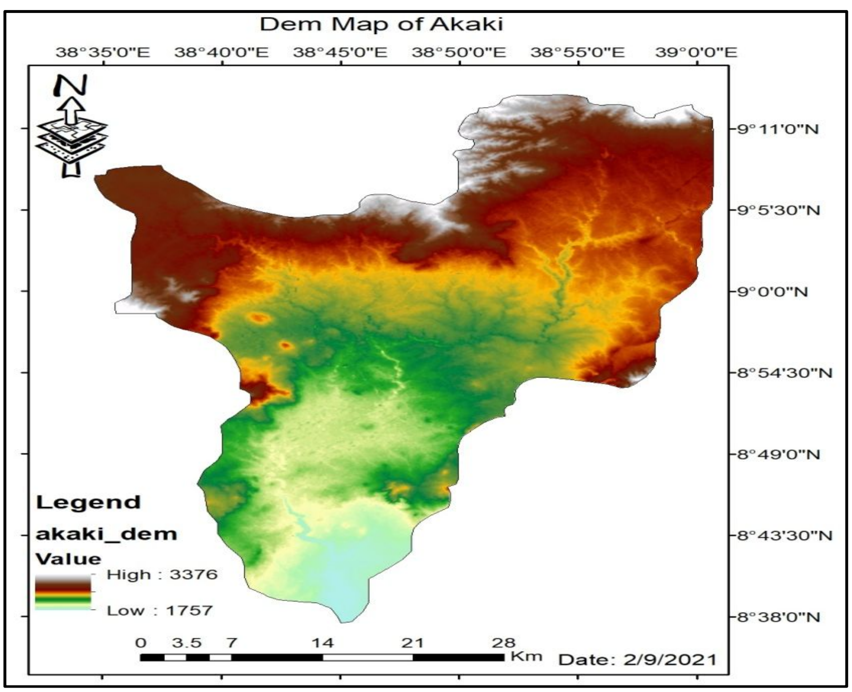


Figure 3.2: Elevation of the project area extracted from DEM

3.1.3. Climate

The climate of the Akaki catchment is characterized by two distinct seasonal weather patterns. The main wet season, locally known as Kiremt, extends from June to September .A minor rainy season, locally known as Belg, contributes moisture to the region from mid February to mid April (Daniel, 1977).

Rainfall

According to Ethiopian National Metrological Service Agency, the main rainy season in the study area is from June to September. Annual minimum and maximum rainfall ranges from 883.8mm to 1404.4 mm. The mean monthly rainfall between June and September is above 100mm. The highest rainfall is recorded in the month of August. The minimum rainfall is observed in the month of November and December.

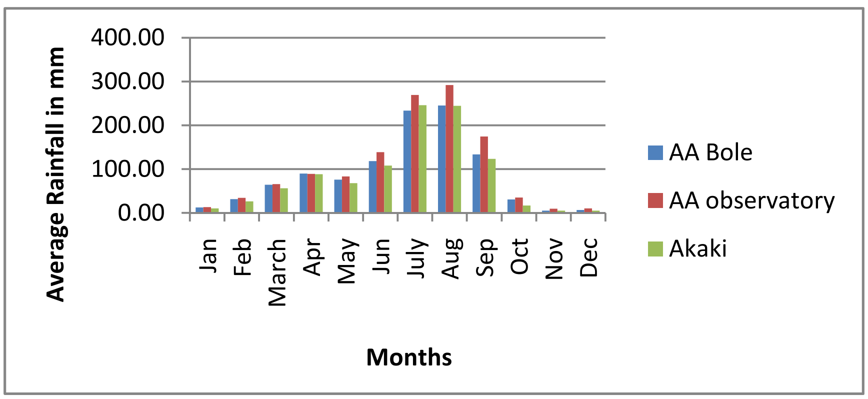


Figure 3.3: Mean monthly rainfall distribution of the study area

Temperature

Under normal conditions, air temperature decreases with increasing altitude at a mean rate of $0.7^{o}c$ for every 328 feet (Fetcher, 1998). This works also in Ethiopia where temperature decreases with increasing elevations. In Akaki catchment, the average temperature ranges in between 20.8 and $17.7^{o}c$. Maximum temperature of the study area ranges Between 23.4(in wet season) to $30.3^{0}c$ (in dry season) while the minimum falls between 6.8 ^{0}c - 12.3 ^{0}c in the year. Highest maximum temperature is observed in the month of March for the study area while the month of June and July is characterized by lowest maximum.

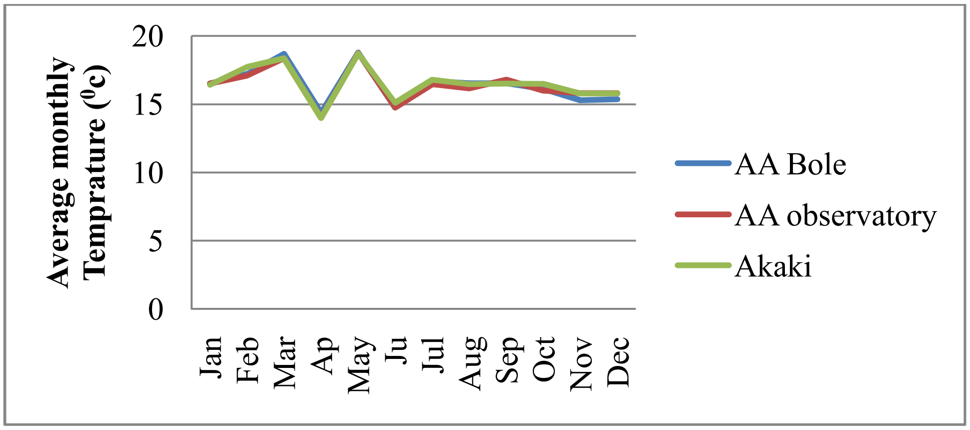


Figure 3.4: Average monthly minimum and maximum temperature of the study area

Sunshine

The sunshine hours of the study area varies from 4.3 to 9.0 hours per day. The highest and lowest sunshine hours are recorded at November and July respectively.

Wind speed

The wind flow pattern is influenced by the seasonal variation of the ITCZ. The predominant wind direction during June to September is southerly to southwesterly. The mean annual wind speed of the study area is 107.25 Km/day. The maximum wind speed is recorded in the month of October and Low wind speed is observed in the month of July and August.

Relative humidity

In Akaki catchment, the mean annual relative humidity of the basin is 59%. The highest humidity is observed in the months of August. The lowest humidity is recorded in the month of February, March and December.

3.1.4. Geology, Soil types and Land cover of the study Area

The north and north eastern area (the Entoto Mountain, the northern and north eastern of study area) is covered with trachytes, rhyolites, basalts and several episodes of pyroclastic materials of older volcanism occur on the upper part and foothill sides of Entoto ridge. Overlying these, younger basaltic rocks (Addis Ababa Basalt) are found covering the central and southern part of the area. Outcrops of ignimbrites north of Bole area (Eastern Addis) and Lideta area (Central Addis) have been observed underlying the Addis Ababa basalt. Younger volcanic of trachybasalt, trachytes, ignimbrites and tuff belonging to the wochecha, Furi and Yerer volcanoes are recognized overlying unconformable on the Addis Ababa basalt in the western, south-western and eastern part of the catchment.

The major soil types of the study area are Pellic Vertisols and Nitosols. PellicVertisols are found at Akaki, just south of Addis Ababa with too shallow soil depth at 3% slope with surface cracking features. Nitosols are found in the high land of Addis Northwest and Northeast of the catchments. Nitosols have very good potential for agriculture and have high water storage capacity. The land cover of the Akaki Catchment is covered by Grass land, Shrub land, cultivated land urban settlement and water body.

3.1.5. Hydrology

The Akaki River, left bank of tributaries of the Awash River, has an extensive drainage system with a catchment area of 1610.2 km^2. It originates from the Intoto range, north of Addis Ababa, and drops about 600m in river length of 90km from its origin to its confluence with Awash River near Dodota. The Akaki River drains in to Abasamuel reservoir, a man-made lake formed by damming of the Akaki River in 1930's. South of the Abasamuel dam, the Akaki River has cut a gorge up to 100m deep, which extends for about 8km. The Akaki river flows in to the Awash river at a point approximately 18km to south of the Abbasamuel reservoir. The Akaki well field is situated within the drainage basin of the Sekalo River, which flows in to Akaki River just before Abbasamuel reservoir. Based on information collected from Ministry of Water, Irrigation and Energy,The Akaki River is gauged since 1981 at the Addis Ababa- DebreZeit Road Bridge. There are three man-made reservoirs in the Akaki catchment, which are Gefersa, Dire and Lega Dedhi, commanding a sizable part of the catchment area. They facilitate transfer of water from one part of the catchment to the other in the form of water supply for domestic and industrial consumptions.

3.2. Methods of data collection

This Research was done based on both primary and secondary data. Appropriate data collection methods are very important to achieve the researcher's objective. The data collection methods for primary data include field observation, interviews with GIS expert and downloading land sat images from USGS website. Whereas secondary data collected from browsing of internet for related literatures, requesting (reports, shape files, maps, etc.) from responsible organizations and reviewing publications of hard and soft copy related to this study of the topics.

3.3. Data Sources

3.3.1. Meteorological data

Meteorological data such as precipitation, temperature, wind speed, sunshine of Addis Ababa Bole, Observatory and Akaki stations for 22 years was collected from Ethiopian National meteorological service agency (NMSA) in a softcopy format. These data have been used to quantify crop water requirement of some selected crops using CROPWAT8.0 software. This software uses the Climate data; Mean daily hours of sunshine (hours/day), Mean monthly wind speed (m/s), Monthly precipitation (mm), Mean monthly maximum and minimum temperatures per month(^{o}C), mean monthly precipitation (mm), and agronomic data as an input data for estimation of irrigation water demand. The location of meteorological stations and monthly precipitation is available in Appendix C.

3.3.2. Agronomic data

The agronomic data such as types of crop, cropping pattern (planting date, growth length, early stage, medium stage development stage and late stage) in days was collected from Agricultural development office of the area and from Ethiopia Statistical Agency.

3.3.3. Hydrological data/Stream flow data

Discharge of the gauge station was collected from Ministry of Water, Irrigation and Energy (MoWIE), Department of Hydrology. This data is very critical to assess the available water potential for both gauged and, ungauged site to meet the objective.

3.3.4. Soil data

Soil data was also collected from Ministry of Water, Irrigation and Energy (MoWIE), Department of GIS and Remote Sensing. This data has been used to soil suitability analysis for surface irrigation.

3.3.5. Land use land cover data

The data was obtained from MoWIE which is done by Halcro for Awash basin Master Plan

Project was used as a benchmark in producing the land use land cover map of the study area.This data was one input for assessing land suitability in the study area.

3.3.6. DEM (Digital Elevation Model)

This data was obtained from internet 30 by 30m dem shutter radar topographic mission (STRM). DEM of 30×30 m provide good terrain representation from which watersheds can be derived automatically using GIS. This digital elevation model which is an input data for Arc GIS to delineate watershed, to derive slope map of the study area, drainage condition/flow direction and check suitability analysis for surface irrigation.

3.4. Material used

The software was used to prepare and analyze data. These are Arc GIS 10.4.1 for map preparation and used to reclassify each parameter, ERDAS Imagine 2014 for Image classification of land use and check the accuracy assessment and CROPWAT 8.0 to determine the crop and irrigation water demand for the crops in the catchment .

3.5. Methodology

The collected data was checked and filling the missed data was done carefully. The GIS software for determining land suitability analysis for surface irrigation considering slope or topography, soil physical properties and land use land cover were implemented and ERDAS Imagine 2014 For Image classification was check the accuracy assessment. In addition to this CROPWAT 8.0 software was used to determine the crop and irrigation water demand for the crops in the catchment. The average values of the data were used to estimate irrigation water requirements of selected crops (Potato, tomato, cabbage and pepper) using CROPWAT software. Some of the input data for relative humidity, sunshine, wind speed for the Akaki climatic station were not recorded. These data were taken from the recorded data of CLIMWAT software for the crop types. The method of the study was summarized below the following conceptual framework in Figure (3.10).

3.5.1. Data pre-processing and checking

Collected data can be containing errors due to failures of measuring device or the recorder. Before using the data for specific purpose, the data should be checked and errors were removed.

Data checking and elimination of errors from hydrological and meteorological data was performed to prepare input data of water resources assessment and irrigation water requirement.

3.5.2. Filling missing rainfall data

Before using Error or missing of data for engineering purpose checking is very important to remove errors. The analysis has been extended to hydrological and metrological data to prepare inputs data for assessing surface water resource and irrigation water requirement using CROPWAT 8.0 software.

The missing data was estimated using the normal annual precipitation ratio method and average annual value from surrounding station. Since some value of normal annual precipitation of neighboring stations is beyond 10% range normal ratio method was applied. The missing data was estimated by;

$$Px = \frac{Nx}{M}\left(\frac{P1}{N1} + \frac{P2}{N2} + \frac{Pm}{Nm}\right) \qquad (3.1)$$

Where;

P_x = missing rainfall data at station x

N_x = missing data station's normal annual rainfall

N_1, N_2, N_3 and N_4 = normal annual rainfall at stations i

P_1, P_2, P_3 and P_4 =precipitation at surrounding gauges station and n is the number of nearby gauges).

Moreover, to calculate percent of difference to decide whether to use arithmetic mean or normal ratio method, the following equation was used.

$$Percent\ of\ difference = \left(\frac{Nx - Ni}{Nx}\right) \times 100 \qquad (3.2)$$

In which Nx is the normal annual rainfall amount from the missing data station and Ni is the normal annual rainfall amount from the one of the nearby stations (Richard H., 1998). Average monthly precipitation for each month was tabulated in Appendix Tables.

3.5.3. Determination of areal rainfall

There are three a number of stations on Akaki watershed and the rainfall data were collected from each station and converted to area rainfall. Rainfall over the watershed was determined by using Thiessen polygon. In this method line are drawn to connect reliable rainfall station and line are bisected perpendicularly to form a polygon around each station. To determine the mean rainfall amount of each station is multiplied by the area of its polygon and sum of the product is divided by the total area.

$$P = \frac{P1A1+P2A2+\cdots PnAn}{A1+A2+\cdots An} \qquad (3.3)$$

Where, n is number of station

3.5.4. Checking the Consistency of Data

The most common method of checking for inconsistency of record is Double Mass Curve analysis. The curve is a plot on arithmetic graph paper, of cumulative rainfall collected at a gauge where measurement condition may have changed significantly against the average of the cumulative rainfall for the same period of record collected at several gauges in the same region. The data is arranged in the reverse order that is the latest record as the first entry and the oldest record as the last entry in the list. A change in the proportionality between the measurements at the suspect station and those in the region is reflected in a change in the scope of the trend of the plotted points. The data series, which is inconsistent, adjusted to consistent values by proportionality. Double mass curve plot made for all three stations available in Appendix.

3.5.5. Assessment of Land Suitability for Surface Irrigation

Irrigable area is the area which is suitable for surface irrigation. Identification of suitable sites for irrigation was carried out by considering the slope, soil and land use land cover. The individual suitability of each factors were first analyzed and finally weighted to get potential irrigable sites. The procedures are presented in the following subsequent sub sections.

3.5.5.1. Slope Suitability Analysis

Land slope is the most important topographical factor influencing land suitability for irrigation. Slope map of the specified basin was derived from SRTM-DEM of 30 m spatial resolution using the Spatial Analysis Slope tool in Arc GIS and its classified based on the classification system on FAO (1999) using the reclassification tool in to suitability classes and Finally slope suitability map was developed and data layers were prepared for further overlay analysis. The four suitability ranges (S1, S2, S3 and N) were classified for surface irrigation as shown in Table 3.1.

Table 3 1: Slope suitability classification for surface irrigation

Legend	Slope (%)	Factor rating
1	0-2	S1
2	2-5	S2
3	5-8	S3
4	>8	N

The classified raster data layers were then converted feature (vector) data layers for the overlaying analysis. Using data management tools in Arc Tool box, generalization of the feature (vector) data layers was performed to make a clearer slope suitability map.

3.5.5.2. Soil Suitability Analysis

To assess soil suitability for irrigation, FAO/UNESCO- soil map of east Africa (1997) was used. It is available in ARC/ INFO format with scale of 1: 1000000. Chemical and physical properties of these soil groups were used for irrigation suitability analysis. The following soil suitability rating was used based on the FAO guidelines for land evaluation land and water bulletin.

Table 3 2: Soil suitability factor rating

Factors	Factor Rating			
	S1	S2	S3	N
Drainage class	well	Imperfect	Poor	Very Poor
Soildepth (cm)	>100	80-100	50-80	<50
Soil texture	C, SiC	Si,SiCL, CL	SC,SiL	SL

Source: FAO, (1991)

Further, the soil vector layer was converted into raster layer using conversion tool to Raster or Feature to Raster module. The rasterized soil map of the study area was then reclassified based on their soil type name texture, depth and drainage class. Using overlay tool in Arc GIS10.4.1 spatial analyst, weighted overlay analysis of these factors were performed to determine their suitability for surface irrigation. Then, the new values were reassigned for each soil factor in order of their irrigation suitability rating based on common evaluation scale from 1-9 available in weighted overlay analysis. A value 1 represents the least suitable factor in evaluation while value 9 repents highly suitable factor in evaluation. Soil factor that is highly suitable was given a value 9 for moderately suitable factor was given a value 6 for marginal suitable factor was given a value 3 and for least suitable factor was given a value 1. When scale values from 1-9 is not assigned for soil factors in evaluation, that cell value restricted for surface irrigation and it should be excluded from evaluation. For example a soil factor with soil depth 10cm is restricted for surface irrigation development and the cell value representing this value is assigned as restricted scale so that it will be excluded from the evaluation.

3.5.5.3. Land Use Land Cover Suitability Analysis

Land use land cover of the study area is also the factor, which was used to evaluate the land suitability for irrigation. Successful identification of land cover usually requires multi-temporal images. The format of this image was IMAGIN Image, which could be imported into ENVI4.3 directly. The SPOT images were geo-referenced by ancillary data such as topographic maps and geographic coordinates of the study area. Then true color composite images were created by combining the spectral bands that most closely resemble the range of vision of the human eye which in the SPOT images are normally used for land cover analysis. Classified images require post-processing to generalize classes for export to image maps and vector GIS. In ENVI4.3 post classification tool, majority analysis was applied to generalize image classification. Then classification to vector tool was used to convert classification results to ENVI polygon vector layers (.evf files) and then exported to shape files, Arc GIS 10.4.1. compatible file set. The classification images will have a vector layer for each selected class.

Table 3 3: LULC Suitability Criteria Based on FOA, 1996

S/N	Suitability class	Suitability Name	Descriptions
1	S1	Highly Suitable	Land having no significant or only minor limitations.
2	S2	Moderately Suitable	Land having limitations which in aggregate are moderately severe for sustained application.
3	S3	Marginally Suitable	Land having limitations which in aggregate are severe for sustained application.
4	N	Currently Not Suitable	Land having limitations which may be surmountable in time but which cannot be corrected with existing knowledge at currently acceptable cost.

3.5.5.4. Weighing of irrigation suitability factors

To find suitable site for surface irrigation, a suitability model was created using model builder in Arc tools box and tools from spatial analysis tool sets. After its individual suitability was assessed, the irrigation suitability factors which were considered in this study, such as slope, soil and land use land cover factors were used as the input for irrigation suitability model to find the most suitable land for surface irrigation

3.5.6. Assessment of Surface Water Availability

Accessible surface water of the Akaki catchments was evaluated using stream flow discharges obtained from the MWIE, Department of Hydrology. Maximum, minimum and annual average magnitudes of river discharge and runoff from the basin were estimated. This is helpful in determination of potential irrigation capacity of surface water. The hydrological network of the River was worked out with the aid of GIS environment. The stream flow data of gauged Akaki River in the watershed were used to estimate surface water resources at the site. The measured values of Akaki River flow for 16 year from 2000 to 2016 are given Appendices . The average value of the river flow is varied from 0.05m^3/s during January to 85.93m^3/s during August. The estimated average flows of the ungauged was computed by transferring the flow from gauged site by using equation 3.5 and the flow duration curve of the transferred minimum flow at Akaki catchment is shown in Figure 3.10.

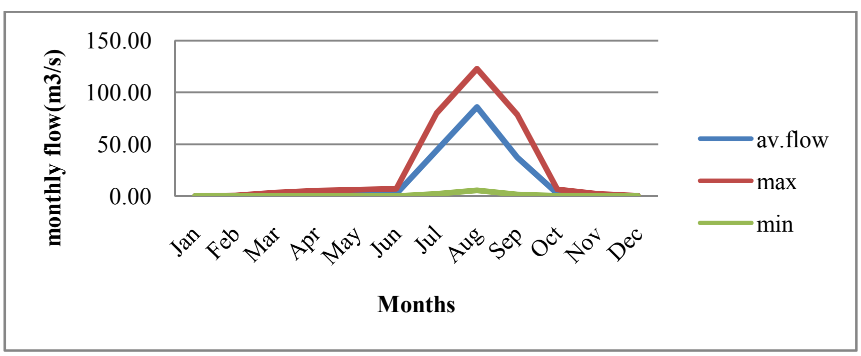


Figure 3.5: Monthly Flow duration curve of minimum flow at Akaki catchment

3.5.6.1. Estimating Discharges at Un-Gauged Sites from Gauged Sites

By using stream flow, discharges and rainfall data the available surface water of the catchments were estimated. The analysis of rainfall data result, together with discharges from gauged sites was used to estimate the stream-flow at the ungauged sites in the watershed. Since only the irrigation potential of perennial rivers was considered in this study, a long term average of stream flow at gauged sites and mean monthly areal rainfall of the sites were used to estimate the discharges at ungauged sites. This was performed by applying runoff coefficient of the gauged sites to un-gauged sites (FAO, 1997; Goldsmith, 2000 and DFID, 2004).

According to Goldsmith (2000) and DFID (2004), to estimate mean monthly runoff volume of ungauged sites from gauged sites, catchment characteristics such as land use land cover, soil type, and catchment slope ranges should be similar. In addition to this, distances between the gauged and un-gauged river catchments should not be more than 50 km and a minimum 10 years mean monthly river flow at the gauged sites should be available. Based on these criteria, the gauged and ungauged river catchments soil, slope and land cover maps were derived using FAO (1997) digital soil map of East Africa, DEM and USGS satellite image, respectively.

Then runoff volume per month for ungauged site was estimated using the following steps:

1. Both gauged and un-gauged catchment areas were calculated
2. Point rainfall data of stations both in and around gauged and un-gauged catchments were converted to a real or average rainfall over an area of river catchments using Theissen polygon method in Arc GIS.
3. Both un-gauged and gauged river catchments in terms of their land cover/use, soil type and slope range were compared to determine their similarities.
4. Runoff coefficient from the ratio of mean monthly discharge to mean monthly areal rainfall of gauged catchments was determined.
5. Above steps were followed to estimate monthly average runoff of the un-gauged river catchments from gauged river catchments using the following equation 3.4. (Jamshid, 2003).

$$Q_{unguaged} = \left(\frac{A_{ungauged}}{A_{gauged}}\right) \times Q_{gauged} \times \frac{P_{ungauged}}{P_{gauged}} \tag{3.4}$$

Where,

$Q_{ungauged}$ = discharge at ungauged site (m^3 /s)

$A_{ungauged}$ = drainage area of ungauged site (km^2)

$P_{un\ gauged}$ = areal rainfall at the ungauged site (mm)

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

A_{gauged} = drainage area at gauged site (km^2)

P_{gauged} = areal rainfall at the gauged site (mm)

The stream flow calculated using above procedure for ungauged sites were used to estimate their adequacy for the potential irrigable sites.

3.5.6.2. Transferring discharges of gauged rivers to the site of interest

For gauged rivers, the discharges from gauge sites were transferred to the site of interest using the following formula.

$$Q_{site} = \left(\frac{DA_{site}}{DA_{guaged}}\right) n \times Q_{guaged} \qquad (3.5)$$

Where,

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

DA_{site} = Discharge area at gauged site (m^2)

DA_{guaged} = Drainage area at gauged site (m^2) and n = the exponent between 0.6 and 1

When DA_{site} is 20% of DA_{gauged} $\mathbf{(0.6 \leq \frac{DAsite}{DAguaged} \leq 1.2),}$ n value equal to 1 unless 'n' equal to 0.6.

3.5.7. DEM and Watershed Delineation

The exported DEM data was processed in Arc GIS 10.4.1 version and watershed delineation of the study area was performed on Arc GIS Spatial Analyst Tools. Further, the delineated watershed was converted to polygon (shape file) and DEM of the study area was clipped from SRTM on Global mapper. From the delineation the Akaki watershed is presented in the Appendex

3.5.7.1. Importing DEM data

The DEM of watershed was projected to UTM Coordinate system using Arc Catalog in Arc GIS 10.4.1 and imported to Arc SWAT to start automatic watershed delineation.

3.5.7.2. Fill

The DEM may have depression. Therefore, before processing delineation first filled by using Arc GIS 10.4.1 in order to remove the depression of the projected DEM. Further, watershed has been delineated.

3.5.7.3. Flow direction

Flow directions for individual DEM cells were created using flow direction tool and accumulation tool in Arc GIS. GIS processing flow direction tools calculate the direction of water flow using slope from neighboring cells. This is usually determined by the direction of the steepest slope in each cell GIS computes the flow direction tool for individual DEM cells having 90m resolution and uses the stream threshold area in hectares to create streams based on these directions.

3.5.7. Irrigation Water Demand

To determine irrigation water demand, dominant crops was identified in the study area with Woreda Agricultural Development Office. Irrigation water demand for each selected crop will be determined by using Akaki river meteorological data.

Dominant crops such as Potato, Tomato, Cabbage and pepper; were identified in the study area with in agricultural development office. Crop distribution on the study area was weighted based on their productivity and profit. Potato has to give 40 % from the total area, Tomato 15%, pepper 10% and Cabbage has 35% for each crop. Agricultural practice on the study area has double cropping such as rain fed agriculture and traditional irrigation in some parts of the study area. According to crop calendar rain fed agriculture is practiced from mid May to end of December and irrigation agriculture Cropping practice on the study area from early January to early May.

Irrigation water demand was estimated by using CROPWAT8.0 software. The software use input data such as climate and agronomic data to calculate Reference Evapotranspiration, irrigation water requirement (IWR), net irrigation water requirement (NIWR) and Gross irrigation water requirement (GIWR).

3.5.7.1. Reference evapotranspiration (ETo)

The only factors affecting ET_O are climatic parameters. Consequently, ET_O is a climatic parameter and can be computed from weather data. ET_O expresses the evaporating power of the atmosphere at a specific location and time of the year and does not consider the crop characteristics and soil factors. The FAO Penman-Monteith method is recommended as the sole method to determine ET_O. It is calculated from climatic data using the FAO Penman-Monteith method.

$$ETo = \frac{0.408\Delta(Rn-G)+\frac{900y}{T+27.3}*U2(es-ea)}{\Delta+\gamma(1+0.34U2)} \qquad (3.6)$$

Where,

ET_o= reference evapotranspiration (mm/day)

Rn = net radiation at the crop surface (MJ/day m^2)

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

T =Mean daily air temperature at 2m height (^OC)

U2 = wind speed at 2m height (m/s)

es= saturation vapor pressure (kPa)

Ea = actual vapor pressure (k Pa)

es-ea = saturation vapor pressure deficit (k Pa)

Δ = Slope vapor pressure curve (k Pa/^OC)

γ = Psychrometric constant (k Pa/^OC)

3.5.7.2. Crop evapotranspiration (ETc)

The crop evapotranspiration (ET_c) is the crop water requirement (CWR) for a given croppingpattern during a certain time period. Crop evapotranspiration was calculated by multiplying the kc values at each growth stage of the specific crop by the corresponding ET_o values (3.6).

$$ETc = ETo \times Kc \qquad (3.7)$$

Where:

ET_c=Crop evapotranspiration (mm/day)

ET_o=Reference crop evapotranspiration (mm/day)

K_c=Crop coefficient (fraction).

3.5.7.3. Net Irrigation water requirement (NIWR)

Using the climate, rainfall, crop and soil data inputs crop and irrigation water requirement of each crop was calculated by the Equation 3.7 in CROPWAT 8.0 software. The net irrigation water requirement (NIWR) was estimated from ET_C and effective rainfall (P_{ef}) using equation 3.8

$$NIWR = ETc - Pef \qquad (3.8)$$

Where:

NIWR=Irrigation water requirement (mm),

P_{ef}=Effective rainfall (mm)

ET_c=Crop evapo-transpiration for a given crop (mm/day)

The values were also calculated in m^3/s from mm/day values using the following relationship.

$$\mathrm{IWR}(\mathrm{m}^3/\mathrm{s}) = \mathrm{IWR}\left({}^{\mathrm{mm}}/_{\mathrm{month}}\right) \times \mathrm{A/T} \qquad (3.9)$$

Where,

A=Irrigable area in (ha)

T= Time per month

3.5.7.4. Gross irrigation water requirement (GIWR)

GIWR of the crops was computed using the following formula;

$$GIWR = \frac{\mathrm{NIWR}}{\mathrm{Ea}} \qquad (3.10)$$

Where,

Ea=Water application efficiency (%)

GIWR=Gross irrigation requirements (mm)

NIWR=Net irrigation water requirement (mm)

The irrigation efficiency (E) expresses the percentage of the quantity of water used efficiently for the growth of the crop in the field to the quantity of intake water from the water source. In the Ethiopian standard of surface irrigation system E mostly accounts in the range of 40% up to 60% under surface irrigation system. But, for the estimation gross irrigation requirements in the study areas E were calculated 50% for surface irrigation.

Based on the Mean available water, the effective irrigable area can be estimated in each month and at different scenario in the following equation.

$$X(ha) = \frac{Acrop \times E \times low\ flow}{GIWR} \qquad (3.11)$$

A_{crop}= Area covered by crop

E= Irrigation efficiency

Conceptual framework followed in this research

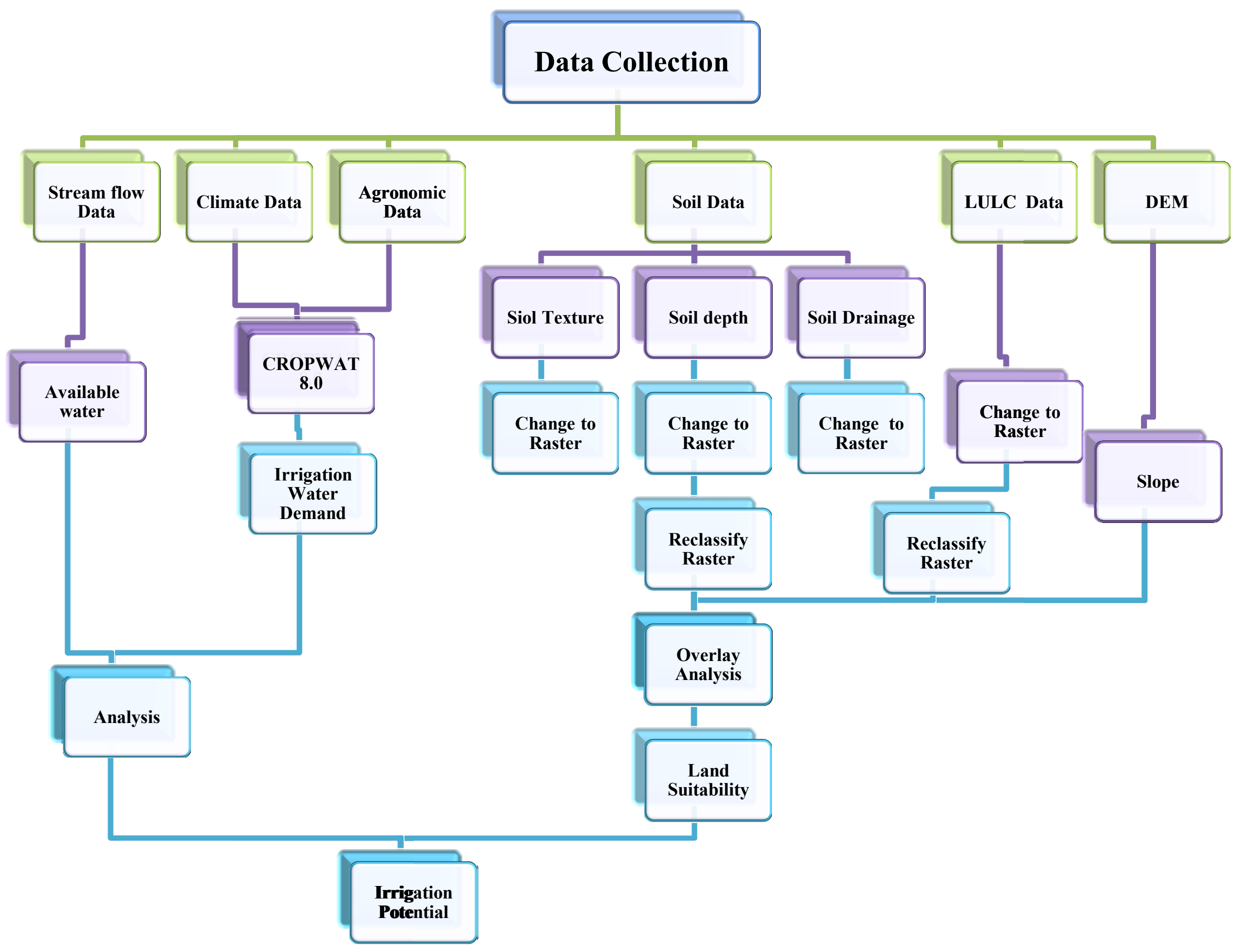


Figure 3.6: Conceptual Frameworks for surface Irrigation Potential assessments.

CHAPTER 4. RESULTS AND DISSCUSSIONS

The results regarding different parameters which were important to achieve the objectives of the study were briefly discussed in this chapter. The different parameters considered were watershed delineation, stream flow and rainfall consistency, slope suitability, soil suitability (soil depth, drainage), gauged and un-gauged watershed similarities, surface water availability, crop water requirement, and finally comparing the water available in the site and crop water requirement and potential irrigable land.

4.1. Parameters for Determining Surface Irrigation Potential

The irrigation suitability was determined by analyzing the evaluation factors such as slope, soil, and availability of water resource to irrigable area. The analysis of the surface irrigation suitability evaluation factors are presented in the following subsequent sub heading.

4.2.1. Slope suitability

According to the slope classification result, the land having slope range below 2 % was classified as highly suitable (S1) while the slope range > 8% categorized as unsuitable class for surface irrigation. The suitability result indicates that 13.98% (22,506 ha) of the land was highly suitable (S1), 39.48% (63,575 ha) moderately suitable (S2), 21.55 % (34,698 ha) marginally suitable (S3) and only 24.99% (40,241 ha) was not suitable (N) class for surface irrigation development.

The result shows that, 75.01% of the watershed range is from highly to marginally suitable for surface irrigation development in the Akaki catchment. The area coverage of each slope suitability class and slope suitability map of the study area for surface irrigation are presented in the Table 4.1 and Figure 4.2.

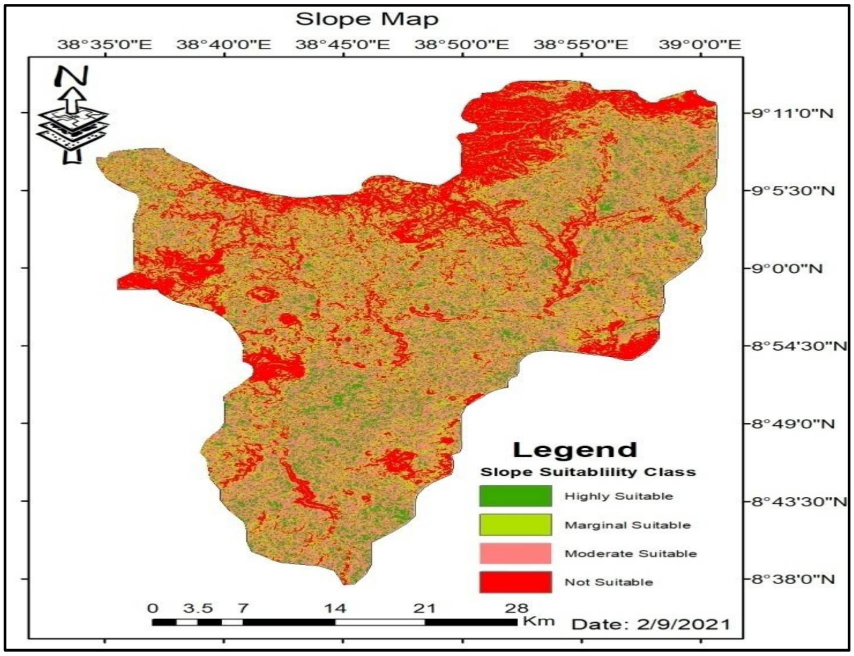


Figure 4.1: Slope suitability map for surface irrigation

Table 4.1: Suitability classes of each slope category and area coverage

Slope range	Suitability class	Area coverage In	
		hectare	percentage
0-2 %	Highly suitable(S1)	22,506.00	13.98
2-5%	Moderately Suitable(S2)	63,575.00	39.48
5-8%	Marginally Suitable(S3)	34,698.00	21.55
>8%	Not suitable(N)	40,241.00	24.99
	Total	161,020.00	100

The result shows that, 75.01% of the watershed range is from highly to marginally suitable for surface irrigation development in the Akaki catchment which was a closer relation to the report of (Asfaw et al., 2019) on Dirma River Basin, obtained slope suitability of 73.9% ranges from high to marginal suitability. This indicates the area was suitable for surface irrigation development with miner modification to negotiate the natural slope. According to Tesfaye et al., (2017)The slope analysis indicated that about 89.7% of the flat lowland area of Low Land Gilo Sub-Basin of Gambella regional state was classified as highly to marginally suitable for surface irrigation, Only 9.5% of the sub-basin area having slope of greater than 8%, which is marginally to permanently not suitable for surface irrigation. By comparing to Akaki catchment slope Suitable percentage area, it indicates larger area is suitable for surface irrigation.

4.2.2. Suitability of Soil

There are a number of soil physical parameters to determine soil suitability analysis, but mainly there are three soil physical properties to evaluate soil suitability in the catchment. These are soil texture, soil depth and soil drainage properties each data's was taken accordingly from FAO standards and general Awash basin soil master plans to describe in detail as follows.

4.1.2.1. Soil depth suitability

Soil depth was identified in Soil map morphological characteristics of FAO guideline in the study area. Due to this classification soil depth range vary from less than (<) 50cm to greater than (>) 100cm. According to FOA, soil depth range of soil suitability was classified into four parts<50cm, 50-80cm, 80-100cm, >100cm and soil depth of the study area was analysis in Arc GIS 10.4.1 version.

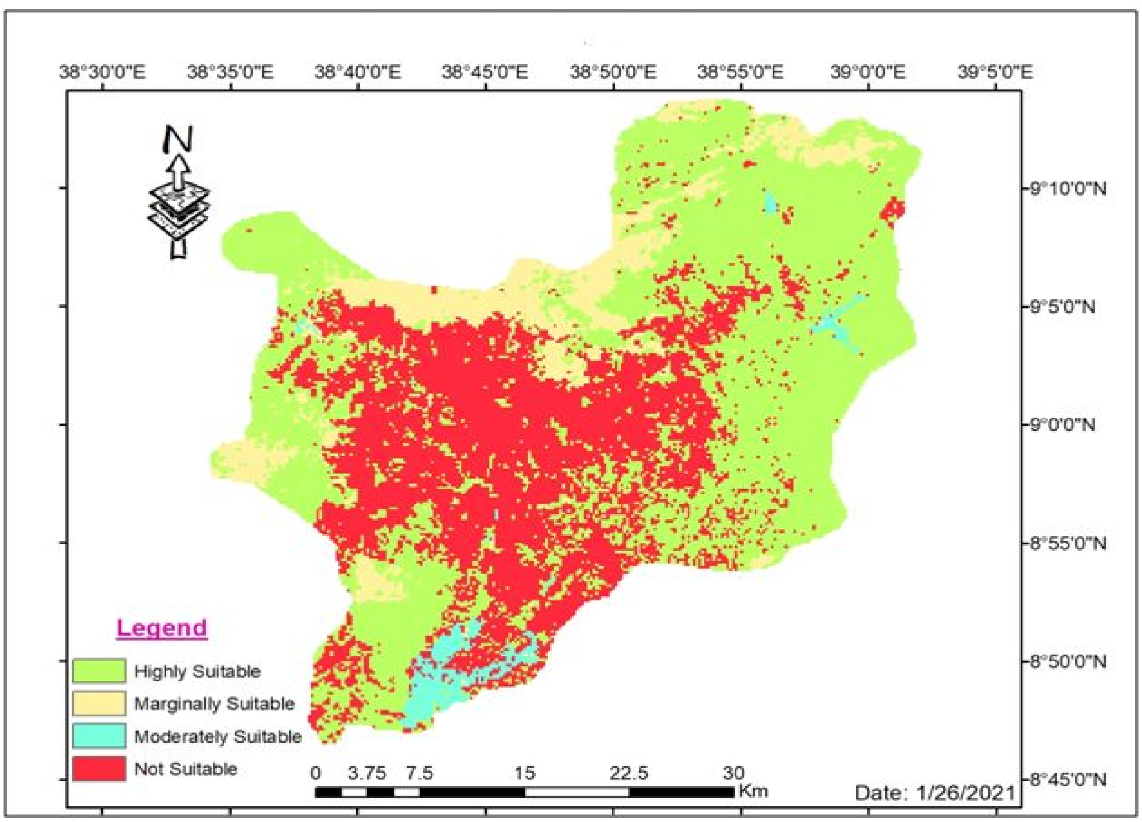


Figure 4.2: Soil depth suitability map of the study area within suitability rate

Table 4.2: Result of soil depth suitability of the study area

No	Suitability Range in cm	Suitability Class	Area Coverage	
			In hectare	In percentage
1	>100	Highly suitable	9,737.69	6.05
2	80-100	Moderately suitable	87,900.60	54.59
3	50-80	Marginal suitable	15,489.00	9.62
4	<50	Not suitable	47,892.71	29.74
		Total	161,020	100

As per the soil depth suitability class the study area is classified as highly suitable, moderately suitable, marginally suitable and non-suitable. Accordingly, the results were found to be 6.01%, 54.59%, 9.62% and 29.74% from the total area of the watershed respectively. Generally, 70.26% of the soil in the study area is in the range of highly to marginally suitable and the remaining 29.74% of the area is grouped as not suitable in terms of soil depth suitability analysis. Suitability result of soil depth and their geographic locations in the catchment area is described in the figure 4.3.

Asfaw et al., (2017) conducted soil depth suitability of the Dirma river basin in Ethiopia for surface irrigation potential with the same methodology. The report indicates most of the southern and central part of the Dirma river basin soil is categorized as highly to moderately suitable (73%) and the northern part is classified as not a suitable class for the use of surface irrigation development which shows more suitable area is reported with soil depth suitability range described in the Akaki catchment area.

The irrigation suitability on lowland Gilo sub basin which located in the lowland Gilo sub basin of Gambella regional state was assessed (Tesfaye et al., 2017). The report indicates effective soil depths of the Gilo area suitable which is not be a limiting factor for crop production through application of irrigation technology. The result of Akaki catchment shows the soil depth was a limiting factor for crop production through irrigation.

4.1.2.2. Textural suitability

The soil textural classes of the study area were investigated as it is vary from clay to sandy loam. The results of texture class analysis reveal that the area was dominated by fine textured soils. The Figure 4.3 elaborates the geographic distribution of the identified soil textural classes and their suitability in the study area. The soil textural classes and their area coverage's were shown in Table 4.3. As described in the Table 4.3, 62.15% of the total areas covered by clay soil while about 35.96%, 1.16% and 0.74% area of the watershed were covered by Loamy, sandy loam and sandy respectively.

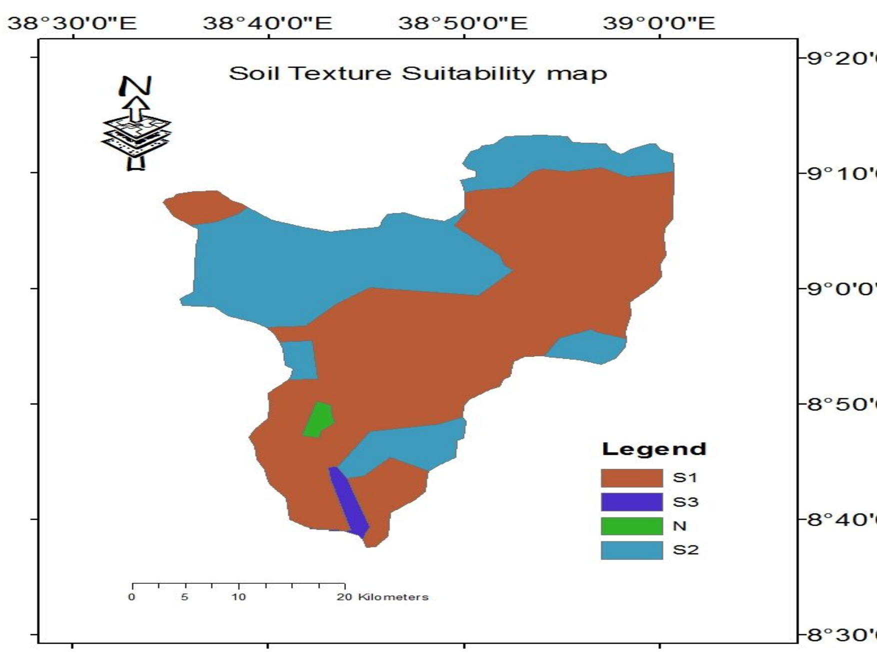


Figure 4.3: Soil textural class map of the study area

Table 4.3: Textural suitability of the study area

No	Texture	Suitability class	Area coverage in hectare	Area coverage in Percentage
1	Clay	S1	100,071.00	62.15
2	Loam	S2	57,900.90	35.96
3	Sandy Loam	S3	1,861.45	1.16
4	Sandy	N	1,186.65	0.74
	Total		161,020	100

The result of soil textural suitability analysis of the area revealed that 62.15% of soils in the area were under highly suitable for surface irrigation. Around 35.96% of the total area, soil was categorized under moderately suitable class for surface irrigation. From the total area 1.16% and 0.74% of the soil textural class was marginally suitable and not suitable respectively. The geographical location of these textural classes was described in texture suitability map is presented in Figure 4.4.

4.1.2.3. Drainage suitability

Soil drainage is one among very important parameter of evaluation of the area for surface irrigation. The well drained soils are good for agriculture in general.

Table 4.4: Result of drainage suitability on the study area

No	Drainage	Drainage suitability	Area Coverage	
			In hectare	In percentage (%)
1	Well	Highly suitable	42,901.98	26.64
2	Imperfect	Moderately suitable	1,974.82	1.23
3	Poor	Marginally suitable	65,888.10	40.92
4	Very poor	Not suitable	50,255.10	31.21
	Total		161,020.00	100

The drainage suitability map of the area shows 26.64% of total area is well-drained which indicates a well suitable class and 1.23% of the area covered by moderately suitable. About 40.92% and 31.21% of the total area were poor and very poor respectively that was not suitable for surface irrigation.

As indicated in the Table 4.4, About 40.92% and 31.21% of the total area were poor and very poor respectively that was not suitable for surface irrigation which shows The Akaki river catchment was limited for surface irrigation development because of drainage problems.

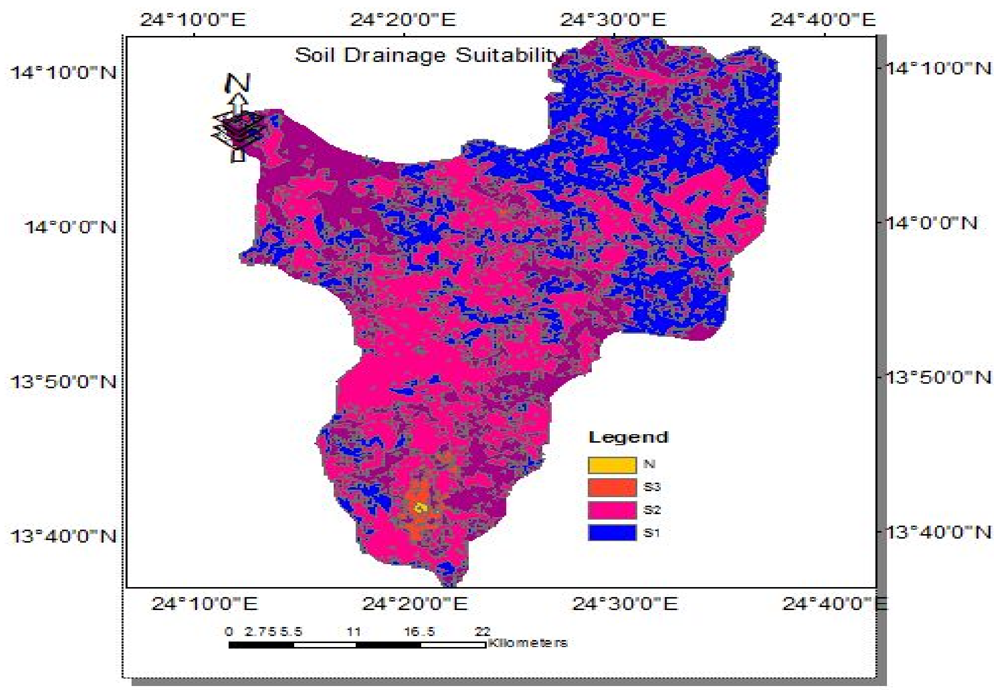


Figure 4.4: Drainage suitability map of the study area

4.1.2.4. Overall soil suitability

The three physical parameters of a soil which is depth, textural and drainage classes were analyzed by implementing Arc GIS. In the suitability analysis of each parameter, soil depth, texture and drainage has four suitability classes (highly suitable, moderately suitable, marginally suitable and not suitable classes) for use of surface irrigation system. To identify potentially suitable soils for the intended irrigation system, the three soil suitability parameters were used in this study (depth, texture and drainage) were evaluated on Arc GIS 10.4.1. In the suitability evaluation of a percent influence for weighted overlay analysis were taken 1 by 5 by 1 (a scale for overlay analysis). The 1, 2, 3, 4 and 5 represents highly suitable class, moderately suitable class, marginally suitable class and unsuitable classes respectively and the % of influence were given to soil in an equal manner in the weighted overlay analysis on Arc GIS 10.4.1. The next map shows the procedure of weighted overlay analysis based on depth, drainage and texture of soil physical properties.

Table 4.5: Overall soil suitability of the study area

No	Soil suitability	Suitability rate	Area (ha)	Area (%)
1	Highly suitable	S1	1153.9	0.72
2	Moderately suitable	S2	97646	60.64
3	Marginal suitable	S3	9176.87	5.70
4	Not suitable	N	53043.23	32.94
	Total		161,020	100

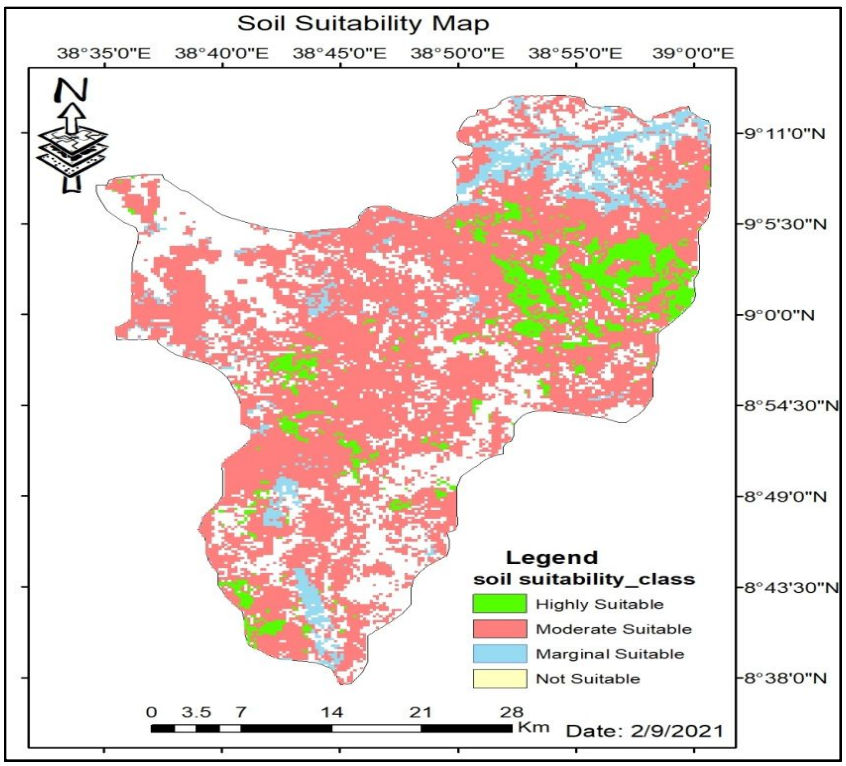


Figure 4.5: Overall soil suitability map of the study area

The soil suitability classes indicate 0.72 % of the total area was in the range of highly suitable, about 60.64 % of the catchment categorized under moderately suitable. The rest 5.70 % and 32.94% were categorized as marginally suitable and not suitable classes respectively with respect to combined effect of soil texture, depth and drainage class. The soil suitability of akaki catchment is covered by moderately to marginal suitable for surface irrigation purpose and area coverage of the soil suitability rate are summarized in the above Table 4.5.

Accordin to Nasir G. et al., (2019) The soil suitability for irrigation development of Shaya River Sub-basin in Bale Zone was evaluated. The final report of Soil suitability for irrigation indicating soil texture, depth, and drainage after reclassification obtained for the watershed Soil type's were having soil texture clay to clay loam, soil depth greater than 2 m and the excellent soil drainage classified as highly suitable (S1). It covered 182,594.91 ha, (56.68%) of the total area coverage of the study area. The second suitability class is moderately suitable classes (S2). It covered the third extent of the area as 42,158.61 ha, (13.08%) in the study area and is comprised of soil type having soil texture clay loam, with a soil depth of 1.4 to 1 m, and moderate soil drainage. Their reasonable drainage condition limits these soil types while the other factors are optimum for surface irrigation. Soil types having silty loam and heavy clay soil texture, with a soil depth of 50 cm having moderate soil drainage was classified as N (marginally not suitable), and it covered4,179.86 ha (1.31%) of the total area coverage of the study area. They were limited by shallow soil depth (Eutric Regosol) while other factors were optimum for surface irrigation. In general, majority soils of the Shaya river watershed were found to be suitable for surface irrigation.

4.2.3. Land use land cover type and it's suitability investigation

From SPOT5 satellite image supervised classification, six land cover/use classes were identified. These classes include: farm land, water bodies, grass land, bush land, urban area and bare land, as shown in Figure 4.4. As presented in Table 4.3, all land cover/use classes were classified with high accuracy. The land cover/use of the study area was classified with over all accuracy of 92.73%. User's accuracy ranged from 83% to 99% while producer's accuracy ranged from 87% to 99%.

Table 4.6: Accuracy Assessment of the Image Classification and Error matrix of land use cover map of akaki catchment

Classified Data	Reference Data						Row Total	Accuracy (producers accuracy)
	Water bodies	Grass Land	Bush land	Urban Area	Bare Land	Farm Land		
Water bodies	94.37	0	0.24	0.99	1	0	96.6	98%
Grass Land	0.18	99.62	0.3	3.58	3.94	0.27	107.89	92%
Bush land	0	1	99.16	1.69	2.97	0.59	105.41	94%
Urban Area	0.45	1.23	0.96	97.89	0	11.84	112.37	87%
Bare Land	0	0	0.15	13.85	99.5	0.07	113.57	88%

Farm Land	0	0.38	0.11	0	0.5	99.66	100.65	99%
Column Total	95	102.23	100.92	118	107.91	112.43	636.49	
Reliability(users accuracy)	99%	97%	98%	83%	92%	89%		

----- End of Error Matrix -----

Average Accuracy =93 %

Average Reliability = 92%

Overall Accuracy =92.73 %

According to Tesfaye et al., (2017), Seven land use land cover classes; grassland, wetland, woodland, forest area (dense), cultivated land, water body (lake and river) and residences, were derived from the Land sat ETM+5 image based on the supervised classification for lowland Gilo sub-basin of Gambella. The classification was classified with over all accuracy of 87.29%, which indicates the land use land cover classification have a strong agreement. As presented in Table 4.3, all land use land cover classes were classified with high accuracy. The land use land cover of the study area was classified with over all accuracy of 92.73% which shows the land use land cover classification of Akaki catchment have more strong agreement.

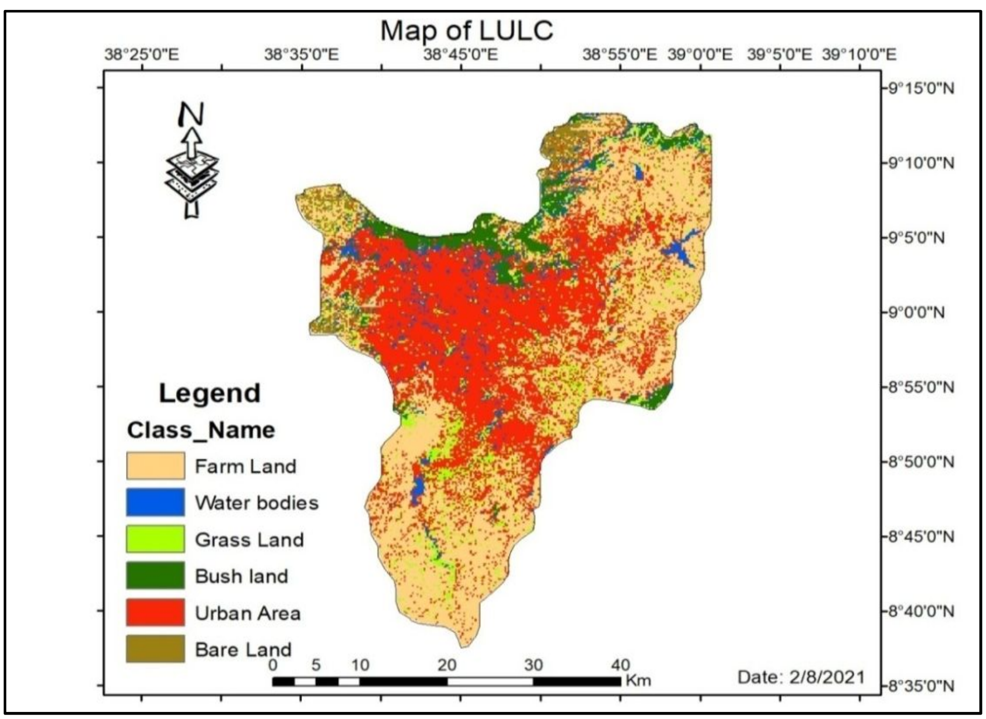


Figure 4.6: Land Use Land Cover of the study area

The LULC of a watershed were classified based on the land cover type resulted from the land sate image by implement EARDAS IMAGIN 2014.

Table 4 .7: LULC classification of the study area

No	LULC Class name	Area in Km^2	Area in percentage
1	Bare Land	8,493.00	5.27
2	Bush land	7,856.00	4.88
3	Farm Land	60,978.00	37.87
4	Grass Land	13,341.00	8.29
5	Urban Area	63,888.00	39.68
6	Water bodies	6,463.00	4.01
	TOTAL	1610.20	100.00

The six land use land cover types in the watershed included dominantly farm land, grass land, shrub land, bare land, water and urban settlement are available. As shown in Figure 4.7Farm land and grass lands were classified as highly suitable for irrigation. It covers 46.16% (74,319 ha) of the total area of the watershed. Moderately suitable class is Bush/shrub land. This land use/cover accounts 4.88% (7,856 ha) of the area. Marginally suitable land is bare land which covers 5.27% (8,493 ha). Other land covers types such as water and urban land covers were categorized under not suitable for irrigation, it covers 43.69% (70,351 ha) of the total size of the study area.

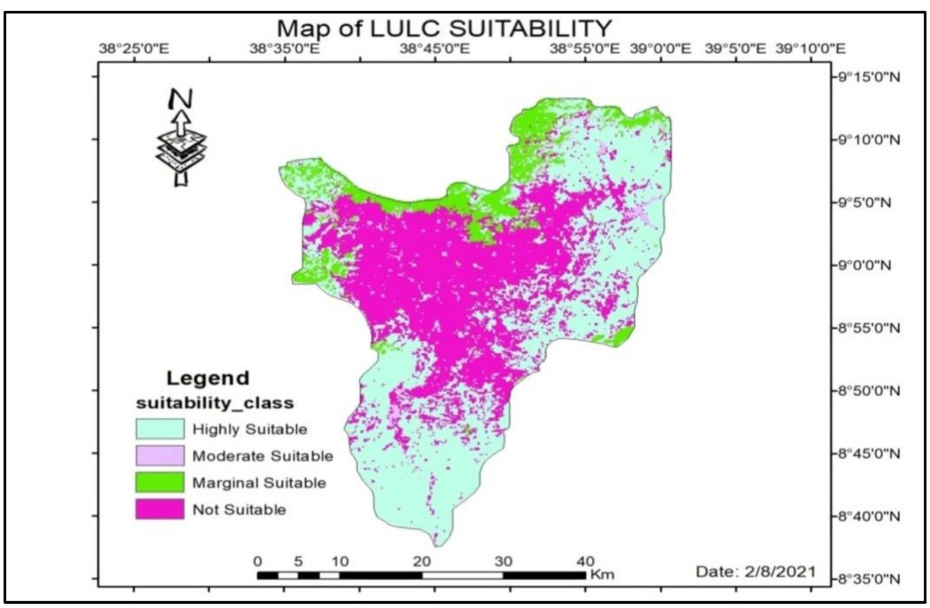


Figure 4.7: Land use/cover suitability map of Study area

Table 4.8: Land use Land cover suitability area

No	suitability class	Suitability rate	Area in Km^2	Area in Percentage
1	Highly Suitable	S1	768.94	47.86
2	Moderate Suitable	S2	41.36	2.57
3	Marginal Suitable	S3	159.65	9.94
4	Not Suitable	N	636.84	39.63
	Total		1606.78	100.00

The report was indicates only the range of Dense forest having ground cover of greater than 50% on the upper part of lowland Gilo sub-basin. An open wood land was seen scattered throughout the study area in associated with open grassland, wetland and moderately cultivated land uses. Scattering cultivation, shifting cultivation and rescission farming of crops observed on lowland Gilo sub-basin. There is no coverage of dense forest on Akaki catchment area rather than urban settlement which cover 39.68% of the total catchment.

4.2.4. Irrigable area for surface irrigation

Potential irrigable sites were obtained using soil suitability, slope suitability and land use land cover suitability on Arc GIS 10.4.1 by means of weight overlay analysis. As described below potentially irrigable land for surface irrigation in the catchment was identified based on their area coverage and geographic location. To identify potentially irrigable land for surface irrigation, three basic suitability parameters were used (slope, soil and land use land cover) by integrating Arc GIS 10.4.1. The three suitability parameters identify potentially irrigable sites in the watershed as highly, moderately, marginally and unsuitable class for surface irrigation development. In the weighted overlay analysis a high weight of % age influence was given for slope, since it is the determinant factor in the evaluation of the given area of surface irrigation development and the result of weighted overlay analysis of irrigation suitability analysis was shown in the Table 4.9 and Figure 4.10 below.

Table 4.9: Result of Land suitability of the study area

No	Land suitability	Suitability rate	Area in ha	Area (%)
1	Highly suitable	S1	10,570.00	6.56
2	Moderately suitable	S2	45,191.00	28.07
3	Marginal suitable	S3	59,178.00	36.75
4	Not suitable	N	46,081.00	28.62
	Total		161,020.00	100

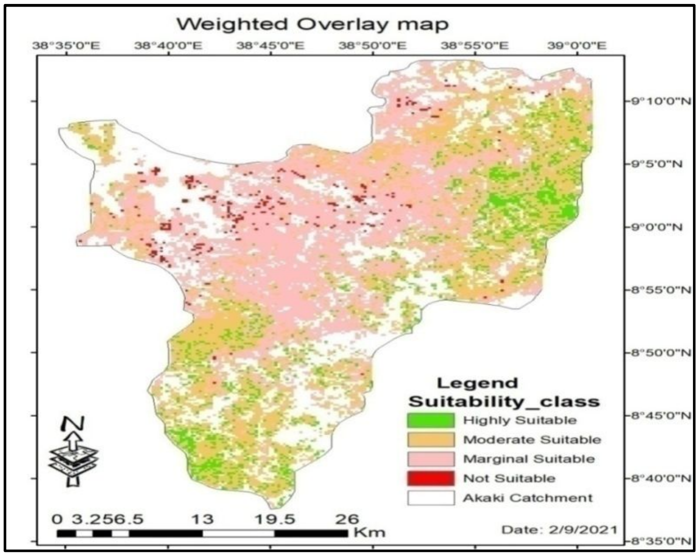


Figure 4.8: Overall land suitability map for surface irrigation

The weighted overlay analysis of surface irrigation suitability revealed that 6.56 % of the total area covers on a highly suitable class, 28.07 % covers moderately suitable class, about 36.75 % of the watershed was covered in marginally suitable class and the rest 28.62 % is unsuitable class. As the result indicated for suitability classes of the watershed suitable site for surface irrigation have a higher coverage due to combined effect of slope, soil and land use land cover.

Nasir GT et al., (2019) reports irrigation potential assessment on Shaya River Sub-Basin in Bale Zone. Irrigation suitability factors such as slope, texture, depth, drainage characteristics, land use/cover and distance to water source were taken in to account to identify irrigation suitability. The suitability analysis of the parameters indicates 66.38% slope, 98.20% soil, 92.93% land use/cover of the study areas classified as potentially suitable for irrigation development in the study area. By weighing analysis of all parameters 22.05% of the study area was found to be highly suitable, 25.27% moderately suitable and 16.20% marginally suitable whereas about 33.57% restricted for irrigation developments.

Potentially irrigable land of Shaya River Sub-basin in Bale was identified based on the specified suitable criteria by creating irrigation suitability model analysis which involved weighting of values of all data sets such as soil texture, drainage, depth, slope, land use land cover. From the total area coverage of the study area 22.05% (71,046.03 ha) was classified as high suitable (S1), 25.27% (81,420.45 ha) moderately suitable (S2), 16.20% (52,187.67 ha) marginally suitable (S3), whereas 33.57% (108,168 ha) not suitable (N) for surface irrigation (Nasir GT et al., 2019). The weighted overlay analysis of surface irrigation suitability revealed that 6.56 % of the total area covers on a highly suitable class, 28.07 % covers moderately suitable class, about 36.75 % of the watershed was covered in marginally suitable class and the rest 28.62 % is unsuitable class. As the result indicated for suitability classes of the watershed suitable site for surface irrigation have a lower coverage when compared with the other assessment result reports.

4.2. Water Resources Assessment

Prior to estimating stream flows at the ungauged sites from gauged sites, watersheds above both gauged and un-gauged sites were characterized. Taking the watershed similarities into account, stream flows at ungauged sites were estimated from the gauged sites by applying runoff coefficient method. In case of gauged sites, discharges from gauge site transferred to site of interest. The results are discussed under the following sub-sections.

4.3.1. Gauged and un-gauged watersheds similarities

The similarity of the watershed characteristics of the two sites, gauged and ungauged was determined in Table 4.10 by using slope and soil characteristics. Un-gauged watersheds are similar with gauged watersheds within similarities of the sub-watershed. Transferring of flow data from gauged site to site of interest has been presented in Table 4.11.

Table 4.10**:** Characteristics of watersheds in both gauged and un-gauged sites.

Suitability parameters	**Gauged watershed**	**Unguaged watershed**
Slope Range	0-2%	0-2%
	2-5%	2-5%
	5-8%	5-8%
	>8%	>8%
Soil type	C, SiC, SC	C, SiC, SC
	Si-SCL	Si-SCL
LULC	Grass land	Grass land
	Shrub land	Shrub land
	farm land	Farm land
	Bare land	Bare land
	Urban land	Urban land
	Water	water

4.3.2. Stream flows at un-gauged sites

Referring to Table 4.10, the characteristics of watershed above the un-gauged sites were similar with the watersheds above the gauged sites on Akaki River. Similarly, the distances between these gauged and un-gauged sites were found to be less than 20 km.

Table 4.11: Estimation of the Ungauged River Flow (m^3/s) from Gauged River

months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oc	Nov	De
Gauged(annual mean flow)	0.01	0.03	0.31	1.01	0.6	0.75	16.02	30.99	14.24	0.88	0.24	0.13
Unguaged(transferred mean flow)	0.02	0.06	0.66	2.16	1.29	1.61	34.33	66.41	30.51	1.89	0.51	0.28

4.3.3. Transferring discharges to sites of interest

Available Surface water on the study area was evaluated by using stream flow discharge obtained from Ministry of Water, Irrigation and Energy. Average annual monthly stream flow, maximum and minimum flow were evaluated. But effective irrigable area was calculated based on minimum stream flow. Table 4.12 and 4.13 shows that mean, maximum and minimum annual monthly flow before and after 25% released for ecological purpose respectively.

Table 4.12: Mean, Maximum and Minimum annual monthly flow

Months	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Total
Av.Flow(m^3/s)	0.05	0.09	0.84	2.73	1.65	2.19	44.18	85.93	37.38	2.50	0.80	0.48	178.82
Max.	0.19	0.75	3.62	5.48	6.24	7.23	80.11	122.93	78.49	6.64	2.27	0.45	314.40
Min	0.03	0.02	0.02	0.03	0.02	0.13	2.10	5.53	1.65	0.22	0.21	0.14	10.11

Total average, minimum and maximum flow were added 178.82 m^3/s, 10.11m^3/s and 314.40 m^3/s respectively. Maximum flows were observed in August and minimum flows were observed in February and March.

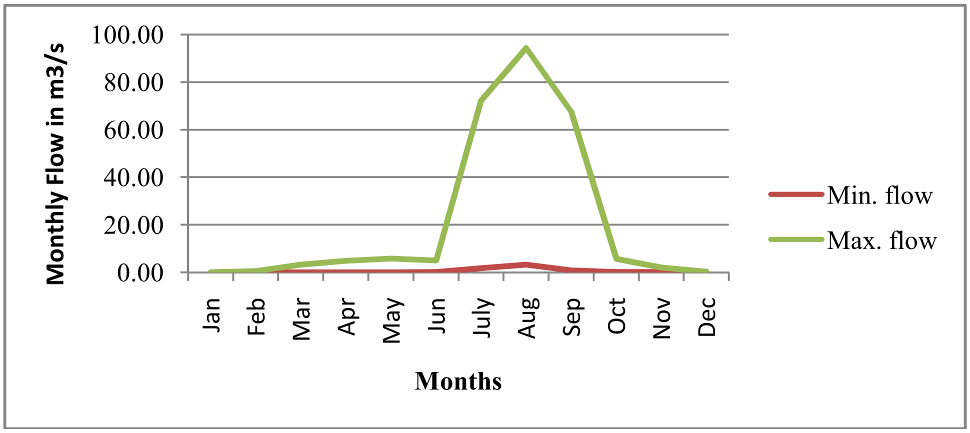


Figure 4.9: Graphical representation of Mean, Maximum and Minimum annual monthly flow

Table 4.13: Mean, maximum, and minimum annual monthly flow after 25% released

	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec	Total
Av. Flow(m^3/s	0.035	0.069	0.628	2.046	1.239	1.645	33.135	64.444	28.035	1.876	0.601	0.363	134.116
Max.	0.143	0.561	2.718	4.111	4.684	5.419	60.082	92.198	58.870	4.977	1.705	0.334	235.802
Min	0.022	0.018	0.015	0.020	0.016	0.097	1.574	4.148	1.241	0.167	0.160	0.105	7.583

Maximum and minimum average flow was observed in August and April respectively.

The average stream flow of the Dirma River varied from 0.55 m^3 /s during March to 931 m^3 /s during August (Birhanu et al., 2017). The Dirma River is the major water source with a mean annual flow of 5310 Mm3. Around 73% of annual flows occur in July and August and the remaining 27% is spread across the other 10 months (September–June). The study was focused on assessing irrigation potential during the low flow periods from January to May.

4.3. Gross Irrigation Water Requirements of the Identified Command Areas

4.4.1. Reference evapotranspiration (ETo)

Reference crop evapotranspiration (ETo) was calculated from CROPWAT8.0 model using monthly average values of climatic data (sunshine, relative humidity, max T, min T and wind speed) for each crops. The calculated monthly values of ET_o from January to May for each crop are given in the Table 4.14.The reference crop evapotranspiration at Akaki climatic stations varied from 4.1mm/day to 4.83 mm/day.

Table 4.14: The Calculated values of ETo in mm/d during different Months of Akaki catchments

Months	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
ETo(mm/day)	4.1	4.42	4.83	4.52	4.65	3.68	3.06	3.17	3.59	4.54	4.51	4.31

4.4.2. Effective Rainfall

The effective rainfall calculated by CROPWAT model by using the average recorded rainfall data is given in the Table 4.9.The effective rainfall at study area varied from 2mm during February to 150 mm during August.

Table 4.15: Effective Rainfall in mm during different Months at Akaki catchment

Months	Jan	Feb	March	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
Rainfall	10	16	54	72	63	77	234	250	103	24	2	5
Eff. Rainfall	9.8	15.6	49.3	63.7	56.6	67.5	146	150	86	23.1	2	5

4.4.3. Calculation of Crop water requirement

Crop Water requirement was calculated from CROPWAT8.0Model using monthly average value of ETo and crop coefficient for each of the crop tomato, Potato, cabbage and pepper at. The crop season was selected according to rainy season for rain fed cultivation. After crops of the first phase cultivation were harvested; land preparation was overtaken and the second phase cultivation followed using the planned irrigation method. According to crop calendar of the area the first phase land preparation was started at the late of April and crops were harvested from mid November till late December. So, land preparation for the second phase irrigated cultivation started at early of January and harvesting period varied from early April to end of May based on the selected crops. The input data used for the calculation of water requirement in the CROPWAT are shown in Appendices A and the effective rainfall computed by entering the average rainfall to the model and the entered values are also given in Appendices A Table 2.The details regarding the input data used for the software and calculated values are given in Appendices D Table 1.Net irrigation water requirement of tomato, potato, cabbage and pepper at study area are given in Appendices Table. Themonthly calculated values of ETc for each crop are given in the Table 4.16.

Table 4.16: Monthly crop water requirement

crops	CWR(mm/month)						Total
	Jan	Feb	Mar	Apr	May	Jun	
Potato	41.7	89.2	169.1	156.7	88.6		545.3
Tomato	50	85.1	155.4	158.9	165.2		614.6
Cabbage	58.3	87.6	124.2	139.4	151	53.1	613.6
Pepper	50	84.4	147.8	145	73		500.2
Total	200	346.3	596.5	600	477.8	53.1	**2273.7**

Different crops have different crop water requirement within the study area. Crop water requirement of all crops such as, Potato, Tomato, Cabbage and pepper was presented for each month in the table above. From all crops, pepper has needed the lowest crop water requirement which recorded 500.2 mm/growing period and Tomato has the maximum crop water requirement in the study area was evaluated 614.6 mm/growing period. Total crop water requirement were evaluated 2273.7mm/growing period. The highest crop water requirement was recorded for all crops on April.

Crop water requirements of tomato and potato crops grown in the area were estimated assuming a mono cropping pattern in the Dirma river basin (Birhanu et al., 2019). The ETc was calculated using the monthly average value of ET_0 and the crop coefficient for tomato and potato crops. The ETc for tomato and potato at Dirma was found to be between 2.62-5.84 and 2.24-5.81 mm/day. These values are in agreement with ETc (4-6 mm/day) for tropical and subtropical regions and the study region in Ethiopia. Crop evapotranspiration for both crops was more than effective rainfall. The effective rainfall was not sufficient to meet crop water requirements. Therefore, irrigation is needed for both crops in the river basin.

As indicated in appendix Table, different percentage of area coverage was adopted for each crop based on the assumed benefits the farmers will obtain from them. To evaluate the water resource and water requirement in the catchment, compute gross irrigation requirement. During evaluation of the water resource in the catchment, 25% of the mean monthly stream flow was maintained for downstream ecological balance. Therefore, the overall irrigation efficiency was calculated using the recommended formula by FAO irrigation and drainage paper no.24 and it was reduced from 100 % to 54 %.The values from the software were estimated in mm/d.

4.4.4. Gross irrigation water demand

Gross irrigation water requirements of potato, tomato, cabbage and pepper at the identified potential irrigable site covers 40%,15%,35% and 10% of the total irrigable area respectively under surface irrigation methods were estimated using climatic data for CROPWAT 8.0 model which are presented in Appendix D. The following Table 4.17 presents monthly gross irrigation water requirements of the dominant crops potato, tomato, cabbage and pepper. These results gives a general overview of monthly water demands for four months of full growth stage of potato, tomato, and three and five of pepper and cabbage respectively that should be abstracted from the sub basins during the local cropping period.

Table 4.17: Gross irrigation water demand for each crop in mm

crops	**Monthly GIWR in mm**							**Total GIWR/growing period**	**Area(ha)**
	Jan	Feb	Mar	Apr	May	Jun	Jul		
Potato	54.5	89.2	124	93.4	37.4			398.3	45976
Tomato	79	76.3	146	83.5	91.7			476.7	17241
Cabbage	82.1	65.4	75.6	92.1	98.7	46		459.9	40229
Pepper	71.7	93	94.8	105				364.2	11494
Total	287.3	323.9	440	374	228	46		1699.1	114939

Table 4.18: Gross irrigation water demand for each crop in m^3/s

Types of crops	**Months**							**Total GIWR/growing period**	**Area(ha)**
	Jan	Feb	Mar	Apr	May	Jun	Jul		
Potato	0.134	0.242	0.304	0.237	0.136			1.052	45975.6
Tomato	0.073	0.078	0.134	0.079	0.119			0.483	17240.85
Cabbage	0.176	0.155	0.162	0.204	0.212	0.146		1.055	40228.65
Pepper	0.044	0.063	0.057	0.091				0.255	11493.9
Total	0.426	0.538	0.657	0.611	0.466	0.146		2.844	114939

Total irrigation water demand for the catchment 1,415.62Mm^3 of water was maintained to irrigate the whole irrigable area of 114939ha of land on these specified crops.

4.4.5. Irrigation Potential of River Catchments

According to FAO, 1997 Physical surface irrigation potential for surface irrigation was obtained by comparing irrigation water requirement in identified irrigable land and the available stream flow of watershed. From the total stream flow, 25% of the available stream flow on watershed was released to the downstream for ecological purpose. In the whole Growing season from January-June irrigation water demand was greater than the available stream flow. Minimum monthly stream flow and gross irrigation water requirement of selected crop such as, potato, tomato, cabbage and pepper were present in the Table 4.16 below.

Nasir et al., (2019) reports Irrigation potential of the shaya river sub-basin obtained by comparing irrigation water demand of the five crops(potato, tomato, maize and pepper) commonly grown in the study area, in considering to the identified suitable land for irrigation and monthly flows of the Shaya River. Results of these analyses revealed that the available monthly flow of the river was higher than the irrigation water requirements of all crops at their corresponding command area.

Table 4.19: Comparing of Gross Water Demand and Available Flows of River Catchment in the Study Area for Potato, Tomato, Cabbage and Pepper in (m^3/s).

Months		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Available flow(m3/s)		0.030	0.024	0.020	0.027	0.021	0.129	2.099		
	Tomato	0.134	0.242	0.304	0.237	0.136				
	Potato	0.073	0.078	0.134	0.079	0.119				
GIWR(m3/s)	cabbage	0.176	0.155	0.162	0.204	0.212	0.146			
	pepper	0.044	0.063	0.057	0.091					
	Total	0.426	0.538	0.657	0.611	0.466	0.146			

The analysis of the result shows the study area is advisable for designing the potential of water delivery for irrigation of the watershed. The value of the requirement is given in Table 4.14. Based on the Minimum available water, the effective irrigable area can be estimated in each month and at different scenario.

Table 4.20: Effective irrigable area at each month for potato

Potato crops								
Months	**Days**	**area**	**Efficiency**	**NIWR(mm/month)**	**GIWR**	**Min flow**	**Irrigable area**	**Un-Irrigable area**
Jan	31	45975.6	0.54	54.5	0.134	0.030	5496.434	40479.17
Feb	28			89.2	0.242	0.024	2437.452	43538.15
Mar	31			123.8	0.304	0.020	1594.322	44381.28
Apr	30			93.4	0.237	0.027	2847.954	43127.65
May	21			37.4	0.136	0.021	3916.949	42058.65
Total	141			398.3	1.052	0.121	16293.11	

As shown in the above table, effective irrigable area of each month is varies from month to month due to variation of minimum flow. Due to lack of available water, most of irrigable area is not irrigated and is not covered by agricultural production. As shown in the table, the maximum irrigable area within the minimum flow for each month Jan, Feb, Mar, Apr and May were 5496.434, 2437.452, 1594.322, 2847.954, and 3916.949 ha respectively. The actual average irrigable area is 3258.622 ha out of 45975.6ha was irrigated within the total minim flow of 0.121 m^3/s and 1.052 m^3/s gross irrigation water covered by the Potato crop. The remaining effective irrigable area was covered by other crop was calculated on the same procedure in Appendix D.

Generally, Akaki river catchment has ample area suitable for surface irrigation 37,169.61 ha and abundant water yield 0.843 m^3/s. As comparing gross monthly irrigation demand of identified irrigable land under Akaki river catchment with corresponding available monthly river flows, the river potential is lower in all months so that the river is potentially not adequate to spray the water without storage provided.

As comparing gross monthly irrigation demand of identified irrigable land under shaya river catchment with corresponding available monthly river flows, the river potential is higher in all months so that the river is potentially adequate to spray the water without storage provided.

The NIR and GIWR from the weekly irrigation schedule for each of the crops for Dirma river catchment was estimated using CROPWAT software (Birhanu et al., 2019). The mean monthly values of irrigation water demand, water flow available from the River Dirma and average area that can be irrigated are clearly identified. Results revealed that the average area that can be irrigated with the Dirma River flows is highly variable, from 366 ha (March) to 9440 ha (May) due to variability in the natural river flow. Only 366 ha can be irrigated by practicing full irrigation; however, it indicates the irrigated area can be increased by practicing deficit irrigation during very low flow periods such as February and March and by creating water storage infrastructures such as reservoirs. Birhanu et al., (2019) reports, the Dirma River Basin was ample area suitable for surface irrigation (30 100 ha) and abundant water yield (5310 Mm3), because of the very high temporal variability in water availability the area can be irrigated with the natural river flows. Thus, this leaves only a tiny fraction of land and water resources utilizable in the river basin. This indicates that suitable infrastructure is needed to store water during high flow periods which can be used during low flow periods.

CHAPTER 5. CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The implementation of the GIS technique reduces the time and cost of the general evaluation process by narrowing the investigation to areas that are already evaluated by the most limiting factor for irrigation agriculture practices. Further this approach help in gathering and using all information, which demanded economical investment of the country and done by different fields of specific and specialized data collection process through site investigation and data preparation.

Surface irrigation potential was evaluated by assessing land use land cover, soil and slope suitability, using weight overlay analysis on Arc GIS 10.4.1 data management tool Accordingly, with available water resource and estimation of crop water demand for most dominantly growing crops of the study area.

The overall suitability of the area for surface irrigation was made using weighted overlay of the three parameters (soil, slope and land use land cover) developed on Arc GIS 10.4.1. About 107976.8 ha (67.06%) of the total lands in the catchment were in the range of highly suitable to marginally suitable for surface irrigation development, whereas 53043.23 ha (32.94%) were grouped in unsuitable class.

The long term measured flow data of Akaki River was obtained from Ministry of Water, Irrigation and Energy, Department of Hydrology. The flow data was used to assess water resources potential of the gauged and ungauged sites for irrigation purpose. The annual mean, maximum and minimum flow was evaluated after 25% released and found as178.82m^3/s, 314.4m^3/s and 10.11m^3/s respectively. Irrigation water demand for dominant crop during the growing season was estimated by using the available climate, soil and cropping pattern data which impute for CROPWAT8.0 software. The result shows that total irrigation water demand is 5,927.5Mm^3, 370.2 Mm^3, 455.4 $Mm^3$and 506.2 Mm^3 for November, December, January and February sowing time scenario respectively to irrigate 114939 ha of irrigable land. Physical surface irrigation was identified by comparing available stream flow and grosses irrigation water requirement based on starting sowing time scenario.

5.2. Recommendation

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

- This study was limited with soil texture, soil depth and drainage to assess Land suitability for surface irrigation. Since, other factors may have its own influence to characterize the suitability of land for surface irrigation. Therefore, further research which can incorporate additional factors such as soil chemical characteristics (such as alkalinity, acidity and pH) electrical conductivity with the aid of laboratory analysis is essential to assess land suitability over the study area.
- Suitability analysis of land for irrigation was done by considering only surface irrigation which covers an area of about 114939 ha. Further investigate is recommended to increase suitability of land for irrigation by considering drip and sprinkler irrigation method.
- Since irrigation water demand is greater than the available stream flow, construction of storage structures is recommended to fully irrigate the identified suitable land for surface irrigation development in the study area.
- In this research, estimation of irrigation water requirement of identified command areas was carried out by selecting four vegetable crops only. But the future research can select several crops to calculate gross irrigation requirements of identified potential irrigable land among river catchments.
- The evaluation carried out in this paper is in terms of physical suitability for irrigation and crops. But the effects of each alternatives use or classes should be appraised in environmental, economic and social terms.

REFERENCES

Abeyou A. (2013). Realistic assessment of irrigation potential on Lake Tana Basin, Addis Ababa, Ethiopia. In Journal of Rainwater Management for Resilient Livelihood in Ethiopia. Nairobi: International Livestock Research Institute.

Abiti G. (2011). Water Resources Potential and Development of Ethiopia, Arba Minch University, unpublished thesis

Albaji et al., (2010). Comparison of Different Irrigation Methods based on the Parametric Evaluation Approach in Abbas Plain, Iran. *Journal of Irrigation and Drainage Engineering.*136 (2): 131–36.

Alexandratos et al., (2012). World Agriculture Towards 2030 /2050: The 2012 Revision, ESA Working Paper No. 12-03, *Food and Agriculture Organization of the United Nations*, Rome.115–118

AltchenkoY.and KG Villholth(2015).*Mapping Irrigation Potential from Renewable Groundwater in Africa,* Quantitative Hydrological Approach, Hydrology and Earth System Sciences 19 (2): 1055–67.

Awulachew S. et al., (2007).*water Resources and Irrigation Development in Ethiopia* .Colombo, Sri Lanka: International Water Institute, working paper 123.

Awulachew S. et al., 2010. *Irrigation potential in Ethiopia: Constraints and Opportunities for enhancing the system.* Unpublished Report to the Bill and Melinda Gates Foundation.

Ayalew and Gizachew(2014). Land Suitability Evaluation for Surface and Sprinkler Irrigation Using Geographical Information System in Guang Watershed, Highlands of Ethiopia. *Journal of Environment and Earth Science* 4 (22): 140–50.

Berhanu B. &Seleshi Y. et al., (2014).Surface Water and Groundwater Resources of Ethiopia, Potentials and Challenges of Water Resources Development. Springer International Publishing Switzerland 2014

Campbell J. (1984).Introductory Cartography, Englewood Cliffs, NJ: Prentice Hall

Dagnenet S. (2013) Assessment of Irrigation Land Suitability and Development of Map for the Fogera Catchment Using GIS, South Gondar. *Asian Journal of Agriculture and Rural Development* 3: 7-17.

DemlieM. (2015). Assessment and estimation of groundwater recharge for a catchment located in highland tropical climate in central Ethiopia using catchment soil–water balance(SWB) and chloride mass balance (CMB) techniques. *Environmental Earth Sciences,* 74, 1137- 1150.

Demlie M. &Wohnlich S. (2006). Soil and groundwater pollution of an urban catchment by trace metals: case study of the Addis Ababa region, central Ethiopia. *Environmental geology 51*, 421-431.

Demlie M. et al., (2007).*Groundwater recharge in the Akaki catchment, central Ethiopia*: evidence from environmental isotopes (δ18O, δ2H and 3H) and chloride mass balance. Hydrological processes*,* 21, 807-818.

FAO(2015).FAOInformation System on Water and Agriculture.*Aquastat.http://www.fao.org/nr/water/aquastat/didyouknow/index3.stm.* Accessed on 2020-04-23.

Fasina A. et al., (2008). Irrigation suitability evaluation and crop yield an example with Amaranthuscruentus in Southwestern Nigeria. African Journal of Plant Science Vol. 2 (7), pp. 61-66, July 2008.

FAO (2009).*Crop water requirements*. Irrigation and Drainage Paper No. 24. FAO, Rome.

FAO (1985).Guidelines Land Evaluation for Irrigated Agriculture. FAO Soils Bull 55, Rome, 290pp.

FAO (1994). Sustainable Agriculture and Environmental Rehabilitation (Working Document),Tigray, Ethiopia.

FAO (1995).Irrigation in Africa in Figures. Rome, Ital*y*

FAO (1995).Use of Remote Sensing Techniques in Irrigation and Drainage. French Institute of Agricultural and Environmental Engineering, Rome, Italy.

FAO (1997). Irrigation potential in Africa: A basin approach FAO Land and Water Bulletin 4

FAO (1998).Guidelines for computing Crop Water Requirements, Irrigation and Drainage Paper, No. 56.Rome, Italy.

FAO (1999).The future of our land facing the challenge. Guidelines for integrated planning for sustainable management of land resources. FAO, Rome. Land and Water Digital Media Series 8.

FAO (2001). Irrigation Water Management: Irrigation Methods, Rome, Italy.

FAO (2007).Land evaluation towards a revised framework. Land and Water Discussion Paper 6 FAO, Rome.

Gebre G. et al., (2021). GIS Based Morphometric Analysis of Gudina Wacho Watershed, Western Ethiopia: *Suggestion for Surface Irrigation Development.* Journal of Water Resources and Ocean Science 10: 92-99.

GLCN (2006). Land cover and Land use definitions. *http://www.glcnlccs.org/index.php*

GoodchildM.F.(2000). The Current Status of GIS and Spatial Analysis.Geographical Systems, 2, 5-10

HailegebrielShiferaw (2007). Irrigation Potential Evaluation and Crop Suitability analysis using GIS and Remote Sensing Technique in Beles Sub basin, BeneshangulGumez Region. MSc thesis, Addis Ababa University.

Jaruntorn B. et al. (2004). *GIS based land suitability assessment for Musa*. Graduate School of Agricultural science, Ethime University, Japan

JanssenR.&Rietveld P. (1990). Multi-criteria Analysis and GIS: An Application to Agriculture Land use in the Netherlands.

KebedeGanole (2010).*GIS- based surface irrigation potential assessment of river catchments for irrigation development in dale woreda, sidama zone, SNNP*. Published master's thesis, University of Harmaya, Harmaya, Oromia Regional State.

Midaksa and Temesgen (2020). Food Science and Technology, *Turkish Journal of Agriculture* 8(1): 139-146, 2020

Ministry of Agriculture (2011).Guideline on Irrigation Agronomy, Addis Ababa, Ethiopia.

MoWR(2002). Water sector development program 2002-2016, Volume II: Main Report. MoWR, FDRE, Addis Ababa, October 2002.

Melaku and Yirga (2003).*Assessment of irrigation potential using GIS and RS for strategic planning*: A case study of Raxodamarea (Portugal). MSc thesis, International Institution for Geo Information Science and Earth Observation, Enscheda, Netherlands.

Meron and Tariku (2007).*Surface irrigation suitability analysis of Southern Abbay Basin by implementing GIS technique,* MSc thesis submitted to Addis Ababa University.

Nasir G et al., (2019). *Irrigation Potential Assessment on Shaya River Sub-Basin in Bale Zone, Oromia Region, Ethiopia*, Irrigate Drainage Sys Eng 8: 225. doi: 10.4172/2168-9768.1000225

Saymen San Woldegebriel, (2005). *Performance Evaluation of Furrow Irrigation System and GIS-based Gravity Irrigation Suitable Area Map Development at Godino Mariam*, Debrezeit.MSc thesis, Alemaya University.

Wilkinson G.G.(1996). A review of Current Issues in the Integration of GIS and Remote Sensing.*International Journal of Geographical Information Systems*, 10, 85-101.

Worqlul andAbeyou W. et al., (2015). Assessment of Surface Water Irrigation Potential in the Ethiopian Highlands: The Lake Tana Basin. *Catena* 129: 76–85.

Worqlul and Abeyou W et al., (2017).Assessing Potential Land Suitable for Surface Irrigation Using Groundwater in Ethiopia. *Applied Geography* 85.

Yang Yi, (2003).*Application of GIS and RS for Assessing Watershed Ponds for Aquaculture development in Thai Nguyen*, Vietnam. School of Environment, Resources and Development Asian Institute of Technology.

APPENDIXES

Appendix Table 1: Climatic Data and Estimated ETo

Monthly ETo Penman-Monteith - D:\AKAKI.pen

Country: Location 88 | Station: AKAKI

Altitude: 2100 m. | Latitude: 8.86 °N | Longitude: 38.78 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	6.8	28.6	50	112	8.0	19.5	4.10
February	9.3	29.1	49	121	7.7	20.1	4.42
March	11.3	30.3	49	121	7.7	21.2	4.83
April	11.8	28.4	56	112	7.2	20.7	4.52
May	11.2	29.6	52	121	7.2	20.2	4.65
June	10.8	26.4	65	78	5.9	17.8	3.68
July	12.1	23.4	77	69	4.3	15.6	3.06
August	12.3	23.4	79	69	4.7	16.5	3.17
September	11.0	25.4	72	86	5.8	18.1	3.59
October	9.7	27.9	54	138	8.0	20.7	4.54
November	6.8	29.1	51	130	9.0	21.0	4.51
December	7.0	28.8	49	130	8.8	20.0	4.31
Average	**10.0**	**27.5**	**59**	**107**	**7.0**	**19.3**	**4.11**

Appendix Table 2: Effective Rainfall of Akaki

Monthly rain - D:\AKAKI.cli

Station: AKAKI | Eff. rain method: USDA S.C. Method

	Rain	Eff rain
	mm	mm
January	10.0	9.8
February	16.0	15.6
March	54.0	49.3
April	72.0	63.7
May	63.0	56.6
June	77.0	67.5
July	234.0	146.4
August	250.0	150.0
September	103.0	86.0
October	24.0	23.1
November	2.0	2.0
December	5.0	5.0
Total	**910.0**	**675.1**

Appendix Table 3: Addis Ababa Bole monthly rainfall data

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	0	42.6	254.7	79	18.4	56.9	273.9	256.1	180.5	24.7	0	2.7
1982	26.6	96.4	90.2	48.1	73.5	63.6	220.3	221.6	142.8	19	40.7	4.9
1983	12.4	41.2	28.9	113.7	186.9	56.1	217.9	213.7	202.2	35.9	0	1.5
1984	0	0.4	11.6	11.6	135	334.2	317.9	180.4	98.8	0	0	7
1985	35.1	0	49.1	132.3	92.8	110.9	209.8	260.8	168.6	29.8	0	0.4
1986	0	37.6	56.2	216.6	37.7	175.2	167.9	222.3	107.4	31.6	0	2.5
1987	0	49.1	180.1	85.7	154.6	71.9	155.9	98.1	57	16.6	0	0.4
1988	4.7	33.4	6.7	157.9	34.7	93.2	181.4	265.3	187.3	57.3	0	0
1989	3.4	33.7	58.4	143.3	0	88.1	218.1	318.6	150	36.8	0	7.9
1990	3.2	161.1	60.4	144.5	25.2	48.3	194.2	293.6	143	46.1	2.1	0
1991	0.2	29.6	134.1	15	7.7	107.5	279.4	287.9	123.1	4.4	2.1	0
1992	14.5	28	35	58.6	55	82.2	254.8	223.3	157	64.4	2.2	0.4
1993	11.7	52.1	11.6	168.3	91.5	157.2	209.5	291.7	190.1	24.1	0	0
1994	0	0	52.9	70	29	112.4	242.3	199.3	99.4	0.5	11	0
1995	0	81.3	73.1	133.3	95.9	77.4	165.5	256.9	97	0	0	29.3
1996	20.5	15.8	134.4	96	124.6	290.2	346.3	312.7	211.4	0.2	0.4	0
1997	29.1	0	22.1	66.8	44.8	128	257	160.7	94.7	58.6	15.3	0
1998	66.6	40	43.8	99.8	197.7	111.6	270.7	236.8	173.4	139.4	0	0
1999	4.4	0	35	17.8	30.5	104.6	294	270.5	62.8	127.1	0	0
2000	0	0	17.6	87.8	95.2	102.1	192.9	221.9	157.5	19.6	7.5	0
2001	0	10.3	174.3	14.8	116.7	166	289.4	207.3	113.3	10.6	0	0
2002	30.6	25.9	79.4	36.6	49.6	115.5	213.9	233.6	72.6	0.5	0	32.8
2003	4.8	44.7	48.9	111.5	18	111	204.3	238.4	130.2	4.6	0	33.3
2004	20.8	11.7	32.4	117.3	7	114.5	240.6	230.1	122.1	50	0.6	0
2005	55.4	14.1	41.8	116.2	164.6	159.1	174.3	248	77.6	25.8	7.2	0
2006	2	36.6	107.8	93.9	37.8	115.1	313.2	331.1	132.5	35.9	0	0
2007	9.9	21.3	61.1	86.8	134	157.6	191.3	305.4	130.9	37.2	0.1	0
2008	0	0	0	34	75.3	73.1	295.1	259.1	192.7	22.2	53.1	0
2009	40.9	0	12.4	46.1	52	77.5	238.2	269.5	86.1	42.4	2	79.9
2010	0.4	115.2	75.6	159.5	94.7	107.2	320.2	138.8	105	0	13.8	15.7
2011	3.4	13.6	27.9	19.1	86	148	183.1	296.5	141.3	0	11.9	0
2012	0	0	34.5	75.1	58.5	72.8	228.8	281.6	176.9	1.2	0	8.2
2013	3.9	0	63.5	114.4	78.5	101.4	157.6	270.2	126.7	45.3	3.2	0

Appendix Table 4: Addis Ababa Observatory monthly rainfall data

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	0.0	75.5	176.0	82.9	3.9	50.1	266.5	320.9	182.1	13.3	0.0	5.2
1982	48.7	80.9	57.8	103.7	115.9	31.9	259.3	257.9	133.8	64.4	43.2	12.8
1983	18.3	21.7	48.7	117.0	237.0	109.3	199.3	244.7	160.9	26.3	0.0	8.8
1984	0.0	8.0	8.8	8.4	127.8	220.8	296.1	295.6	142.4	0.0	4.4	16.3
1985	14.2	0.0	17.5	96.3	83.7	112.2	270.4	327.7	205.9	58.0	3.3	1.2
1986	0.0	35.7	88.0	197.6	125.4	179.5	180.1	250.4	127.8	36.1	0.0	2.8

1987	0.5	63.4	248.9	82.4	241.3	92.9	196.5	254.4	115.2	21.3	0.8	0.3
1988	9.7	53.4	5.3	144.6	16.6	106.2	277.9	299.3	229.7	59.9	0.0	0.0
1989	0.8	75.9	75.7	154.4	0.5	120.9	357.7	325.3	187.7	14.8	0.0	7.6
1990	0.8	155.9	59.2	106.4	20.0	88.8	218.7	268.6	184.0	16.2	6.0	0.0
1991	0.0	74.5	106.6	34.7	8.7	121.1	248.9	262.6	126.4	3.4	0.0	50.0
1992	20.2	33.7	20.2	41.0	52.0	109.1	248.5	294.7	209.4	69.7	0.0	2.9
1993	10.8	67.2	16.1	157.9	97.2	208.3	274.0	426.5	243.3	62.1	0.0	4.5
1994	0.0	0.0	82.4	82.3	63.3	123.4	308.9	225.0	142.0	0.5	14.7	0.0
1995	0.0	69.0	41.5	174.4	68.2	102.9	190.2	314.9	136.1	0.0	0.0	33.0
1996	28.1	5.2	106.8	128.2	122.0	258.5	266.4	338.7	294.2	0.2	0.2	0.0
1997	39.2	0.0	24.5	51.3	38.5	104.0	272.6	194.3	113.8	62.4	50.3	1.5
1998	55.2	20.5	49.0	48.5	154.2	124.4	285.4	260.0	213.6	126.9	0.0	0.0
1999	2.9	0.3	28.8	16.3	23.8	119.6	331.2	305.3	88.4	75.4	0.0	0.0
2000	0.0	0.0	17.6	49.9	110.0	144.5	244.8	306.2	250.6	46.4	21.1	0.0
2001	0.0	12.2	210.8	25.0	168.0	216.2	428.0	246.4	131.7	13.7	0.0	0.0
2002	14.7	21.0	90.2	56.3	63.1	172.5	256.9	215.9	108.8	0.2	0.0	16.5
2003	10.5	53.3	62.6	99.3	20.2	151.8	291.8	233.3	193.3	0.8	1.5	54.9
2004	24.8	20.3	49.5	139.9	30.1	141.9	238.5	272.6	164.0	76.9	0.0	0.0
2005	45.9	51.6	83.2	160.9	133.7	179.8	246.0	315.2	162.5	29.1	4.4	0.0
2006	0.7	11.2	121.4	78.9	74.6	150.1	356.3	243.6	239.1	54.0	0.3	8.0
2007	51.3	19.1	59.8	73.8	120.1	177.5	261.8	381.2	147.6	24.8	0.0	0.0
2008	0.0	13.0	0.0	49.4	94.3	88.9	277.0	360.9	256.7	88.2	79.4	22.9
2009	21.3	2.7	28.4	80.6	58.9	82.6	349.9	388.3	112.7	45.8	4.4	65.0
2010	2.6	79.8	55.5	97.8	74.4	271.1	313.9	205.8	237.8	1.8	25.7	15.0
2011	14.1	13.1	44.3	22.8	66.1	182.0	180.9	340.8	146.0	0.0	42.3	0.0
2012	0.0	0.0	15.8	84.6	50.2	69.4	324.2	298.0	215.5	2.3	0.0	9.8
2013	4.4	0.0	71.5	92.3	85.0	153.2	177.5	353.2	142.7	58.4	22.3	0.0

Appendix Table 5: Akaki station monthly rainfall

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1981	0.0	13.3	179.8	132.0	1.3	49.2	402.6	165.0	223.1	5.0	0.0	0.0
1982	12.1	35.4	39.5	94.6	75.2	63.5	238.8	255.9	125.2	25.8	11.0	8.1
1983	1.8	33.3	20.2	142.1	175.0	83.0	237.7	275.3	146.7	0.0	0.0	0.0
1984	0.0	0.0	40.4	5.1	130.0	215.3	277.9	227.1	71.7	0.0	0.0	1.9
1985	3.6	0.0	32.4	71.8	96.6	96.5	303.0	324.1	164.3	1.6	0.0	0.0
1986	0.0	95.4	67.7	148.7	83.2	143.4	189.4	216.5	86.1	9.4	0.0	0.0
1987	0.0	65.6	181.9	81.2	187.7	69.3	202.0	246.9	82.5	4.4	0.0	0.0
1988	0.0	44.5	0.0	96.0	23.8	124.6	255.9	278.1	253.5	35.4	0.0	0.0
1989	2.1	63.8	53.8	226.3	7.1	58.6	264.2	301.0	170.9	37.9	0.0	0.0
1990	7.7	120.6	48.4	159.1	37.3	78.9	280.7	222.9	107.3	5.8	1.2	0.0
1991	0.0	37.6	62.4	11.6	45.6	90.4	263.7	308.5	113.3	4.4	0.0	56.5
1992	33.5	24.2	30.5	15.5	25.6	100.4	218.4	276.0	86.7	43.3	0.2	0.0
1993	1.2	53.9	5.6	118.4	54.6	116.5	218.0	251.5	118.3	20.5	0.0	0.0
1994	0.0	0.0	62.7	72.2	20.2	131.2	219.3	181.0	94.5	0.0	11.0	0.0
1995	0.0	25.4	62.7	102.1	20.9	95.7	279.0	242.3	79.5	0.0	0.0	4.8

1996	15.3	0.3	79.7	38.8	90.5	240.1	292.5	234.1	119.0	1.9	0.0	0.0
1997	27.6	0.0	29.5	102.7	25.2	57.0	203.6	203.4	89.2	114.9	10.3	0.0
1998	32.7	30.2	19.6	69.3	159.9	116.9	207.8	280.0	118.5	36.9	0.0	0.0
1999	1.3	1.8	91.8	12.1	45.4	92.8	282.6	300.7	61.7	65.0	0.0	0.0
2000	0.0	0.0	29.1	93.0	64.9	100.1	188.9	210.0	124.1	17.2	23.4	3.8
2001	0.0	20.7	121.2	23.6	118.0	142.6	257.5	145.0	64.9	2.2	0.0	0.0
2002	31.1	10.5	87.8	53.9	76.6	108.0	167.1	166.3	52.3	0.0	0.0	17.7
2003	19.6	24.8	23.9	114.0	1.4	125.4	325.1	307.4	113.4	0.0	0.0	40.8
2004	15.6	15.8	61.4	154.5	15.4	95.2	150.3	189.1	80.9	4.8	3.4	0.7
2005	28.8	7.3	47.9	112.2	140.7	139.9	218.7	231.4	152.7	9.1	15.2	0.0
2006	2.6	44.2	56.3	79.7	22.0	84.3	276.4	262.6	148.1	38.0	0.0	3.2
2007	34.2	24.7	25.6	96.8	64.6	132.7	254.2	221.8	148.5	14.3	1.3	0.0
2008	0.0	0.0	0.6	34.2	62.4	140.2	253.5	252.3	181.6	7.2	64.8	0.0
2009	60.2	0.0	10.0	118.7	47.7	63.5	235.3	322.4	71.3	32.8	4.0	16.8
2010	0.0	63.8	126.2	170.0	95.2	164.8	334.4	169.8	154.1	5.2	14.8	7.8
2011	0.0	2.5	45.2	20.7	128.7	60.0	204.3	304.0	194.5	0.0	4.7	0.0
2012	0.0	0.0	32.5	61.0	26.1	80.6	228.0	243.9	122.9	0.0	0.0	0.0
2013	0.0	0.0	77.0	89.1	73.4	111.5	179.6	242.4	142.5	20.6	0.0	0.2

Appendix Table 6: Akaki River Flow in each years

Year	**Average Monthly Flow in each year**											
	Jan	Feb	Mar	Apr	May	Jun	July	Aug	Sep	Oct	Nov	Dec
2000	0	0	0	0.075	0.142	0	2.296	25.769	2.304	0.018	0	0
2001	0	0	0	0.065	0.193	0.6	20.024	25.49	4.352	0	0	0
2002	0	0	0	0.086	0	0	4.538	6.615	1.425	0	0	0
2003	0	0	0	0	0	0	6.999	29.925	8.292	0	0	
2004	0	0	0	0	0	0	2.11	9.242	7.875	0	0	0
2005	0	0	0	0	0.356	0	3.741	16.977	3.179	0	0	0
2006	0	0	0.048	0.012	0.247	0.05	23.35	38.51	16.04	1.532	0.733	0.623
2007	0	0	0	0	0	0	1.967	40.267	5.988	0.7	0	0
2008	0	0	0	0	0.312	1.34	14.197	39.287	29.21	0.988	0.248	0.191
2009	0	0	0	0	0	0	3.926	11.89	4.744	0.062	0	0.019
2010	0	0.339	0	0.518	0.272	0.08	25.242	14.377	9.91	0	0	0
2011	0	0	0	0	0.241	0.27	7.479	35.791	4.995	0.759	0.791	0
2012	0.014	0	0.379	0.422	1.062	0.66	18.91	35.731	37.06	0.267	0	0.006
2013	0	0	2.772	1.694	4.068	2.45	31.622	37.912	34.13	4.455	1.336	0.705
2014	0	0.088	1.887	0.758	0.504	0.06	11.874	48.714	22.07	0.607	0.15	0.126
2015	0.12	0.128	0.135	0.032	2.705	4.43	38.991	56.82	16.76	4.167	0.809	0.472
2016	0.061	0.023	0.05	13.536	0.15	2.8	55.066	53.446	33.74	1.371	0	0

Appendix Table 7: Potato Water Requirement

Crop Water Requirements

ETo station: AKAKI | Crop: Potato

Rain station: AKAKI | Planting date: 12/01

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	2	Init	0.50	2.05	18.5	3.0	15.2
Jan	3	Init	0.50	2.10	23.2	3.9	19.2
Feb	1	Deve	0.53	2.30	23.0	3.7	19.3
Feb	2	Deve	0.73	3.23	32.3	3.9	28.4
Feb	3	Deve	0.93	4.24	33.9	8.1	25.9
Mar	1	Mid	1.12	5.24	52.4	13.3	39.1
Mar	2	Mid	1.16	5.62	56.2	17.3	38.8
Mar	3	Mid	1.16	5.50	60.5	18.6	41.8
Apr	1	Mid	1.16	5.38	53.8	20.3	33.5
Apr	2	Mid	1.16	5.26	52.6	22.2	30.3
Apr	3	Late	1.10	5.03	50.3	21.1	29.2
May	1	Late	0.97	4.54	45.4	19.1	26.2
May	2	Late	0.84	3.98	39.8	18.1	21.7
May	3	Late	0.76	3.36	3.4	1.8	3.4
					545.1	**174.5**	**372.1**

Appendix Table 8: Monthly Irrigation Water Requirement of Potato crops

Date	Day	Stage	Rain (mm)	Ks (fract.)	Eta (%)	Depl (%)	Net Irr (mm)	Deficit (mm)	Loss (mm)	Gr. Irr (mm)	Flow (l/s/ha)
12-Jan	1	Init	0	0.73	73	48	23.5	0	0	33.6	3.89
19-Jan	8	Init	0	1	100	28	15.3	0	0	21.8	0.36
27-Jan	16	Init	2	1	100	25	15.7	0	0	22.5	0.33
4-Feb	24	Init	0	1	100	27	18.7	0	0	26.8	0.39
12-Feb	32	Dev	0	1	100	28	21.4	0	0	30.5	0.44
19-Feb	39	Dev	0	1	100	28	22.7	0	0	32.4	0.54
26-Feb	46	Dev	0	1	100	30	26.4	0	0	37.7	0.62
6-Mar	54	Dev	0	1	100	34	32.7	0	0	46.8	0.68
12-Mar	60	Mid	0	1	100	34	32.2	0	0	46	0.89
19-Mar	67	Mid	0	1	100	31	29.9	0	0	42.7	0.71
28-Mar	76	Mid	0	1	100	30	29	0	0	41.4	0.53
5-Apr	84	Mid	0	1	100	33	32	0	0	45.7	0.66
12-Apr	91	Mid	0	1	100	33	32	0	0	45.7	0.76
20-Apr	99	Mid	0	1	100	31	29.4	0	0	42	0.61
2-May	111	End	0	1	100	39	37.4	0	0	53.5	0.52
21-May	End	End	0	1	0	47					

Appendix Table 9:Tomato Water Requirement

Crop Water Requirements

ETo station AKAKI | Crop Tomato

Rain station AKAKI | Planting date 12/01

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	2	Init	0.60	2.46	22.2	3.0	18.9
Jan	3	Init	0.60	2.53	27.8	3.9	23.9
Feb	1	Init	0.60	2.59	25.9	3.7	22.2
Feb	2	Deve	0.68	2.99	29.9	3.9	26.0
Feb	3	Deve	0.80	3.66	29.3	8.1	21.2
Mar	1	Deve	0.93	4.36	43.6	13.3	30.3
Mar	2	Deve	1.07	5.16	51.6	17.3	34.3
Mar	3	Mid	1.16	5.48	60.2	18.6	41.6
Apr	1	Mid	1.16	5.36	53.6	20.3	33.3
Apr	2	Mid	1.16	5.24	52.4	22.2	30.2
Apr	3	Mid	1.16	5.29	52.9	21.1	31.8
May	1	Late	1.15	5.37	53.7	19.1	34.6
May	2	Late	1.05	4.99	49.9	18.1	31.8
May	3	Late	0.93	4.08	44.9	19.6	25.4
Jun	1	Late	0.84	3.35	16.7	9.6	7.2
					614.7	201.8	412.5

Appendix Table 10: Monthly Irrigation Water Requirement of Tomato

Date	Day	Stage	Rain (mm)	Ks (fract.)	Eta (%)	Depl (%)	Net Irr (mm)	Deficit (mm)	Loss (mm)	Gr. Irr (mm)	Flow (l/s/ha)
12-Jan	1	Init	0	0.71	71	53	27.8	0	0	39.8	4.6
19-Jan	8	Init	0	0.99	100	34	23	0	0	32.8	0.54
28-Jan	17	Init	0	1	100	33	28.2	0	0	40.3	0.52
7-Feb	27	Init	1.8	1	100	30	32.7	0	0	46.6	0.54
19-Feb	39	Dev	0	1	100	33	43.6	0	0	62.3	0.6
8-Mar	56	Dev	0	1	100	37	62.3	0	0	88.9	0.61
29-Mar	77	Mid	0	1	100	42	83.9	0	0	119.9	0.66
25-Apr	104	Mid	0	1	100	42	83.5	0	0	119.2	0.51
22-May	131	End	0	1	100	46	91.7	0	0	131	0.56
5-Jun	End	End	0	1	0	15					

Appendix Table 11: Cabbage Water requirement

Crop Water Requirements

ETo station: AKAKI | Crop: CABBAGE Crucifers

Rain station: AKAKI | Planting date: 12/01

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	2	Init	0.70	2.87	25.9	3.0	22.6
Jan	3	Init	0.70	2.95	32.4	3.9	28.5
Feb	1	Init	0.70	3.02	30.2	3.7	26.5
Feb	2	Init	0.70	3.09	30.9	3.9	27.0
Feb	3	Deve	0.73	3.31	26.5	8.1	18.4
Mar	1	Deve	0.78	3.66	36.6	13.3	23.3
Mar	2	Deve	0.84	4.06	40.6	17.3	23.3
Mar	3	Deve	0.90	4.27	47.0	18.6	28.3
Apr	1	Deve	0.97	4.47	44.7	20.3	24.4
Apr	2	Deve	1.03	4.64	46.4	22.2	24.1
Apr	3	Mid	1.06	4.83	48.3	21.1	27.2
May	1	Mid	1.06	4.95	49.5	19.1	30.4
May	2	Mid	1.06	5.03	50.3	18.1	32.2
May	3	Mid	1.06	4.66	51.2	19.6	31.6
Jun	1	Mid	1.06	4.24	42.4	19.2	23.3
Jun	2	Late	1.02	3.74	37.4	19.3	18.1
Jun	3	Late	0.96	3.33	16.6	14.6	2.1
					657.0	**245.3**	**411.3**

Appendix Table 12: Cabbage Monthly Irrigation Water Requirement

Date	Day	Stage	Rain(mm)	Ks (fract.)	Eta (%)	Depl (%)	Net Irr (mm)	Deficit (mm)	Loss (mm)	Gr. Irr (mm)	Flow (l/s/ha)
12-Jan	1	Init	0	0.91	91	55	27.9	0	0	39.8	4.61
21-Jan	10	Init	0	1	100	48	26.4	0	0	37.7	0.48
31-Jan	20	Init	0	1	100	46	27.8	0	0	39.7	0.46
11-Feb	31	Init	0	1	100	49	32.2	0	0	46	0.48
22-Feb	42	Dev	0	1	100	47	33.2	0	0	47.5	0.5
9-Mar	57	Dev	0	1	100	47	36.6	0	0	52.3	0.4
25-Mar	73	Dev	0	1	100	45	39	0	0	55.7	0.4
10-Apr	89	Dev	0	1	100	46	43.2	0	0	61.7	0.45
30-Apr	109	Mid	0	1	100	49	48.9	0	0	69.9	0.4
16-May	125	Mid	0	1	100	49	49.2	0	0	70.2	0.51
31-May	140	Mid	0	1	100	49	49.5	0	0	70.7	0.55
21-Jun	161	End	0	1	100	46	46	0	0	65.7	0.36
25-Jun	End	End	0	1	0	7					

Appendix Table 13: Pepper water requirement

Crop Water Requirements

ETo station AKAKI | Crop Sweet Peppers

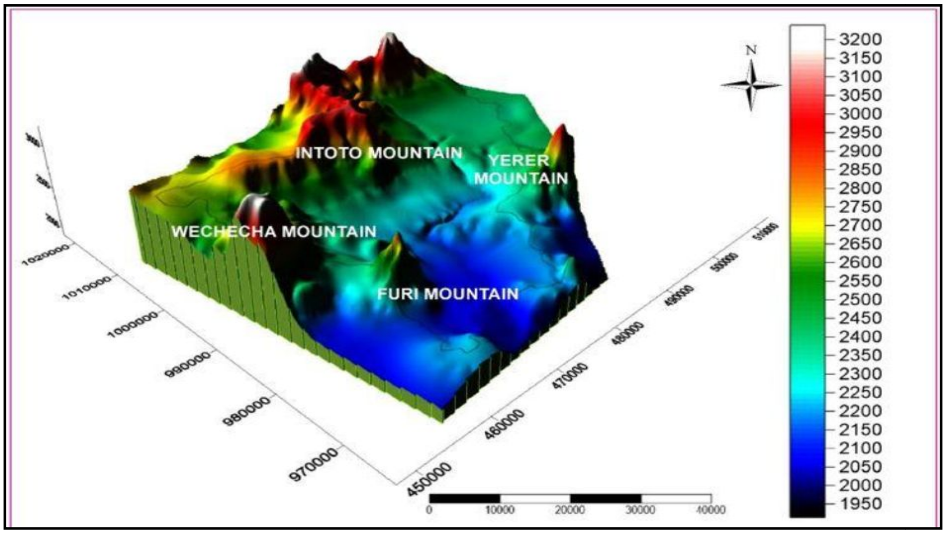
Rain station AKAKI | Planting date 12/01

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	2	Init	0.60	2.46	22.2	3.0	18.9
Jan	3	Init	0.60	2.53	27.8	3.9	23.9
Feb	1	Init	0.60	2.59	25.9	3.7	22.2
Feb	2	Deve	0.67	2.97	29.7	3.9	25.8
Feb	3	Deve	0.79	3.60	28.8	8.1	20.7
Mar	1	Deve	0.91	4.27	42.7	13.3	29.4
Mar	2	Mid	1.03	4.99	49.9	17.3	32.6
Mar	3	Mid	1.06	5.01	55.2	18.6	36.5
Apr	1	Mid	1.06	4.90	49.0	20.3	28.7
Apr	2	Mid	1.06	4.79	47.9	22.2	25.7
Apr	3	Late	1.05	4.81	48.1	21.1	27.0
May	1	Late	0.99	4.64	46.4	19.1	27.2
May	2	Late	0.93	4.44	26.6	10.8	17.6
					500.2	**165.5**	**336.2**

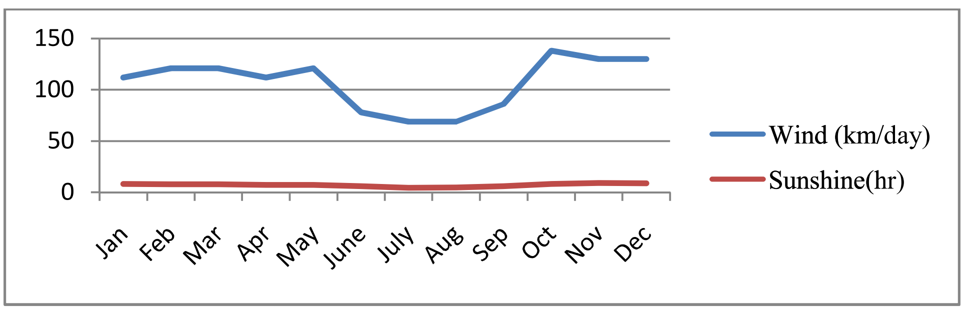
Appendix Table 14: Pepper Monthly Irrigation Water Requirement

Date	Day	Stage	Rain (mm)	Ks (fract.)	Eta (%)	Depl (%)	Net Irr (mm)	Deficit (mm)	Loss (mm)	Gr. Irr (mm)	Flow (l/s/ha)
12-Jan	1	Init	0	0.62	62	53	27.4	0	0	39.1	4.53
16-Jan	5	Init	0	1	100	23	13.2	0	0	18.8	0.54
20-Jan	9	Init	0	1	100	20	13.1	0	0	18.7	0.54
26-Jan	15	Init	0	0.99	100	24	18	0	0	25.7	0.5
1-Feb	21	Init	0	1	100	23	19.8	0	0	28.3	0.55
8-Feb	28	Init	0	1	100	20	19.8	0	0	28.3	0.47
15-Feb	35	Dev	0	1	100	21	23.5	0	0	33.5	0.55
24-Feb	44	Dev	0	1	100	24	29.9	0	0	42.8	0.55
9-Mar	57	Dev	0	1	100	30	44.1	0	0	63	0.56
22-Mar	70	Mid	0	1	100	32	50.7	0	0	72.4	0.64
6-Apr	85	Mid	0	1	100	33	52.8	0	0	75.5	0.58
22-Apr	101	Mid	0	1	100	32	51.9	0	0	74.2	0.54
16-May	End	End	0	1	0	40					

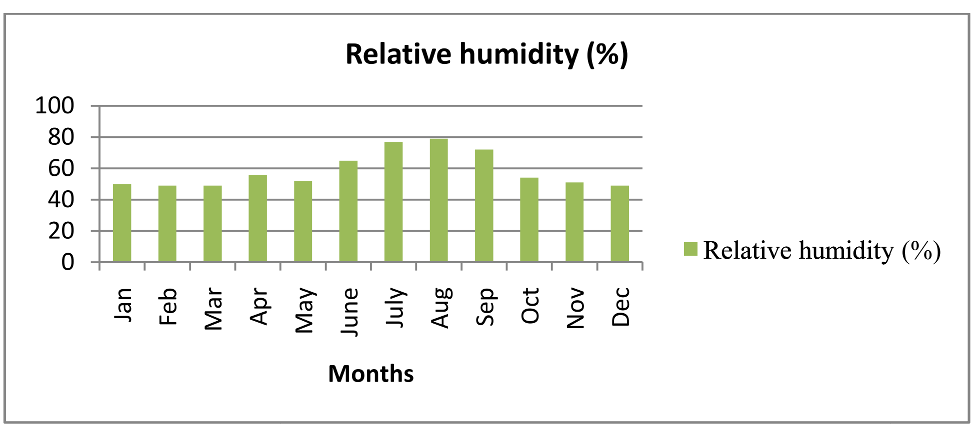
Appendix Figure 1: Physiographic map of Akaki catchment



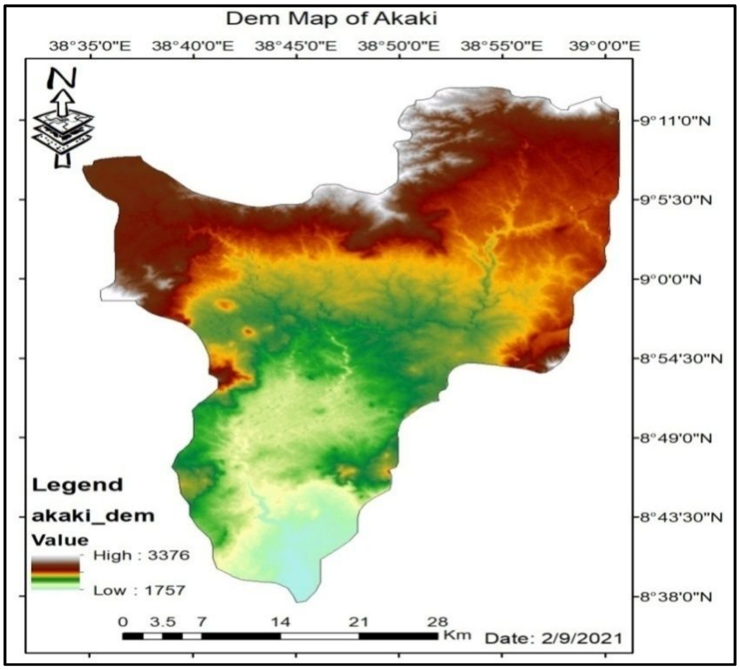
Appendix Figure 2: Average monthly Wind speed and Sunshine hours of the study area



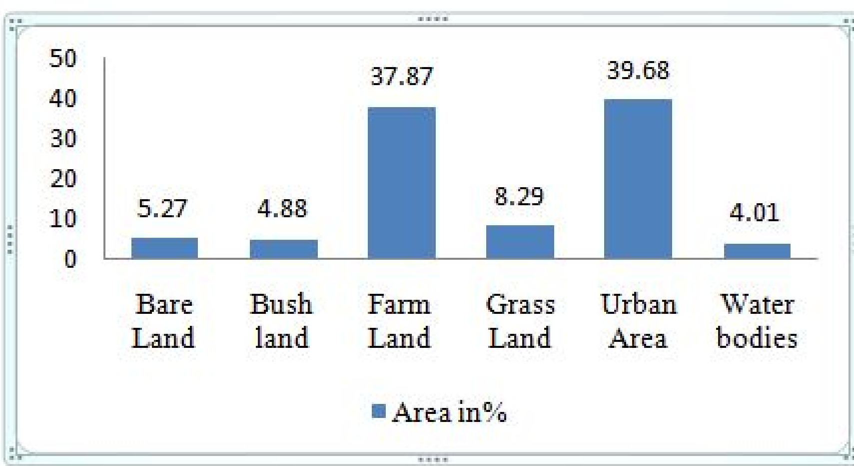
Appendix Figure 3: Average Relative humidity



Appendix Figure 4: DEM of the study area



Appendix Figure 5: Graphical Description of Land Use Land Cover of the Watershed.



Appendix Figure 6: Double Mass Curve For each Station