Land Suitability and Water Availability Evaluation for Surface Irrigation: The Case of Borta River Catchment, Western Oromia

Husen Siri Hasan

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

September, 2023

Adama, Ethiopia

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DECLARATION

I hereby declare that this Master Thesis entitled "**Land Suitability and Water Availability Evaluation for Surface Irrigation: The Case of Borta River Catchment, Western Oromia**" 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

Husen Siri Hasan	________________	______________
Name of student	Signature	Date

RECOMMENDATION

I, the advisor of this thesis, hereby certify that I have read the revised version of the thesis entitled "**Land Suitability and Water Availability Evaluation for Surface Irrigation: The Case of Borta River Catchment, Western Oromia**" prepared under my guidance by Husen Siri submitted in partial fulfillment of the requirements for the degree of Mater's of Science in Water Resource Engineering (Irrigation Engineering).

Therefore, I recommend the submission of revised version of the thesis to the department following the applicable procedures.

Mesfin Benti Tolera (Ph.D.)	____________________	__________________
Major Advisor	Signature	Date

APPROVAL SHEET FOR THESIS

I, the advisors of the thesis entitled **"Land Suitability and Water Availability Evaluation for Surface Irrigation: The Case of Borta River Catchment, Western Oromia"** and developed by **Husen Siri** hereby certify that the recommendation and suggestions made by the board of examiners are appropriately incorporated into the final version of the thesis.

Mesfin Benti Tolera (Ph.D.)	____________________	____________
Major Advisor	Signature	Date

We, the undersigned, members of the Board of Examiners of the thesis by **Husen Siri Hasan** have read and evaluated the thesis entitled "**Land Suitability and Water Availability Evaluation for Surface Irrigation: The Case of Borta River Catchment, Western Oromia"** 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)**

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TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

ACRONYMS AND ABBREVIATIONS

AHP	Analytical hierarchy process
BMC	Billion-meter cube
CR	consistency ratio
DEM	Digital Elevation Model
DMC	Double Mass Curve
ERDAS	Earth Resources data analysis System
ETc	Crop Evapo-transpiration
ETo	Reference Crop Evapo-transpiration
FAO	Food and Agriculture Organization
GDEM	Global Digital Elevation Model
GIS	Geographic Information System
GLCN	Global Land Cover Network
GPS	Geographic Positioning System
IWIM	International Water Institute Management
LULC	Land Use Land Cover
MCDM	Multi–Criteria Decision Making
MoWe	Ministry of Water and Energy
NASA	National Aeronautics and Space Administration
NMA	National Meteorology Agency of Ethiopia
PCM	Pairwise comparison matrix
SRTM	Shuttle radar topographic mission
USGS	United States Geological Survey

ABSTRACT

Surface irrigation is crucial for enhancing agricultural productivity and food security in Ethiopia. However, optimal utilization of land and water resources is required for sustainable irrigation development. This study evaluated land suitability and water availability for surface irrigation in the Borta River catchment, western Oromia. The methodology combined geospatial analysis using ArcGIS, field soil sampling, and irrigation water requirements estimation through CROPWAT model. The study utilized GIS-based multi-criteria evaluation and weighted overlay analysis to assess the suitability of land considering slope, soil properties, land use/land cover, and proximity to water sources as key parameters. Soil samples from representative pits were tested for pH, electrical conductivity and calcium carbonate content. Results showed that the chemical properties of the soil were not limiting factor for surface irrigation in the catchment, since the test value fell in the range of highly suitable to moderately suitable. The slope classification results showed that 7.1 % of the land is highly to moderately suitable for surface irrigation. Soil texture of the study area was clay and clay loam and revealed as suitable textures. Land cover evaluation revealed 20% of land under crops or agricultural land as highly suitable and a very small portion, accounting for only 0.1% and totaling 12.92 hectares, was identified as unsuitable for surface irrigation development. Regarding water availability, the river had a mean annual flow of 23.8 m^3/s, with a minimum flow 4.5 m^3/s during the dry season. After 25% released for ecological purpose annual average flow of 17.848 m^3/s founded. However, during selected irrigation season (January to May) it is found to be 3.5 m^3/s flow were available for irrigation purpose which can irrigate an area of 3587 ha out of suitable areas, this shows irrigation potential of the catchment was about 49.5% of overall suitable command area. Gross irrigation requirements were computed for dominant crops - maize, onion, and potato. Comparative analysis of water demand was (7.0035 m^3/s) and Available flow was 3.5 m^3/s. The findings clearly indicated that the demand for irrigation water exceeds the available stream flows. To address this water scarcity issue, it is advisable to implement advanced irrigation water management techniques, leverage technology to enhance water use efficiency, construct water harvesting structures, and investigate groundwater sources to fully unlock the identified irrigation potential within the study area. The integrated methodology has offered a comprehensive evaluation of land suitability and the availability of water resources for the planning of surface irrigation. These significant findings will serve as invaluable insights for stakeholders, facilitating sustainable agricultural water management within the Borta River catchment area.

Key words: water availability, GIS, land suitability, surface irrigation, crop water requirement**.**

CHAPTER ONE

INTRODUCTION

1.1. Background

Land and water are the two most precious and important resources needed for irrigation, sustaining life, social and economic advancement of all country in the world. Due to the exponential growth of the world population, these resources are decreasing and, as a result, the need for land and water has increased enormously. However, knowledge-based management of land and water resources is lacking in many parts of the world. The first and most important information to enable better decision-making and management is understanding the temporal and spatial availability of land and water resources (Gonfa et al., 2021)

Ethiopia has around 122-124 BCM of annual surface runoff from 12 river basins, approximately 30-40 BCM of annual groundwater flow, and approximately 70 BCM from natural and constructed reservoirs with vast cultivable land (30 to 70 Mha) (Berhanu & Hatiye, 2020). However, the current extent of cultivated land stands at around 15 million hectares, representing roughly one-third of the available potential. Moreover, the existing irrigation systems in the country encompass approximately 640,000 hectares. But, the research indicates that the overall potential for irrigable land in Ethiopia is estimated to be 5.3 million hectares(S. Awulachew, 2010). This includes 3.7 million hectares from gravity-fed surface water, along with an additional 1.1 million hectares from groundwater sources and 0.5 million hectares from rainwater collection(S. Awulachew, 2010). As a result , about 10 - 12% of the total irrigable potential are currently under production using traditional and modern irrigation schemes (Belachew Muche Mekonen, 2022).

The implementation of a series of five-year plans over three consecutive terms in Ethiopia has led to a significant and accelerated development trend in irrigation(Gebul, 2021). These plans include the Development and Poverty Reduction Program (SDPRP) from 2002/03 to 2004/05, the Plan for Accelerated and Sustained Development to End Poverty (PASDEP) from 2005/06 to 2009/10, and the Growth and Transformation Plans (GTP) - GTP I from 2010/11 to 2014/15 and GTP II from 2015/16 to 2019/20(Gebul, 2021).

Notably, during the latter two plan periods (GTP I and GTP II) medium and large-scale irrigation development has registered an average annual expansion of 20% and 22% respectively and reached an estimated area of 539,736 hectare in the year 2019. Small-scale irrigation practice to supplement rain-fed agriculture has had a long history in Ethiopia and area under small-scale irrigation in this country is around 2.528 million ha at the end of 2019 with the annual expansion rate of 35% (Gebul, 2021)

But mostly, Ethiopia relies on rain fed agriculture, which is extremely sensitive to high levels of fluctuation and unreliability (Meaza et al., 2018) that resulted in persistent failures of crops, which have had an adverse effect on crop production and food availability for the nation's fast expanding population. The dry plains of Ethiopia heavily rely on rain-fed agriculture, and the unpredictable rainfall makes finding other strategies for boosting agricultural output and efficiency necessary (Bedane *et al.,* 2022). Traditional rain-fed agricultural methods must be combined with irrigated agriculture in order to sustainably feed Ethiopia's population. Due to its capacity to stabilize supply and output of fruits and vegetables and to double crop yields, irrigated agriculture is becoming increasingly crucial for meeting society's demands. The government is still concerned with irrigation-based wheat production today in order to stabilize the supply as well as to generate foreign revenue. These are achievable with the right growing conditions and irrigation. Surface irrigation is an application of water to fields via gravitational flow, either flooding the whole area (basin irrigation) or feeding it through a small channel (furrow) or band of land (borders). It's the earliest and most widely utilized way of applying water to crops. Surface irrigation has various advantages for less trained and poor growers. Even though local farmers have little knowledge of how to use and upkeep the system, surface irrigation is used by over 90 percent of the world (Yadeta *et al.,* 2022). Proper assessment of both land and water assets in irrigation developments is required for improved resource usage, which helps to maximize and sustain land production.

Water allocation for surface-irrigation systems necessitates knowledge of site suitability, accessibility of water, as well as the water needed by crops in irrigable locations throughout time and space. Assessing the possibility of water-related assets and areas that are suitable for irrigation assists in increasing water and agricultural production as well as economical land management. Evaluating suitable land under surface irrigation necessitates an assessment of various criteria affecting agriculture with irrigation, such as slope, soil properties, land use/cover, and distance to water supplies. As a consequence, such characteristics are analyzed in a GIS, or geographic information system, utilizing a multiple-criteria evaluation (MCE) (da S. Alves et al., 2021)

The multi-criteria assessment (MCE) approach is commonly used for determining land suitability. Furthermore, the Analytic hierarchy process (AHP) created by Saaty in 1970 and it was widely used for mulita-criteria decision making of land suitability across diverse fields. It calculates the weight of relevance for different land uses using pairwise comparisons of various factors depending on how important they are. The analytic hierarchy process was extensively used as a multi-criterion decision-making approach for handling a wide range of issues based on complicated factors across many levels where interactions among factors is a common characteristic. The weighted overlay analysis approach (WOA) in conjunction with the analytic hierarchy procedure generates a highly satisfying result for assessing the site appropriateness of agricultural land use (da S. Alves et al., 2021)

There are a limited studies evaluating both land and water resources of the western Oromia region. Understanding the area's potential for land and water resources is crucial for improved administration and usage. The suitability of the land in the Borta river catchment will be assessed using weighted overlay analysis (WOA) approaches based on AHP and GIS since no study has been conducted concerning weighting the land resources for irrigation potential. Through a comprehensive analysis incorporating literature reviews, field research, and guidance from the Food and Agriculture Organization (FAO), various standards were derived for evaluating irrigation land suitability. The outcome serves as a benchmark for scholars and decision-makers when it comes to irrigation-related land use management and development.

1.2. Statement of the Problem

Evidently, the primary driver of increased irrigated agricultural production in Asia has been the expansion into new areas, including those with less favorable production conditions, alongside efforts to boost production per unit of land through intensification However, in numerous African nations, such as Ethiopia, there remains untapped irrigation potential that must be harnessed to enhance agricultural output, thereby ensuring food security and alleviating poverty(Gebul, 2021). Ethiopia has tremendous potential for expanding irrigation to enhance agricultural productivity and food security. As a result , about 10 - 12% of the total irrigable potential are currently under production using traditional and modern irrigation schemes (Belachew Muche Mekonin, 2022). The agricultural system heavily dependent on rain fed farming, making it highly vulnerable to recurrent droughts and rainfall variability. This over-reliance on rain fed agriculture leads to food insecurity, poverty and vulnerability to climate shocks(Gebul, 2021). To achieve sustainable food production and rural livelihoods, there is an urgent need to increase irrigation infrastructure by optimally utilizing land and water resources(Wakjira *et al.,* 2021). While Ethiopia has abundant water resources, comprehensive assessment of land suitability and water availability is lacking, especially at the local level, hindering the development of tailored irrigation plans (Kassie et al., 2022).

A variety of investigations, largely based on master plan studies and official publications, have been carried out to assess the Ethiopian irrigation potential (Awulachew et al., 2007; IWMI, 2007; Awulachew et al., 2010; FAO, 2016). According to IWMI (2007), the total estimated irrigable land in Baro Akobo river basin is 1,019,523 ha. However, this river basin consists of various tributaries, streams, and partially irrigable land, with most agricultural practices relying on rainfed systems. The study area is situated within the Baro Akobo river basin, specifically in the western part of the Oromia region known as Kellem Wollega zone, with Dambi Dollo as its capital town. In Borta River catchment, agriculture predominantly relies on rainfall due to limited feasible land use planning and management. The lack of irrigation makes agricultural productivity and food security unreliable. It results in low crop yields, household food shortages and poverty among residents who rely on livelihood agriculture.

Limited research has been conducted on assessing land suitability for surface irrigation in the Borta River catchment area, with a particular focus on factors such as slope, soil properties, land use/land cover, and proximity to water sources. Furthermore, there is a notable absence of studies that have systematically gathered data on surface water resources within the region and their compatibility with agricultural irrigation demands.

In the Borta River catchment area, an investigation into the suitability of land for surface irrigation remains a relatively unexplored field of study. Factors such as slope, soil characteristics, land use and land cover patterns, and the proximity of land parcels to available water sources have not been comprehensively analyzed. Moreover, there is a critical gap in research when it comes to quantifying and assessing the surface water resources in the region. Adequate information regarding the availability, distribution, and seasonal variations of surface water sources, which could potentially be harnessed for agricultural irrigation, has yet to be systematically collected and analyzed. Additionally, the crucial step of aligning the available surface water resources with the varying water demands of the agricultural sector has not been addressed. This requires a nuanced understanding of the water needs of different crops, as well as an evaluation of the feasibility of utilizing surface water for irrigation purposes.

The purpose of this study was to evaluate land suitability for surface irrigation through GIS-based multi-criteria analysis incorporating slope, soil characteristics, land use/cover and distance to water sources; to quantify the surface water availability during low flow periods based on hydrological data and to provide key insights for sustainable irrigation development.

1.3. General Objective

The main objective of this study was to evaluate land suitability and water availability for surface irrigation in Borta river catchment.

1.3.1. Specific Objectives

The following three specific objectives were formulated to achieve the general objective of the study.

- To asses suitable land for surface irrigation development.
- To estimate water resources that can be used for surface irrigation.
- To determine irrigable area

1.4. Research Questions

The following three research questions were developed to address the specific objectives of the study:

- What is the extent of land that is suitable for the development of surface irrigation?
- What is the quantity of water accessible for surface irrigation?
- Does the available water adequately irrigate extent of irrigable area?

1.5. Significance of the Study

The most popular strategy for guaranteeing sustainable agriculture is irrigation. However, agriculture still depends on rain fed and supports around 85% of the population in Ethiopia. The agricultural sectors of Ethiopia experience the most unreliable rainfall regime and the distribution of rainfall is seasonal and unpredictable. If the country's population's irrigation potential is recognized, irrigation will considerably improve food security, reduce poverty, and the quality of life for rural residents in particular (Hordofa et al., 2008). Planning and managing agriculture must take into account the suitability of the soil and the availability of water for surface irrigation. It aids in determining whether the land is suitable for surface irrigation.

To determine whether regions are ideal for irrigation, factors including soil characteristics, slope, LULC, and proximity to water sources are taken into account. By assessing the suitability of the land, farmers and land managers may discover locations that are suitable for crop production and avoid regions where irrigation may not be feasible or advantageous. Additionally, surface irrigation depends on availability of water for irrigation. Assessing water availability is essential for determining the amount of water resources present in a specific region. This data plays a vital role in developing irrigation systems and formulating strategies for water allocation and planning(Tolera et al., 2023).

By understanding water availability, stakeholders can make efficient use of water resources, preventing overexploitation and ensuring sustainable irrigation practices. It also contributes to informed crop selection decisions. Different crops have varying water and soil requirements. Evaluating land suitability helps match crops to the specific characteristics of the land, ensuring optimal crop growth and productivity. Additionally, by considering water availability, farmers can select crops that align with the available water resources, preventing water stress and crop failure(Levidow et al., 2014).

Generally, the goal of land suitability analysis is to direct ideas on how to utilize land in a manner that maximizes the productive potential of the areas land resources for human life while protecting the same for future generations to inherit (FAO. (1976). by making informed decisions based on these evaluations, stakeholders can promote sustainable and productive agriculture while ensuring the long-term viability of water and land resources.

1.6. Scope of the Study

Despite there are many issues in the study area, the main focus of this study is on evaluating the accessibility of surface water and the potentials of irrigable land with consideration of slope, soil physical characteristics (depth, drainage, and texture), soil chemical characteristics (EC, Ph, and $CaCo_3$ content), LULC, and distance to water source to determine suitability of land for surface irrigation, and assess available surface water to compare with irrigation water requirements. However, this study did not evaluate the quality of the irrigation water, the depth to ground water or potential of the groundwater in the study area due to budgetary limitations and a lack of data.

1.7. Organization of the Research

The thesis is structured into five chapters, each addressing specific aspects of the research.

Chapter one: Serves as a general introduction, encompassing the research's background, problem statement, research objectives; significance of the study and the scope of the study.

Chapter two: It focuses on conducted comprehensive literature review. This chapter presents relevant works and studies that are closely related to this research.

Chapter three: Detailed information about the chosen study area is provided and also includes description of the methodology employed in the research and the materials or data utilized during the study.

Chapter four: Shows the findings obtained from the research work. It encompasses a thorough presentation of the results, and subsequent discussions are conducted to analyze and interpret these findings in relation to the research objectives.

Chapter five: Encapsulates the conclusion drawn from the obtained results. Additionally, recommendations according to the results of the study are included in this chapter. The conclusion provides a comprehensive summary of the study's outcomes and their implications for the research field.

CHAPTER TWO

LITERATURE REVIEW

2.1. Irrigation Potential

Irrigation potential refers to the extent of land that can potentially be irrigated. It is influenced by various physical characteristics of the land, like its slope, land use and land cover, soil type, and access to water sources. Additionally, it also considers the water requirements for irrigation that would be needed for specific crops and climatic factors. Evaluating irrigation potential helps determine if land is suitable for developing irrigation systems. The idea of irrigation potential also takes into account the feasibility and economic viability of irrigated fields in nations like Ethiopia that have ample water resources (FAO, 2015)

2.2. Ethiopian Irrigation Potential

Ethiopia has a total land area of 112 million hectares, of which 99.3% (111 million hectares) is land area, while 0.7% is water. The country has a significant amount of potentially cultivable land, estimated between 30-70 Mha (Berhanu & Hatiye, 2020). Ethiopia has an irrigation potential of 5.3 million ha (Mha). However, about 10 - 12% of the total irrigable potential are currently under production using traditional and modern irrigation schemes (Belachew M. Mekonin, 2022). With 2.528 million hectares being small-scale irrigation and the remaining 539,726 hectares being medium or large-scale irrigation projects. As a result, a sizable amount of Ethiopia's arable land is still unirrigated. For Ethiopia, improving irrigation methods is crucial to address issues like population pressures, soil and land degradation, variable climatic conditions, and insufficient agricultural production. Developing agricultural water program is vital for the survival and income of the smallholder farmers in the country. Since irrigation can help farmers increase yields, expand crop variety, and prolong their agricultural seasons, an agricultural water program is key for smallholder livelihood and earnings in Ethiopia (Awulachew, 2010; Gebul, 2021).

The nation possesses abundant natural resources, including water that might be used to increase irrigated agriculture. Twelve main river basins hydrologically divide the nation. Eight of the basins are rivers, one is a lake, and the final three are dry basins. Tekeze, Baro-akobo, Abbay and Omo River basins comprise 80–90% of the nation's total surface water supply. The second- biggest basin in the country is the Abbay basin. According to (S. B. Awulachew et al., 2010), Our country's 12 river basins contribute between 2.6 and 13.5

billion cubic meters of water and have an average surface runoff volume of about 125 billion cubic meters.

2.3. Irrigation Development in Oromia

Oromia stands out as the most extensive region in terms of both population and land area, encompassing a vast geographical expanse of approximately 355,000 square kilometers. The region's topography is marked by diverse and impressive features, including elevated and rugged mountain ranges that are intersected by the expansive East African Rift Valley. Oromia boasts a substantial estimated population of 26,553,000 individuals, with a majority of 23,030,000 (approximately 86.7 percent) residing in rural areas, while 3,523,000 (about 13.3 percent) live in urban centers (CSA, 2005).

Within the Oromia regional state, there has been a concerted effort to advance irrigation development. Currently, the region hosts 199 irrigation schemes, which collectively cover an irrigated area spanning 33,765.19 hectares. This area is distributed among small-scale (4,627.29 hectares), medium-scale (2,800.01 hectares), and large-scale (26,338 hectares) schemes, benefiting a total of 37,479 people(S. Awulachew, 2010).

Various government entities are actively engaged in irrigation development in Oromia, including the Oromia Irrigation Development Authority (OIDA), the Bureau of Agriculture (BoA), and the Bureau of Water. Additionally, multiple non-governmental organizations and donors are involved in these efforts, such as the African Development Bank (AfDB), the French Agency for Development (AFD), ADF, ESRDF, the European Economic Commission (EEC), IFAD, the Japan International Cooperation Agency (JICA), and the Oromo Self-help initiative (S. Awulachew, 2010).

2.4. Irrigation Potential in Baro Akobo River Basin

The Baro Akobo river basin, which spans an area of 75,912 square kilometers, extends across parts of the Benishangul-Gumz, Gambella, Oromia, and SNNPR regions. This basin exhibits a range of elevations, with its lowest point at 390 meters and its highest point at 3,244 meters. The collective annual flow from the river basins within this region is estimated to be approximately 23.6 billion cubic meters(S. B. Awulachew et al., 2007)

Within the Baro-Akobo basin, there are twenty-two potential large-scale irrigation sites that have been identified, offering an estimated irrigable area of 1,019,523 hectares (refer to Appendix, table A21). This makes the Baro-Akobo basin the second most promising basin in terms of its irrigation potential, following closely behind the Genale Dawa basin.

The population in this basin predominantly resides in the sparsely populated lowland areas, creating favorable conditions for the development of water resources. Due to periodic flooding, these lowlands have primarily been utilized as grazing pastures. As a result, significant water resources development in these areas has been limited up to the present time. In the basin, 22 big prospective irrigation areas have been found. In terms of potential for irrigation, this basin is second next to Genale Dawa (S. B. Awulachew et al., 2007)

Table 2.1: Large scale irrigation in Baro-Akobo River basin

S/No	Project description	Sub basin	River	Potential(ha)
1	Baro RB, Itang Dam, Gravity	Lower basin	Baro	66,581
2	Baro RB, Itang River, Pumping	Lower basin	Baro	41,267
3	Baro RB, Gambela Dam	Lower basin	Baro	17,335
4	Baro, RB, River Pumping, gravity Conveyance	Lower basin	Baro	17,338
5	Baro, LB, Itang Dam, Gravity Lower basin	Lower basin	Baro	61,900
6	Baro, LB, Pumping		Baro	15,832
7	Baro, LB, Gambela Dam		Baro	57,018
8	Baro, LB, River pumping		Baro	57018
9	Alwero project, Abobo, Dam Gravity		Alwero	13,600
10	Alwero, Chiru Dam		Alwero	17,054
11	Gilo, RB, Gilo-1 Dam		Gilo	81,346
12	Gilo, LB, River pumping		Gilo	79,652
13	System 2+Relift Station	Lower basin	Baro	57,495
14	System 3+ Low lift	Lower basin	Baro	41,016
15	System 3A+ High lift	Lower basin	Baro	67740
16	System 4+ Low Lift	Lower basin	Baro	41,016
17	System 4A+High lift	Lower basin	Baro	67,740
18	Alwero, RB Dumbong		Alwero	23192
19	Alwero, Chiru and Dumbong Dams		Alwero	34,665
20	Gilo, LB, River pumping		Gilo	65,538
21	Gilo, LB, Gilo 2 Dam		Gilo	33,855
22	Gilo, RB, Gilo 2 Dam		Gilo	61,325

(Source: IWMI, 2007, appendix A21).

2.5. Evaluation Factors for Irrigation Land Suitability

A land unit's suitability is determined by how well its characteristics match the requirements for a particular land use. An area of land can only be considered suitable for a certain use if it possesses the appropriate qualities. Land suitability assessment evaluates how suitable an area of land is for a defined use, considering both its current state and potential future improvements. The process of land suitability classification involves assessing and categorizing specific land areas based on their suitability for intended uses. The goal is to appraise and group land units according to their compatibility with certain purposes (FAO , 1976).

Land evaluation primarily involves analyzing data about the land, including soil, climate, and vegetation, to identify optimal alternatives for land use. When assessing land suitability for irrigation, key emphasis is placed on the physical soil properties, access to water sources, and terrain factors relevant to irrigation methods (FAO, 2007). Land cover and use types are also considered as restrictive factors in evaluating the appropriateness of land for irrigation (Shiferaw, 2007). According to FAO guidelines on land evaluation (FAO, 1976), the suitability of these factors for surface irrigation and specific land uses can be classified into the following suitability classes.

2.5.1. Order S – Suitability classification

The classes under this order are:

- ✓ **S1 (Highly Suitable**) - Land that has no significant limitations for the sustained application of a given use.
- ✓ **S2 (Moderately Suitable) -** Land that has moderate limitations that collectively may be somewhat severe for the sustained application of a given use.
- ✓ **S3 (Marginally Suitable)** - Land that has severe limitations that will restrict productivity or benefits for the sustained application of a given use.

2.5.2. Order N – Suitability classification

- ✓ **N1 (Currently Not suitable):** Land possesses constraints that might be overcome in the future, but they are not currently remediable using the available knowledge and resources at a reasonable expense.
- ✓ **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(FAO, 1976) .

2.5.3. Land slope analysis

The slope of a surface is its inclination or gradient, which is sometimes expressed as a percentage. Slope plays a crucial role in the development and upkeep of soil because of its effects on runoff, drainage, erosion, and the choice of irrigation methods. The choice of irrigation systems is significantly influenced by the slope of the ground. Surfaces with slopes lower than 2% are extremely suited for surface irrigation, according to the FAO's standard recommendations for determining slope gradient. Conversely, slopes greater than 8% are often discouraged (*FAO, 1999).*

2.5.4. Soil

When evaluating soils for irrigation, one must consider enduring characteristics that cannot be altered or changed. These characteristics encompass factors like depth, drainage, salinity, texture, and alkalinity (AS Fasina, 2008). While it is possible to mitigate salinity and alkalinity issues through soil amendments or management techniques, they are still regarded as constraints when assessing the suitability of soils for irrigation (*FAO, 1997*). As a result, certain types of soil that may be considered inappropriate for surface irrigation might still be acceptable for other types of irrigation as well as for particular land-use objectives.

Soil texture

Soil texture refers to the proportion of different sized particles that make up the soil. It can be classified into three main categories based on the particle size; clay, silt, and sand. Soil texture plays a crucial role in determining how quickly water can penetrate it. If the capacity for water infiltration is significantly higher than the subsoil's permeability, the basic intake rate of the soil will be greatly influenced by the permeability. According to (*FAO, (1991*), assessing the infiltration rate is important because it impacts decisions on irrigation techniques, scheduling, layouts, economics, and appropriate crops for the site. The rate of water infiltration into the soil profile is a key consideration for irrigation planning and practices.

Soil depth

The term "soil depth" describes how thick the soil is. It gives the plant nutrition, water, and structural support. When calculating the quantity of water that a particular soil profile can contain, other important aspects to take into account are soil depth, soil layering, and depth to an estimated water table (Yarahmadi & Vekerdy, 2003).

Soil drainage

When deciding whether or not an area of land is appropriate for irrigation, the assessment of soil drainage qualities should be given major consideration since it effects soil quality, nutrients, and the soil's capacity to store water, which affects soil moisture levels and crop water (Hussien et al., 2019). The drainage ability of soil controls the movement of water and salts through the soil profile, which is critical. If salt accumulates without continuous leaching, it can reach levels that are detrimental to the landscape and vegetation. In the evaluation of land suitability, well-drained soil is highly favorable due to its abundance of nutrients, effective retention capacity for nutrients, and the ease with which water can penetrate it. In contrast, poorly drained, imperfectly drained or excessively drained soils are only marginally suitable since they may not store adequate water within the soil particles. Inadequate drainage leads to poor soil conditions for irrigation.

2.5.5. Land Cover/ Use

While often used interchangeably, land cover and land use have distinct differences. According to the *(GLCN, 2006)*, land cover refers to the observable physical material on the earth's surface, whether natural vegetation, human structures, water, ice, rock or sand. It can be seen on the ground or through remote sensing. In contrast, land use involves human activities and actions to produce goods and services within the environment.

A particular land use may occur on multiple land cover types, and one area of land cover can have several land uses.

Along with economic analysis, these land cover and use classifications provide the basis for assessing potential agricultural land's suitability for irrigation. The alignment of current land use and cover with topography and soils is used to determine suitability classes for irrigation. This helps identify suitable areas for potential agricultural expansion. This approach aids in identifying suitable areas for prospective additional agricultural production (Boonyanuphap et al., 2004).

2.6. Geographic Information System (GIS) Technology an Overview

Geographic Information System (GIS) is a computer-based tool used to analyze, capture, store, retrieve and display spatial data within an organization. It combines information obtained through remote sensing and other methods to create a comprehensive system for managing and planning. The information within a GIS can be presented in two primary formats: maps and tables, providing the necessary information for users. The main goal of GIS is effective geographical data management. The structure of the data can be thought of as stacked "floating" maps with identical registrations, allowing users to view across layers. All GIS solutions require hardware and software components for entering, storing, processing and presenting computerized maps.

GIS systems have three key functional areas: computer mapping, spatial database management, and cartographic modeling (Stighafian, 1996). This technology plays a crucial role in managing and analyzing spatial data in various domains, including agriculture and water resources. In the context of these fields, GIS technology helps capture, store, manipulate, analyze, and visualize geospatial data, enabling better decision-making and resource management.

2.6.1. Watershed delineation

A watershed is the defined area of land or drainage basin from which water naturally flows into a common outlet. In simple terms, a watershed collects rainfall and directs it through channels and gullies until it reaches a single point of discharge. The process of delineating a watershed involves determining its boundary, typically identified by the highest points or ridgelines. Geographic Information Systems (GIS) utilize Digital Elevation Models (DEMs) as input data to define watershed boundaries by using hydrology tools in ArcGIS spatial analysis (Di Luzio et al., 2004) ridgelines. Geographic Information Systems (GIS) utilize Digital Elevation Models (DEMs) as input data to define watershed boundaries by using hydrology tools in ArcGIS spatial analysis (Di Luzio et al., 2004)

2.6.2. Mapping

The main uses of GIS are to map geographic locations, carry out editing tasks, and facilitate map-based searches and analysis (Campbell, 1984). A key component of GIS operations is the use of maps as the user interface for interacting with geographic information. Through layers and other components, the map creates a visual representation of geographic data. These elements include the data frame, which has layers for each area, as well as a scale bar, a north arrow, a title, illustrative text, and a caption outlining the symbols.

2.6.3. Multi–Criteria Decision Making (MCDM)

Multi-Criteria Decision Making (MCDM) models are useful tools for evaluating and making decisions by taking into account a number of different alternatives and choosing the best criteria. These are intended to handle decision-making issues involving several criteria and involve the broader subject of operations research. According to (Sorooshian & Dodangeh, 2013), there are two main types of MCDM: Multi-Objective Decision Methods (MODM) and Multi-Attribute Decision Methods (MADM). Within MADM, approaches like Analytical Hierarchy Process (AHP), Simple Additive Weighting (SAW), and Ordered Weighted Averages (OWA) are used (Azizi Khalkheili & Zamani, 2009). Making decisions incorporating numerous factors can be complicated, but by using MADM approaches, decision-makers can navigate these challenges and make better informed and logical decisions.

AHP (Analytic Hierarchy Process)

The Analytical Hierarchy Process (AHP) was first introduced by Saaty in the 1970s. As described by (Azizi Khalkheili & Zamani, 2009), AHP is a ranking technique used in group decision-making across many industries, including agriculture. Ranking and analyzing difficult decision issues are good uses for the AHP approach. It is well-suited for ranking and analyzing complex decision problems. AHP is one of the best and simplest methods under MCDM due to its ease of use, ability to check and remove inconsistencies between alternatives. (Azizi Khalkheili & Zamani, 2009) strongly recommend AHP for researchers and professionals facing multi-criteria decision problems with several sub-criteria and alternatives. AHP uses principal eigenvectors and eigenvalues to generate ratio scales and consistency index. It aims to prioritize selection criteria into more and less important groups. Although some critique AHP benefits (Soroshian, 2015), it is a straightforward strategy that focuses on peer comparisons and is appropriate for assessing both qualitative and quantitative analysis (Zamani & Yousefi, 2013).

2.6.4. Weighted Overlay Analysis

The weighted overlay technique combines multiple diverse inputs into a single analysis using a common scale of values. In order to solve geographic challenges, GIS is frequently used to analyze a wide range of variables. For example, weighing factors like land cover, slope, soil, and distance from water is needed to determine the best site for irrigation (Yang, Yi D.H. G, 2003).

Weighted overlay uses a scale of 1-9 to rank the importance of different factor values. A value of 1 represents the least suitable evaluation factor, while 9 is the most suitable factor. Weighted overlay only accepts integer raster inputs, such as raster's of land cover/use, soil types, slope, and Euclidean distance outputs to identify suitable irrigation land. Euclidean distance measures the straight-line distance from the center of the source cell to surrounding cells (Malczewski, 2010).

2.7. Water Availability Assessment

The possibility of irrigation practice or growth in one location is not guaranteed by the presence of land resources alone. The availability of water resources must also be evaluated in order to determine whether irrigation development can be carried out using various methods. Because it's essential to have a sufficient water supply for irrigation. A lack of water during any period of the irrigation season will have a detrimental effect on crop output, reduce profits, and cause some of the investment to be lost (*FAO, 2001*). As a result, the assessment of land suitability for irrigation depends upon the amount and variation in seasons of water supply throughout the year (*FAO,1985)*).

When thinking about increasing its use, it is crucial to assess the amount of water available for irrigation and determine the most affordable areas for water transportation. To enable gravity-based irrigation across the entire field, it is desirable to place the water supply above the command area wherever possible. Additionally, having the water source close to the center of the irrigated area reduces the need for lengthy pipelines and delivery channels. As a result, it is advantageous to minimize the distance between water sources and the command area and ensure that rivers are nearby in order to maximize the conveyance system(A. Mekonnen et al., 2020)

2.7.1. Precipitation Data Analysis

One of the most crucial elements of the water source is precipitation. The amount of rain and other types of precipitation is gauged and given in millimeters (*WMO), 2008)* . Around 85% of cropland and 95% of all agricultural area worldwide rely entirely on precipitation as their sole source of water for the cultivation of crops(Burke & World Resources Institute., 2001).

I. Missing data analysis

Changes in observational procedure and incomplete records can disrupt both consistency and continuity. These disruptions can range from short periods of one or two days to long spans of several decades. Methods employed for estimating missed rainfall data, include arithmetic mean, inverse distance, normal ratio method and areal precipitation ratio method (De Silva et al., 2007). The normal ratio method is most common for estimating missing rainfall data (Chow et al., 1988). Here are the formulas for several different methods used to estimate missing data.

A. Normal ratio method

This method estimates missing rainfall data by weighting observations from N gauges based on their respective yearly averages (*Yemane Gebreegziaber. 2004).*

$$p_X = \frac{1}{N}\left(\Sigma \frac{p_x}{p_i} \times pg\right) \quad (1)$$

Where,

PX - Missing data,

Px - Annual average precipitation at gauge with the missing data.

Pi - Annual averages at neighboring stations.

Pg - Monthly rain fall data in station for the same month as missing station.

N - the total number of gauges.

B. Inverse distance method: Estimates precipitation as weighted average of measurements at nearby stations (Simanton & Osborn, 1980).

$$\text{Px} = \sum_{i=1}^{N} \frac{1}{d^2} P_i \tag{2}$$

Where, Px = estimate of rainfall for the un-gauged station, Pi= rainfall values at gauges used for estimation, d = distance from each station to point estimated, N = number of surrounding stations. Since weighting depends entirely on distance and the inverse distance method's Limitations depend on minimum distances between stations, so this method is unsuitable for mountainous areas (Abraham et al., 2015).

C. Arithmetic mean method: The arithmetic mean can estimate missing observations if normal annual rainfall at nearby gauges is within 10% of the average at the missed station (Chow et al., 1988).

$$\text{pavg} = \frac{1}{\text{n}} \sum_{i=1}^{n} pi \tag{3}$$

Where: P_{avg}= Average precipitation, n= total number of stations and Pi=precipitation depth at gauge i. Its limitations are it assigns equal weighting regardless of location, and using the basic average as the estimate

II. Consistency analysis

The prominent double-mass curve method checks consistency of a station's rainfall series. The double mass curve makes it clear that the adjusted values at the station under investigation will be more precise irrespective of how homogeneous the base station records are. (*Garg, S.K., 2005).*

$$\text{p} = \text{px} \times \frac{\text{M}'}{\text{M}} \tag{4}$$

Where:

P - is corrected precipitation at station X (mm)

Px - is original recorded precipitation at station X (mm)

M' - corrected slope of the double mass curve (%)

.M - original slope of the double mass curve (%).

2.7.2. Irrigation Water Requirement

Water used for irrigation should fulfill its purpose without having an adverse impact on the soil's fertility or the health of the plants. General problem of irrigation such as salinity, acidity, sodicity, and specific ion toxicity of various elements are discussed in relation to the suitability of water for irrigation (FAO, 1985*;* Kassie et al., 2022). When figuring out how much water is required for irrigation, it is important to make the distinction between gross irrigation water requirements, crop water requirements, nest irrigation water requirements, and their components, as described below with relation to the irrigable command area (*FAO, 1985).*

A. Effective rainfall: It constitutes a portion of the precipitation that the crop can make optimal use of, contingent on factors such as the crop's depth of root zone and the soil's capacity to store water. This portion plays a role in fulfilling the crop's water needs, affecting either its total irrigation demand or the combined demand of net irrigation and other water requirements (*FAO, 2002)*

B. Reference crop Evapo-transpiration (ETo): Reference crop evapotranspiration (ETo) refers to the evapotranspiration rate from a reference surface with adequate water supply. The hypothetical reference crop is grass with specific characteristics. ETo is affected only by climatic factors (Ganole, *K.2010*). Thus, it is a climatic parameter calculated from weather data, without considering crop or soil specifics. ETo indicates the evaporating power of the atmosphere for a given location and time. It is advised that ETO be calculated using only the FAO Penman-Monteith method. Additionally, methods for guessing missing climatic factors have been devised.

$$\text{ETO}=\frac{0.408\Delta(Rn-G)+\gamma\frac{900}{T+273}U2(es-ea)}{\Delta+\gamma(1+0.34U2)} \quad (5)$$

Where; ETo = Reference evapotranspiration (mm/day)

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

G = Soil heat flux density (MJ/m2 per day)

T = Mean air temperature at 2m (°C)

u2 = Wind speed at 2m (m/sec)

es = Saturation vapor pressure (kPa)

ea = Actual vapor pressure (kPa)

Δ = Slope of saturation vapor pressure curve (kPa/°C)

γ = Psychrometric constant (kPa/°C)

2.7.3. Crop water requirement (CWR) and crop evapotranspiration (ETc)

(*FAO, 1984*) defined crop water requirements as the depth of water needed to meet a crop's evapotranspiration water loss, be disease-free, grow in large fields under unrestrictive soil conditions, including soil water and fertility, and achieve a crop's maximum production potential under the conditions of the growing environment. According to FAO (2002), the amounts of ETc and CWR, which indicate the water lost by evapotranspiration and the amount of water necessary to make up for the loss, are equal. FAO (2002) claims that by directly incorporating the effects of crop attributes into ETO, ETc may be estimated from climatic data. There is an estimation of ETO using accepted techniques. Crop coefficients (Kc), which are derived through experimentation, are used to connect ETc to ETO.

$$ETc = ETO \times Kc \tag{6}$$

Where: ETc = Crop evapotranspiration (mm/day), Eto = Reference crop evapotranspiration (mm/day) and Kc = Crop coefficient (fraction).

2.8. Description of CROPWAT Model

Using crop and climate data, CROPWAT is a computer software that determines irrigation, reference evapotranspiration, and crop water needs. The application also enables the creation of irrigation schedules for various management scenarios and the estimation of scheme water supply for various agricultural patterns. Any IBM-PC-style computer with a minimum memory size of 360Kb may execute the application *(FAO), 1992.*). One of the models created by Food and Agricultural Organization (FAO) and widely utilized in the field of water management worldwide is CROPWAT.

(*George, et al.,2000*) claim that CROPWAT makes it simpler to calculate irrigation schedules, crop water requirements, and evapotranspiration for various cropping patterns. The decision support tool CROPWAT was developed by the FAO's Land and Water Development Division to aid in the management and planning of irrigation systems. It makes it possible to plan irrigations under various water supply scenarios, come up with ideas for better irrigation methods, and assess production in rain-fed or shortfall irrigation settings *(FAO, 1992*).

Differed weather conditions result in varied water requirements for an identical crop. Accurate data on crop water demands, irrigation withdrawal as a function of crop, soil type, and meteorological conditions are required to enable successful planning on water resources. CROPWAT is an FAO model for irrigation management that integrates climate, crop, and soil data to determine reference evapotranspiration (ETO), crop evapotranspiration (ETc) and irrigation needs. The climate inputs are monthly reference ETO and rainfall data. ETO can be calculated from temperature, humidity, radiation and wind speed data per the FAO Penman-Monteith method (FAO, 1998). The CLIMWAT database provides monthly climate data for CROPWAT for 144 countries (Latham et al., 2002). By integrating climate, crop, and soil factors, CROPWAT models crop water requirements and irrigation needs for improved agricultural water management.

2.9. Previous Studies on Irrigation Potential Assessment

Land suitability assessment plays a crucial role in optimizing agricultural productivity and sustainable water resource management. Several studies have focused on developing methodologies and models to evaluate land suitability for surface irrigation.

For instance Worqlul et al (2017) conducted research to evaluate the potential for surface water irrigation in the Ethiopian highlands near Lake Tana Basin. They used Geographic Information System (GIS)-based Multi-Criteria Evaluation (MCE) methods to assess the suitability of the land for groundwater irrigation. They considered factors like climate, proximity to rivers, soil type, land cover, topography/slope, and access to markets. Their findings showed that about 20% of the Lake Tana Basin area has potential for surface irrigation. However, after analyzing 27 years of river discharge data, they found that less than 3% of the potentially irrigable area (or less than 0.25% of the total basin area) could be sustainably irrigated with water from the river systems.

Shitu & Berhanu (2020) used GIS to evaluate the prospective area in the Borkena watershed that would be appropriate for surface irrigation while taking into factors such soil type, slope, land use/cover, and proximity to water sources. By weighted overlay of these suitability parameters, the final area of existing and perhaps irrigable land was found. They found that only 16.13% of the land is highly suitable (S1), 47.12% is moderately suitable (S2), 31.58% is marginally suitable (S3), and 5.17% is not suitable (N) for surface irrigation development. The weighted overlay method in Arc GIS software was used to combine physical suitable area determination factors. They concluded that the majority of an area falls within the range of high to moderate land suitability for surface irrigation.

Bushira & Abdule (2020) also evaluated the potential for spate irrigation in the Logiya watershed using GIS-based Analytic Hierarchy Process (AHP) techniques. They assessed prospective areas for spate irrigation based on land use/cover, slope, and soil suitability. They used the CROPWAT program to calculate the reference crop evapotranspiration, effective rainfall, net irrigation requirement, and gross irrigation water requirement. According to the compatibility model they developed, only 26.15% of the total land area falls into categories ranging from marginally suitable to highly suitable for spate irrigation development. They found that the seasonal river flow in the Logiya watershed from July to October was 301.64 Mm3. However, the annual flood water available from the river during the growing season was 8.77 Mm3 less than the total gross irrigation water requirement. In conclusion, they suggested that excess water available from the river before July could be stored and used for irrigation during dry spells in the growing seasons.

Gonfa et al (2021) assessed the land suitability and surface water potential in the Becho Plain, Upper Awash basin. The GIS-based AHP technique was used to assign entire suitability classifications to the irrigable area, based on slope, land use/cover, and soil attributes. Additionally, the SWAT model was used to assess surface water availability, and it was also used to determine how much water was needed for important crops. According to the findings, roughly 70% of the land area is appropriate, while surface irrigation is prohibited on the remaining 30% of the land. Additionally, the research of water supply and demand showed that there is enough water available in the region to support irrigation development.

Negasa & Wakjira (2021) emphasized integrating land suitability, water availability, and crop water requirements for surface irrigation planning in Ethiopia's Birbir River watershed. They used Analytic Hierarchy Process to weight 7 factors and performed weighted overlay in ArcGIS to develop an irrigation suitability map. The results showed 17% highly suitable (S1), 63% moderately suitable (S2), and 20% marginally suitable (S3) land for surface irrigation. Around 68,000 ha of the 106,223 hectares suitable for surface irrigation was found to be irrigable without storage structures. This study demonstrated integrating land suitability analysis with water availability and crop needs assessment using GIS for delineating areas appropriate for surface irrigation development.

Hagos et al (2022) conducted a study in the Minch Yekest watershed in West Amhara, Ethiopia using geospatial and multi-criteria decision-making techniques to assess land suitability for surface irrigation. They considered parameters like slope, land use, altitude, and distance from water source, soil characteristics, and available water storage capacity. Their results showed that 63% of the watershed area is highly suitable, 6.25% is moderately suitable, 28.69% is marginally suitable, and 2.06% is not suitable for surface irrigation based on the parameters.

Kassie et al (2022) conducted a study carried out a study in Ethiopia's Abbay basin to assess land suitability for irrigation using both surface and groundwater sources. They utilized the analytic hierarchy process and considered multiple factors that affect irrigated agriculture productivity. Their results showed that nearly 10% of the basin area (19,192 km2) and 5.3% of the basin (10,364 km2) were found suitable for surface irrigation from rivers and groundwater, respectively. The depth to groundwater was shallower for the Muger sub-basin compared to others. The validation results showed more than 83% and 73% overlap for surface and groundwater sources, respectively

Generally, there were numerous research papers, articles, and studies related to land suitability and water availability for surface irrigation even in our country Ethiopia. These works cover a wide range of geographic regions, cropping systems, and hydrological conditions. The existing literature provides valuable insights into land suitability and water availability for surface irrigation, but there is still a need for further research in several areas.

CHAPTER THREE

MATERIALS AND METHODS

3.1. Description of Study Area

3.1.1. Location

The study area is located in Baro Akobo River basin western part of Oromia region, specifically in Kellem Wollega Zone, the capital city of the Zone is Dambi Dollo about 652 km from Addis-Ababa, with Latitude of (8°31´20´´N and Longitude 34°47´10´´E). The total land area of the zone is about 9709.3 square kilometer (km^2). Kellen Wollega zone is bounded by West Wollega Zone in the North, Buno Bedale Zone in the East, Ilu A/Bora Zone in South and Sudan in the West (Gebre Gidey et al., 2021). Borta river catchment covers an area of 17,214.7 ha at the altitude of 664m to 2123 m above sea level. The figure 3.1 below shows the location of the study area.

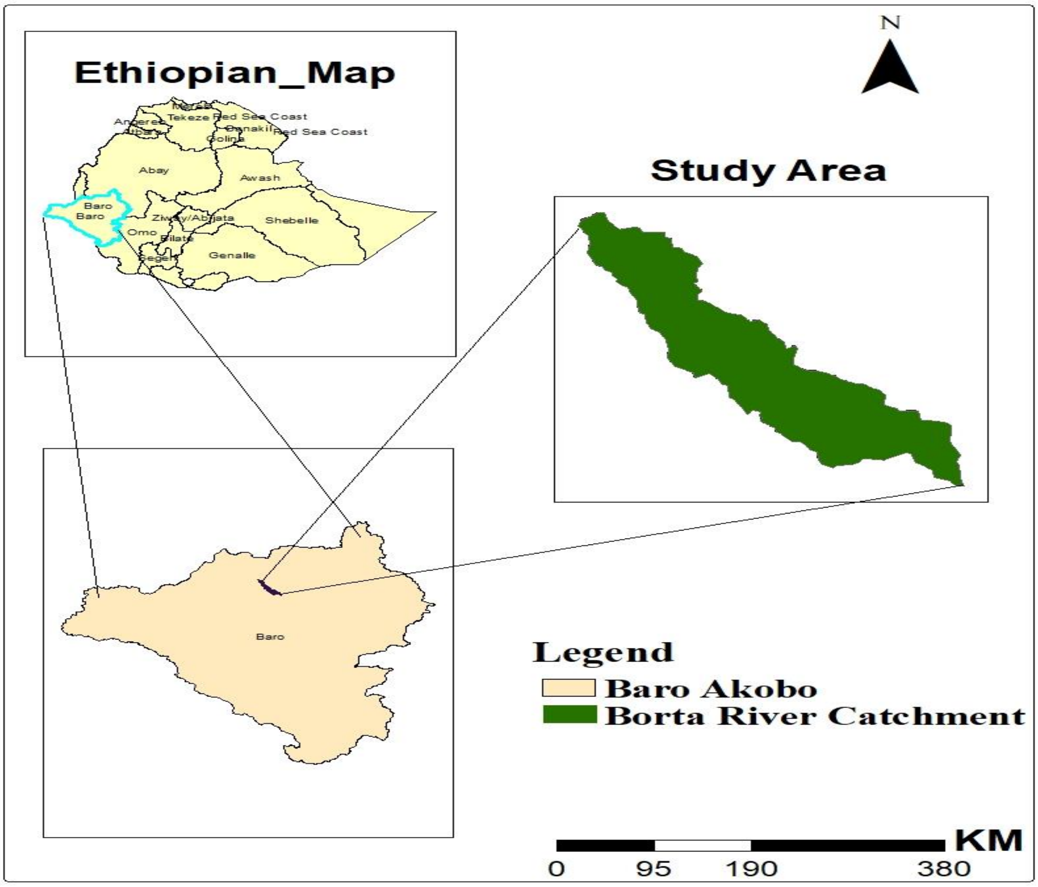

Figure 3.1: Location map of Study Area

3.1.2. Climate

Climate refers to the long-term pattern of weather conditions observed in a particular region over a significant period of time, typically spanning decades to centuries. It encompasses various factors such as temperature, precipitation, humidity, wind patterns, and atmospheric conditions that determine the prevailing weather conditions in a specific area. Ethiopia is a diverse country with varying climatic conditions due to its diverse topography and geographical location. Generally, Ethiopia experiences a predominantly tropical monsoon climate, but there are significant variations across different regions (M. Mekonnen, 2012).

Also, Oromia Region, including Kellem Wollega Zone, is characterized by a tropical monsoon climate. The region experiences two main seasons: a wet season and a dry season. The wet season typically occurs from May to end of October, with July and August being the peak months for rainfall. This is the main rainy season, which accounts for more than 70 % of the annual rainfall total. The little rainy season was from the middle of March to the end of April, while the remaining months are typically dry. Use to the wide variance in elevation found throughout the Baro Sub- Basin, the region's mean annual rainfall pattern exhibits significant geographic variation. At the research area, the average annual rainfall ranged from 1250mm to 1400mm. The mean annual PET is estimated to be about 1325mm. In the study area, the maximum temperature ranges from 26 ^{o} C to 29 ^{o}C in the wet and dry season, respectively, in contrast, the minimum temperature in the dry and wet seasons, respectively, varies from 12 ^{0}C to 17 ^{0}C.

3.2. Data Collection and Sources

This Research was based on both primary and secondary data. Appropriate data collection methods are very important to achieve the research objectives. The data collection methods for primary data were field observation (soil sampling for laboratory analysis) and downloading land sat images from USGS website. Whereas secondary data were collected from browsing of internet for related literatures, requesting (shape files, maps, etc.) from responsible organizations and reviewing publications of hard and soft copy related to this study. The data that was collected and the Software tools and Materials used for this study was listed on the table 3.1 and 3.2 below

Table 3.1: Collections of data and Sources.

Data	**Purposes**	**Source**
DEM	To generate slope, with ArcGIS	From freely available earth explorer USGS data. Shuttle Radar Topographic Mission (SRTM)
Soil	The input for ArcGIS and to identify chemical and physical properties of the soil.	Collected from the representative pits by field survey for chemical property identification and Harmonized World Soil data base.
LULC	The input for ArcGIS to assess the response of watershed characteristics for land use change for different periods.	The LULC data set of 01/01/2021 to 03/31/2021period with 30m*30m spatial resolution was downloaded from Earth Explorer - USGS
Climatic data	Input for CROPWAT to calculate crop water requirement.	National meteorology agency (NMA)
Hydrological data	To asses available water potential.	Ministry of Water and Energy of Ethiopia (MoWe)

3.3. Materials and Software Tools

Table 3.2: Software tools and Materials used

Materials and software's	**Uses**
Arc GIS 10.4	For processing the spatial data. And evaluating overall suitability
CROPWAT 8.0	For calculating the water requirements for crops, ETo, and irrigation water requirement
ERDAS Imagine 2015	For land use map generation and classification from Landsat image and used for the accuracy assessment of classified land use map.
Geographical positioning System (GPS)	To accurately record the geographic coordinates of soil profile pit locations, ensuring precise spatial referencing for our data.
Google earth pro	For accuracy test of LULC
Microsoft excels	For rearranging input data's
Auger	For soil sampling
plastic bag	For soil sampling

3.4. Methods

The collected data was checked and filling the missed data was done carefully. This study contains two parts. The first part was evaluating the land that was suitable for surface irrigation using GIS software, taking into account factors such as physical characteristics of soil, slope or topography, soil depth, texture, drainage and laboratory analysis for chemical soil characteristics (electrical conductivity, calcium carbonate percentage and Ph. level), as well as land use/cover, and proximity to a water source. ERDAS Imagine 2015 For Image classification was check the accuracy assessment and the result were checked using google earth. 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 (Maize, Potato and Onin) using CROPWAT software. Then the water availability during the dry season was quantified by analyzing long term discharge records.

3.4.1. Data Pre-Processing and Analysis

Errors in the collected data might be the result of measuring instrument malfunction or human mistake during data collection. Therefore, prior to utilizing the data for a specific purpose, a meticulous process was undertaken to examine and eliminate any errors. Data checking and elimination of error from hydrological and metrological data was performed to prepare input data of water resources assessment and irrigation water requirement.

a. Consistency checking for rainfall data

Hydro-meteorological data may show inconsistencies and non-homogeneity in their time series. One particular aspect that can introduce outliers in precipitation time series data is the replacement of rain gauges, repositioning of instruments to new locations, and errors in precipitation observations. These outliers disrupt the consistency of the data. To assess the inconsistency of rainfall data, a commonly employed method is the double mass curve analysis. The double mass curve is a graphical representation that plots the cumulative sum of one quantity against the cumulative sum of another quantity for the same time period. In an ideal scenario where the data is proportional, this plot will appear as a straight line. The slope of this line represents the constant of proportionality between the quantities (Khalil, 2021).

Double mass curve analysis was used to assess the consistency of the rainfall data and prepare them for future use. A visualization of the collected data at the place of interest versus the cumulative average at the neighboring stations is often used to check the consistency of rainfall data (Nemec, 1973). The hydro-meteorological datasets, such as rainfall, maximum and minimum temperatures, wind speed at two-meter, relative humidity and sunshine hour for the year 1995 to 2015 were obtained from the National Meteorology agency of Ethiopia. To calculate the crop water requirements and irrigation need of the study area.

The consistency of the accumulated rainfall at Dambi Dollo station with the average accumulated rainfall of the surrounding two-gauge stations, Ayira and Bure rainfall stations, was checked using the Double Mass Curve method. The mean annual cumulative rainfall of Dambi Dollo station over a period of twenty-one years (1995 to 2015) was plotted on the yaxis, while the mean annual cumulative rainfall of Bure and Ayira stations was plotted on the x-axis. This double mass curve analysis allowed for a comparison of the rainfall patterns among the stations. The analysis revealed that the rainfall data from Dambi Dollo station exhibited a small breakpoint at different years compared to the other stations. However, despite this variation, a single straight sloped line was obtained when plotting the cumulative rainfall of all three stations together. This finding indicates that the rainfall data from Dambi Dollo station were consistent with the rainfall data from Ayira and Bure stations as shown on appendix A2.

b. Estimation of the missed data

The meteorological data that were collected for this study may have a missing data for some times. Gaps in temperature and precipitation statistics are often examined during the generation of climatic data before any missing information is filled in. Using meteorological and climatic data from close or surrounding stations, it is possible to generate the missing climatic data for each of the stations in accordance with the guidelines stated in (*Dr. K Subramanya (2013*). Several methods, such as the arithmetic mean approach, the normal ratio method, the inverse distance weighting method, etc., can be used to fill in the missing data. For this investigation, the gaps in the station records were filled using the normal ratio approach, which is indicated to estimate missing data in areas where yearly rainfall differences between stations are more than 10%. As seen below, by dividing the measurements at N gauges by the yearly average rainfall for each, this method permits the estimation of missing rainfall data (Yemane, 2004).

3.4.2. Watershed delineation

The USGS's shuttle Radar Topographic Mission (SRTM) created a DEM of 30 m x 30 m, which was used to delineate the watershed. The DEM with a 30 by 30 m resolution was imported into Arc GIS, and the area's watershed was delineated using the Arc GIS special analyst tool. The fig. 3.2 below shows digital elevation model (DEM) of the study are.

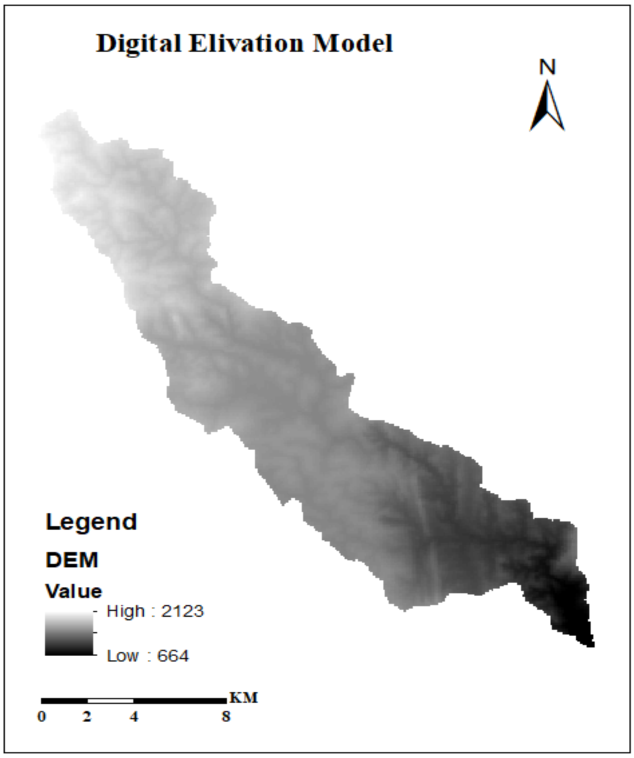

Figure 3.2: Digital elevation model of the study area

3.4.3. Identification of suitable site for surface irrigation

By taking into account the slope, soil, proximity to a water source, and land use/cover, suitable irrigation areas were identified. In order to identify possible irrigable areas, each factor's particular suitability had initially assessed.

Slope Suitability Analysis

Due to its influence on controlling runoff, drainage, and erosion, as well as its significant role in determining irrigation suitability, slope gradient holds considerable importance in soil formation and preservation. To assess the slope of the research area, ArcGIS 10.4's spatial analyst tool was utilized alongside a 30-meter DEM (Digital Elevation Model). A reclassified digital map of slope variations was then generated through spatial analyst applications. Using ArcGIS's "Reclassification" tool, an attribute simplification technique, the slope values derived from the DEM were categorized according to the FAO (Food and Agriculture Organization) classification system introduced in 1990. Slope gradient was one of the important assessment characteristics used to determine whether irrigation was feasible. The analysis relied on four slope classes: " Highly suitable " (S1)", " Moderately suitable "(S2), "marginally suitable" (S3), not suitable" (N) for surface irrigation, and. (*FAO, 1990*).

Soil Suitability Analysis

Laboratory analyses were performed on the watershed's selected chemical soil prosperities (electrical conductivity, calcium carbonate concentration, and Ph. level); For soil texture, depth and drainage, 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 reclassified based on their soil texture, depth and drainage classes, and the results will be rated according to the guide lines (FAO, 1985). Electric conductivity of saturation extract (EC) will be determined by 1:2.5 ratio of soil to water suspension using EC meter, and Percentage of calcium carbonate (% $CaCO_3$) will be measured using rapid manometric method meter, PH (soil reaction) was measured using a glass electrode pH meter (Allison & Moodie, 2016)

Soil depth suitability

Soil depth plays essential role in assessing the suitability of surface irrigation, as it directly impacts the soil's water holding capacity and nutrient content (Mandal et al., 2018). Additionally, soil depth influences root growth and determines the availability of water and air within the soil. To determine the soil depth in the study area, data was collected from the harmonized world soil database. Based on this information, the soil depth was categorized into four suitability classes according to FAO: highly suitable (greater than 100 cm), moderately suitable (80–100 cm), marginally suitable (50–80 cm), and not suitable (less than 50 cm) (Kassie et al., 2022).

Soil drainage suitability

The classification of soil drainage classes, as per FAO (1976), has been redefined into four suitability classes based on soil depth. These suitability classes are categorized as follows. Well-drained to moderately drained soil: This class includes soils with a depth greater than 100 cm, which are considered to have good drainage capabilities. Imperfectly drained soil: Soils falling under this class have a depth ranging from 80 to 100 cm, indicating moderate drainage capabilities. Poorly drained soil: This class encompasses soils with a depth ranging from 50 to 80 cm, suggesting limited drainage capabilities. Very poorly drained soil: Soils falling under this class have a depth less than 50 cm, indicating severe limitations in drainage (Kassie et al., 2022). Well-drained soils are considered preferable for surface irrigation.

Soil texture suitability

According to (Twarakavi et al., 2010), soil texture refers to the ratio of the three sizes of soil particles (sand, silt, and clay) as well as the fineness or coarseness of the soil. Mixtures like silt-clay, clay-loam, sandy loam, etc. are present in these primary categories. Sandy clay loam, loam, and silt loam are categorized as medium-textured soils, while clay, clay loam, and silty clay loam are categorized as fine-textured soils. The other soils, such as sandy soils, are categorized as coarser-textured soils.

Soil chemical property analysis and suitability test

The study area was divided into three zones, namely upper (zone one), middle (zone two), and lower (zone three), to facilitate data collection and ensure representative soil sampling. In each subdivided zones, four profile pits were excavated to a depth of 30cm, and soil samples were collected from each pit. Four samples from each sampling unit (zone) were collected (totally twelve samples) and thick slices were removed then the sample placed in a prepared plastic bag for sampling and transported to soil laboratory of melkasa agricultural research center for test. Additionally, the GPS was used to collect coordinates of the soil data at each representative pit as shown on figure 3.3 below and Appendix 10.

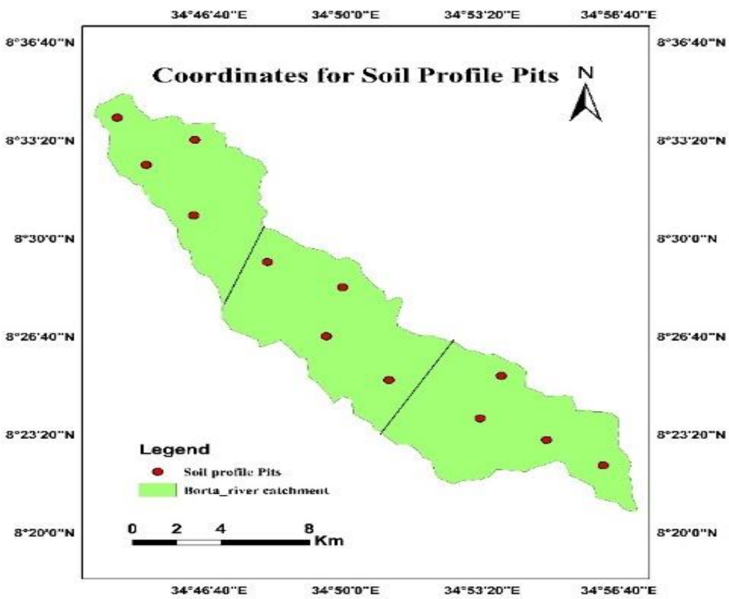

Figure 3.3: Division of the study area for soilsampling

The suitability of the soil for the research area was determined by measuring particular chemical characteristics of the soil, such as pH, percentage of calcium carbonate and electric conductivity, by laboratory analysis. The soil samples collected from each pit were subjected to various laboratory tests to assess specific chemical properties. The following methods were employed to test these properties:

PH Testing: The pH level of the soil was determined using a pH meter or pH indicator solution. The soil sample was mixed with water, and the pH of the resulting soil-water suspension was measured. This test helps to determine the acidity or alkalinity of the soil.

Percentage of Calcium Carbonate: The calcium carbonate content in the soil was determined using rapid monometer.

Electrical Conductivity (EC) Testing: The electrical conductivity of the soil was measured using a conductivity meter (EC-meter). A soil-water suspension was prepared by mixing the soil sample with distilled water at ratio of 1:2.5 of soil to water suspension. This test provides an indication of the soil's salinity level and can help assess its suitability for certain crops

The table 3.4 below shows that the suitability classes of individual factors that were considered in this study.

Table 3.3: Soil suitability factor rating

Soil suitability factors				
Factors	**Highly suitable**	**Moderately suitable**	**Marginally suitable**	**Not suitable**
Slope	0 - 2 %	2 – 5 %	5 – 8 %	>8
Soil Drainage	Well to moderately	Imperfect drain	Poor drain	Very Poor drain
Soil depth	>100	80 – 100	50 - 80	<50
Soil texture	C	Si-CL, CL-C	SL	CS
PH	5.4–6.5	6.5–7.8	4.4–5.4	<4.4
EC (dS/m)	< 0.1	0.1–0.7	0.7-1.1	>1.1
$CaCo_3$ (%)	0–5	5–10	10–15	>15

Source: (*FAO, 1991*and *2002*) Guide line for land evaluation

Where C - clay, Si-CL – silty clay loam, CL –clay loam, SL – silty loam and CS - coarse sand

Land Cover/Use Analysis

The suitability for irrigated agriculture is influenced by various factors, one of which is Land Use and Land Cover (LULC). To analyze LULC, a dataset with a spatial resolution of 30m*30m for which is Acquired on the Date 2021/01/10 while the sky is clean was download from Landsat 8-9 OLI/TIRS C2 L1 (LC08_L1TP_20210110_20210307_02_T1) with Path: 171 and Row: 054 from Earth Explorer - USGS. By combining spectral bands that closely approximate what the human eye can see, true color image composites have been produced. These bands are commonly used in Landsat images for LULC analysis. The LULC classification was performed using ERDAS Imagine, and the resulting classification was then imported into ArcGIS. To facilitate further analysis in the suitability assessment, the classification was reclassified. In the study area, the various land use/cover categories were graded according to how well suitable they were for surface irrigation.

Distance to water source

To determine suitable land for irrigation near a water source, the process involved calculating the straight-line distance from watershed outlets using a 30 m * 30 m cell size Digital Elevation Model (DEM). This distance was then reclassified, likely to categorize it into different distance ranges. The reclassified distance was subsequently combined with other factors using a weighted overlay analysis. This analysis allowed for the integration of various criteria to generate a final map indicating areas with proximity to the water supply and other favorable conditions for irrigation.

3.4.4. Multi-Criteria Evaluation (MCE)

A series of methods called multi-Criteria Evaluation is intended to make decision-making easier. The main goal is to look at several options for selection in the context of various criteria and conflicting objectives. The logic used to choose between options is an aspect of decision theory. However, the possibilities change depending on the issue. They might represent other courses of action, alternate explanations for an occurrence, or alternate items to add to a set. In the current study, site suitability modeling based on several criteria was created to determine suitable and viable places for irrigation development based on a number of restrictions and criteria. Four distinct limitations and criteria will be chosen based on their value and significance to agriculture. The identification of many criteria, such as soil characteristics, slope, land use/land cover, and distance from water, depends on the maximum limitation approach that determines the usage of land for irrigation. The

Analytical Hierarchy Process (AHP) was utilized to give each criterion a weight. To construct a suitability map, a weighted overlay analysis technique was then used.

Analytical Hierarchy Process (AHP)

An analysis of a model based on the MCDM (Multiple Criteria Decision Making) techniques suggested by FAO (1976) was done to find a suitable land for surface irrigation. AHP (Analytic Hierarchy Process) is a method for ranking and analyzing complicated decision-making situations, and it has been recommended by (*Aziz.et al*, *2016*) for the purpose of future researchers. The AHP method is considered ideal and straightforward, as it is user-friendly and allows for the evaluation and reduction of inconsistencies in opinions. This study utilized the AHP method, following the model and logic developed by (*Saaty, T. L. (1970*). Saaty developed a comparison matrix to assess the suitability parameters in a one-to-one manner, and he also devised a weighted linear combination approach to determine the weights. The irrigation suitability model considered various input factors, including slope, soil characteristics like texture, depth, and drainage, land usage and cover, as well as distance. These parameters were employed to determine the optimal areas for implementing surface irrigation.

Table 3.4: Pairwise comparison scale and definition (*Saaty, T. L. (1970*)

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

There are numerous ways to evaluate the relative importance of the criteria in the whole pairwise compression matrix, and it is possible to ascertain the level of consistency that was applied when developing the ratings.

$$\mathrm{CR} = \frac{CI}{RI} \tag{7}$$

$$\mathrm{CI} = \frac{\lambda max - n}{n-1} \tag{8}$$

Where: CI - Consistency index

CR - consistency ratio

$\lambda\, max$ - Largest or Principal Eigen value of the matrix

n - Number of elements being compared in the matrix

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

Table 3.5: Random index table (*Saaty, T. L.1970*)

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

3.4.5. Weighing of irrigation suitability factors to find potential irrigable sites

An irrigation suitability model was developed using Model Builder in the Arc Toolbox, utilizing various spatial analysis tools. The model assessed the suitability of potential sites for irrigation by incorporating several factors. These factors, including slope, soil properties, land cover/use, and distance, were individually evaluated to determine their impact on irrigation suitability. The results from these assessments were then used as inputs for the irrigation suitability model, which integrated all the factors to identify the most suitable lands for irrigation.

3.4.6. Estimation of surface water resources potential of the river catchments.

Assessing the availability of land resources alone is not enough to determine the feasibility of implementing irrigation practices in a particular area. It is also crucial to evaluate the availability of water resources and determine if irrigation development is feasible using various approaches. The assessment of water resources requires a comprehensive understanding of all water flows and storage systems within the considered catchment. In order to quantify the amount of water available for surface irrigation during the dry monsoon period, information on low flows is necessary. These low flows are calculated based on the daily average discharges, which are obtained from the Ministry of Water and Energy of Ethiopia (MoWe)

3.4.7. Computing irrigation water requirements

In the study area, a major crop was determined in order to calculate the irrigation water need. The Dambi Dollo metrological station was used to calculate the irrigation water requirements for each crop that was chosen. The major crops cultivated in this catchment area were maize, onions, and potatoes, they were selected for their profitability and yield potential within the region. Out Of the total suitable land, the area assigned for maize were approximately 34% due to its high demand and productivity as a staple food crop, for Onions it's accounted to 34% because of high demand and also this catchment could provide ideal growing conditions for bulb according to information from the growers in this catchment. Finally, potatoes were up 32% based on their reliability as a subsidized commodity with well-established production techniques. The roughly equivalent portions of arable land devoted to maize, onions, and potatoes in this catchment highlight the importance of crop diversification to reduce risk and stabilize agricultural incomes. While the catchment relies primarily on rain fed agriculture, some farmers employ double cropping methods or small-scale traditional irrigation to maximize agricultural output. According to crop Calendar rain fed agriculture is practiced from the beginning of June to the last of November. And irrigation agriculture cropping practice in the catchment area is from early January to the mid of May.

Reference evapotranspiration (ETO)

The assessment of crop water requirements was carried out by selecting suitable crops that are likely to be grown under the specific climatic conditions, together with their essential crop coefficients (Kc) and the associated reference evapo-transpiration. (Allen et al., 1998) FAO 56, states that the dominant crop's coefficient (kc) might reach a maximum value of 1.15. From knowledge of the agricultural water need, the irrigation water needs of catchment areas were calculated. Using the Cowpat 8 model, ETo was estimated for the Dambi Dollo meteorological stations by using climatic data such as: temperature (maximum and minimum), humidity, wind speed, and sunshine) that was taken from NMA to calculate ETo by loading in CROPWAT using Penman-Monteith formulas.

Effective rainfall

To compute effective rainfall in this study, we need data on rainfall. The chosen approach for calculating effective rainfall is the Dependable Rainfall method, specifically targeting an 80% probability exceedance. This method, established by the FAO, is particularly useful for design purposes when estimating reliable rainfall.

$$ER = 0.6TR - 10 \qquad (9)$$

This equation is valid where ($TR < 70mm$)

$$ER = 0.8TR - 24 \quad (10)$$

Equation 12, is valid when (TR>70 mm). Where; ER is Effective Rainfall and TR is Total Rainfall.

Crop evapotranspiration (ETc)

The program includes a collection of common crop coefficient data files as well as a cropping pattern that details the planting date, crop coefficient data files (which contain Kc values, phase days, root depth, and depletion %), and the area planted. The following formula is used to determine ETc and IWR using the CROPWAT model.

$$ETc = ETO \times Kc \quad (11)$$

$$IWR = (ETO \times Kc) - ER \quad (12)$$

Net irrigation water requirement

Using the climate, rainfall, crop, and soil data inputs, equation 11 in the CROPWAT 8.0 edition computed the amount of water needed for irrigation and crop growth. In the following step, the net irrigation water demand (NIWR) was determined using ETc and effective rainfall (P_{eff}).

$$NIWR = ETc - P_{eff} \quad (13)$$

Where, NIWR - is Net irrigation water requirement (mm)

P_{eff} - is effective rainfall (mm)

ETC - is Crop evapotranspiration

Gross irrigation water requirement

Gross irrigation water requirement can also be calculated from

$$GIWR = \frac{NIWR}{Ea} \quad (14)$$

Where: Ea – application efficiency and GIWR is Gross irrigation requirement (m^3 /month). Following data entry, CROPWAT 8.0 Windows computes the findings automatically and displays them as tables or graphs. The results' time step can be set to any suitable time step, such daily, weekly, monthly, or even a decade. For the purposes of this study, the irrigation efficiency value was determined to be 50% of the average value within the range that was recommended by FAO. The Conceptual framework for the methodology was expressed on figure 3.4 below.

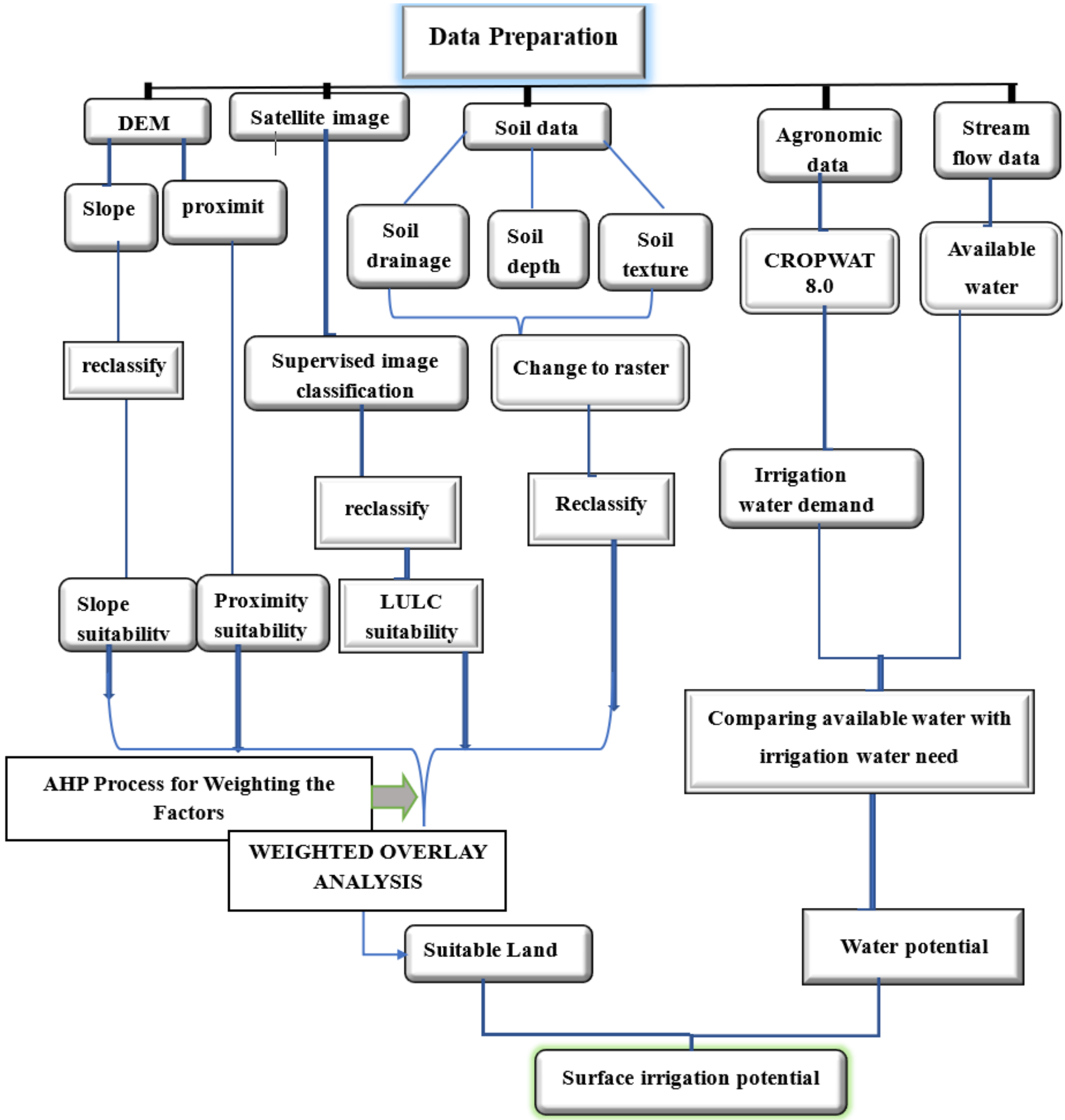

Figure 3.4: Conceptual framework for the methodology

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1. Land Suitability Evaluation for Surface Irrigation

In order to determine if a particular area of land is suitable for surface irrigation, a variety of factors that may affect that ability must be evaluated (Haile & Abebe, 2022). In this study, investigation of the suitability of surface irrigation has been done by taking into account a number of variables, such as slope/topography, soil properties (such as soil texture, drainage, depth, pH, calcium carbonate content and electric conductivity), land use and land cover (LULC), and proximity to rivers.

4.1.1. Slope suitability

Slopes have a direct impact on soil management and productivity, and larger slopes restrict the amount of agriculture that can be mechanized (Zhang et al., 2015). The "Reclassification tool" of ArcGIS, Special Analysis tool were used to reclassify the catchment area's slope as shown on the figure 4.1 below.

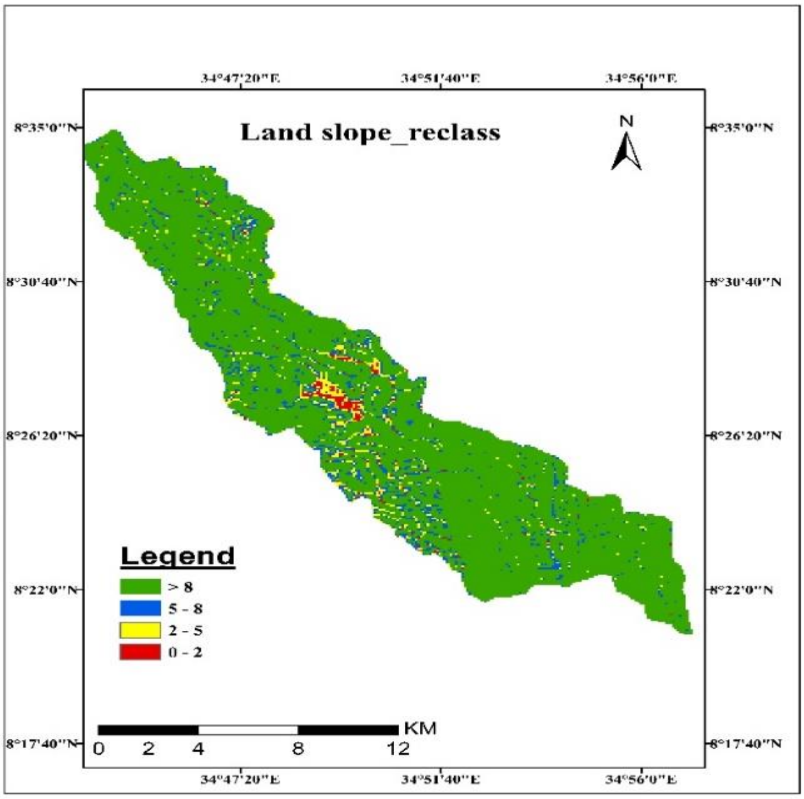

Figure 4.1: Slope suitability map of the study area

The map indicates that a significant portion of the study area consists of steep slopes. Table 4.1, located below provides further insights. It reveals that 7.1% of the total area, which accounted to 1229.75 hectares, falls into the categories of high to moderate suitability, making it suitable for surface irrigation development. Additionally, 9.3% of the area, equivalent to 1598.5 hectares, is classified as marginally suitable. However, the majority of the study area, amounting to 83.6% or 14386.45 hectares, is deemed unsuitable for surface irrigation development.

Table 4.1: Slope suitability class of the study area

Slope range (%)	Area coverage (ha)	% coverage	Suitability classes
0-2	265.4	1.5	S1
2-5	964.35	5.6	S2
5-8	1598.5	9.3	S3
>8	14386.45	83.6	N
Total	**17,214.7**	**100**	

4.1.2. Soil suitability test

The suitability of an area for surface irrigation, which has a considerable influence on productivity and production costs, is mostly determined by the soil.

- **Soil depth suitability**

The study area exhibited varying soil depths, ranging from highly suitable to marginally suitable conditions as shown in figure 4.2. and table 4.2 below

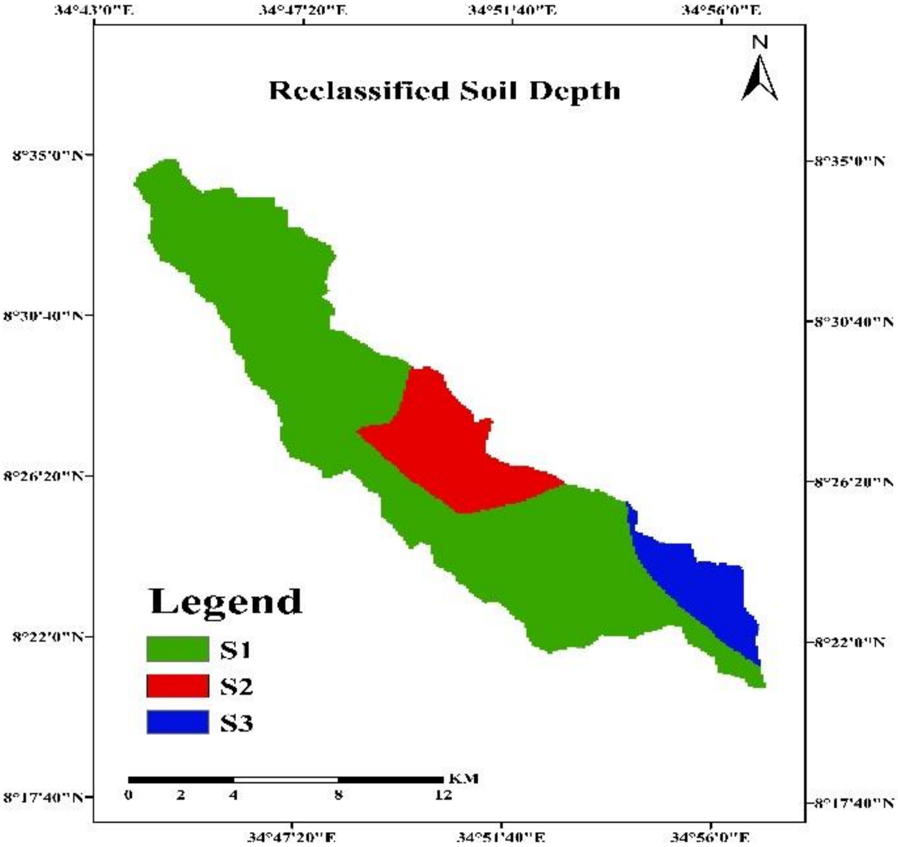

Figure 4.2: Soil depth class suitability map

As shown on the above figure 76.55% of the study area is highly suitable and 15% of the studyb area fail under moderately suitable and the rest is marginally suiable.This shows tha the area is mostely under the condition of highly suiable for surface iirrigation the areal distribution and the suitability classes wese expressed in table below.

Table 4.2: Soil depth classes and suitability rating

Soil depth classes	Area (ha)	Area (%)	Suitability classes
>100	13185.2	76.55	S1
80-100	2592.3	15.1	S2
50-80	1437.22	8.35	S3
Total	**17214.7**	**100**	

Soil drainage suitability

By reclassifying the soil drainage classes into four suitability classes based on soil depth, it becomes easier to assess and determine the most suitable soils for surface irrigation purposes. Accordingly, Borta river catchment's soil drainage classes are presented on figure 4.3 and table 4.3 below.

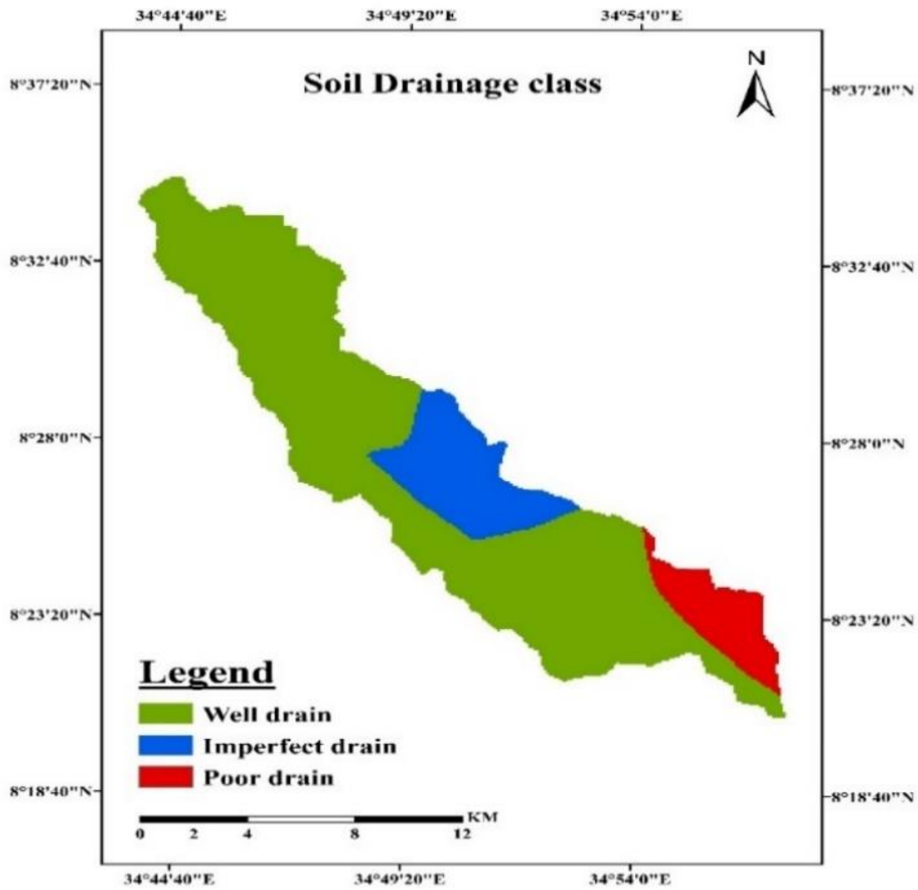

Figure 4.3: suitability map of Soil drainage

The above fig revealed that the majority of the Borta river catchment is range between well drained to imperfect drain that allows surface irrigation development according to FAO recommendation. The suitability class and areal distribution of soil drainage is expressed on the table below.

Table 4.3: Soil drainage classes and suitability rating

Soil drainage classes	Area (ha)	Area (%)	Suitability classes
Well to moderately drain	13,185.2	76.55	S1
Imperfect drain	2592.3	15.1	S2
Poor drain	1437.22	8.35	S3
Total	**17214.7**	**100**	

Soil texture suitability

Based on these textural categories, clay soil and clay loam soil texture are the most prevalent soil textures identified in Borta river catchment. The majority of the study area has clay soil texture. While clay loam is considered as moderately suitable, clay soil texture has an excellent characteristic that has greater moisture and nutrient content and considered as highly suitable for surface irrigation as shown on Figure 4.4 and Table 4.4 below.

Table 4.4: Soil textural class and suitability ranges

Soil textural classes	Area (ha)	Area (%)	Suitability class
Clay	11800.36	68.54	S1
Clay loam	5417.16	31.46	S2
Total	**17217.52**	**100**	

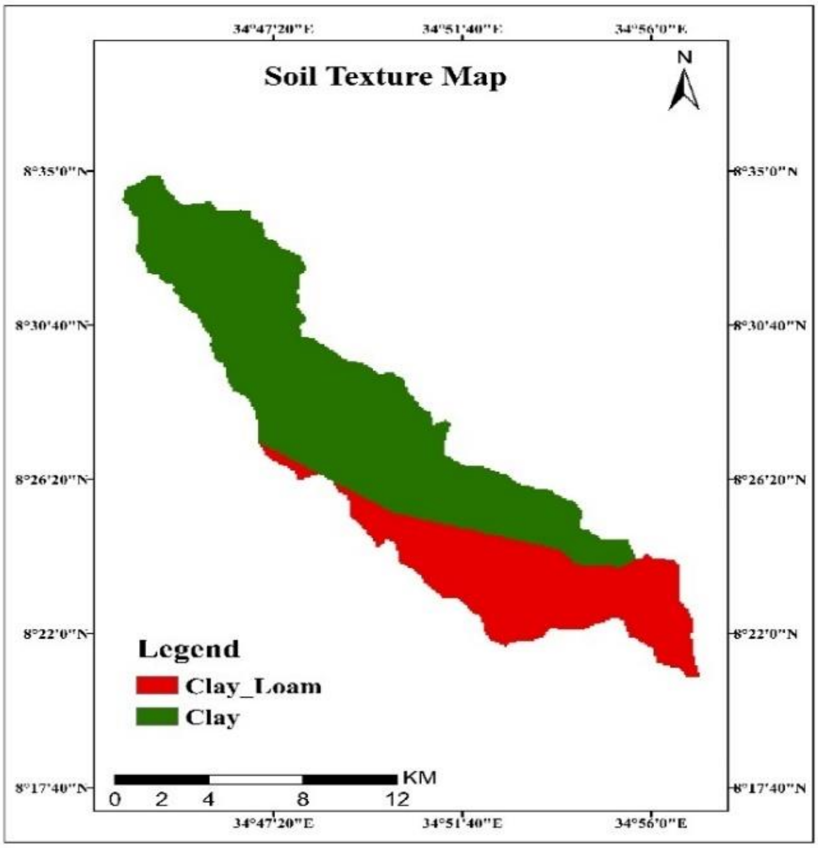

Figure 4.4: soil texture map of the study area

4.2.3. Soil chemical property analysis and suitability test

Comprehensive laboratory testing conducted on soil samples collected from the Borta River catchment. In this laboratory soil analysis, the results of these findings provide valuable insights into the selected soil's chemical characteristics, facilitating informed decision-making for surface irrigation planning. The table below shows that the average value of each selected chemical properties.

Table 4.5: Investigated average values of selected soil chemical properties.

Area division	$CaCo_3$ (%)	EC (dS/m)	ph.
Zone1	5.4	0.4	5.87
Zone2	5.3	0.14	5.81
Zone3	6.6	0.12	5.43

A. Percentage of calcium carbonate (%$CaCo_3$)

A low percentage of calcium carbonate (CaCo3) improves soil structure and is typically good for crop productivity, but larger quantities can cause iron shortage and, when cemented, can reduce the capacity of soils to store water. The presence of calcium carbonate in soil can significantly impact its suitability for surface irrigation. High levels of calcium carbonate can lead to the development of soil characteristics known as calcareous soil. Calcareous soils tend to have poor water infiltration and drainage properties, which can result in waterlogging, reduced root penetration and increased soil salinity (*Nachtergaele, et al, 2009.* As a result, the average calcium carbonate content is 5.76 % entire the study area. This indicates CaCo3 (lime) were not considered as limiting factors. This shows that CaCo3 (lime) was not limiting factor. This is due to the fact that CaCo3's composition ranges from highly suitable to moderately suitable values according to laboratory test and the minimum percentage and maximum percentage acquired in the study area is 4.37 % in zone2 6.87 % in zone3 respectively. The average calcium carbonate content in three classified zone was 5.4 % for zone one, 5.3 % for zone two and 6.6 % for zone three.

B. Soil Ph.

When evaluating the suitability of surface irrigation for crop production, soil acidity is a crucial element to consider. On agricultural yield, it has a direct effect (USDIBR, 2003). The development of crops is negatively impacted by acidic soils, which are also unsuitable for surface irrigation. Acidic soils are those with a pH value below 4.4. On the other hand, soils with a pH value between 5.4 and 6.5 are highly suitable for surface irrigation because they have low acidity or alkalinity levels, resulting in better nutrient availability for most crops. Soils with pH values ranging from 6.5 to 7.8 are considered moderately suitable for surface irrigation. However, if the soil pH values fall within the range of 4.4 to 5.4, the land is deemed marginally suitable for surface irrigation. Some crops, such as tea and pineapple, are tolerant of this relatively high level of acidity or alkalinity (Hussien et al., 2019). Accordingly in this study area the lower Ph level and higher Ph level of the soil of the area is 5.42 in zone3 and 6.24 in zone1 respectively as determined by laboratory test. An average Ph. level for the three-zones was 5.87 for zone1, 5.805 for zone2 and 5.43 for zone3. In the perspective of suitability for surface irrigation the value that acquired from laboratory shows that: the overall soil in the study area was highly suitable.

C. Electric Conductivity (EC) of the soil (ds/m)

Soil electrical conductivity, or EC, is a measure of the soil's ability to conduct or transmit electrical current. It serves as an indicator of soil salinity and saturation, which are crucial factors to assess when considering the potential for surface irrigation. High salt concentration in soils can be detrimental to crop growth and productivity, as it reduces water availability and hinders nutrient uptake. Soil EC is commonly classified into different categories based on its suitability for various purposes. Soils with an EC below 0.1 DeciSiemens per meter (dS/m) are considered highly suitable, while those ranging from 0.1 to 0.7 dS/m are categorized as moderately suitable. Soil with EC values between 0.7 and 1.1 dS/m is considered marginally suitable, and soils with an EC greater than 1.1 dS/m are deemed unsuitable for most crops. These categorizations have been established by sources such as the United States Department of the Interior, Bureau of Reclamation ((*Nachtergaele, et al, 2009*). Laboratory analysis revealed that the average soil EC values were 0.109 for zone1, 0.1143 for zone2, and 0.1364 for zone3. In terms of it's the suitability for surface irrigation, the laboratory result demonstrates that: the overall soil in the study area was, in the moderately suitable conditions. Since it was not limiting factor, it allows surface irrigation development.

4.2.4. Land cover /use suitability

Land use land cover (LULC) is an important factor to consider in land suitability analysis for surface irrigation (Hagos et al., 2022). It is essential for figuring out an area's potential yield for irrigation. In this work, supervised categorization of Landsat satellite images was used to create a map of land use for the year 2021. Numerous significant land use types, including agricultural land, open forest land, shrub land, water bodies and built-up areas could be seen in the area of the study. According to Hagos et al., 2022 and Worqlul et al., 2017, the Agricultural land class was found to be highly suitable. However, due to the greater initial costs for site preparation, both open forest land and shrub land were classed as marginally suitable. In contrast, built-up areas representing settlements and urban areas and water bodies, were classified as unsuitable for surface irrigation

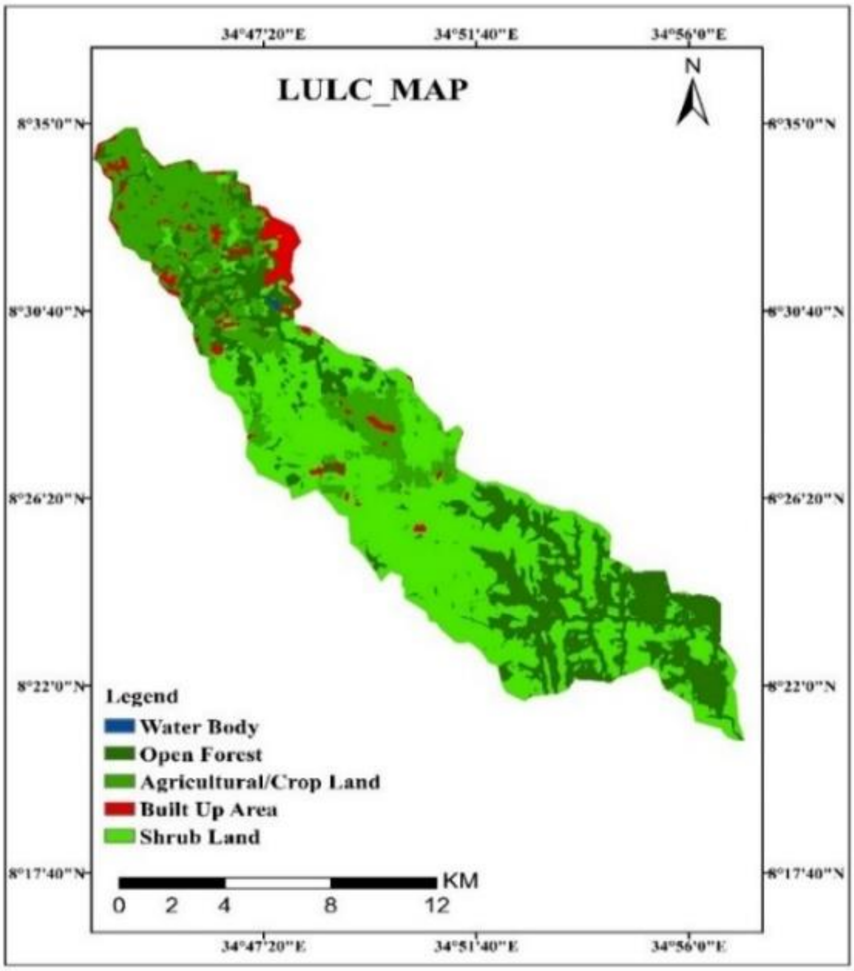

Figure 4.5: Land cover/use map of study area

Table 4.6: LULC suitability of the study area

LULC classes	Area (ha)	Percentage (%)	Suitability
Agricultural/Crop land	3483	20.23	S1
Shrub land	8205	47.7	S3
Built up	728	4.23	N
Open Forest	4785.8	27.765	S3
Water body	12.92	0.075	N

As revealed from the above table Agricultural or crop land, covering approximately 20.23% of the area, is highly suitable (S1) for surface irrigation. The dominant category, shrub land, encompassing 47.7% of the region, is classified as marginally suitable (S3) for surface irrigation, suggesting that some adjustments may be necessary to optimize irrigation practices. Built-up areas, representing 4.23% of the catchment, are also not suitable (N), Open Forest areas, constituting 27.765% of the landscape, are marginally suitable (S3) for surface irrigation, requiring careful management for efficient irrigation. Lastly, water bodies, occupying a minimal 0.075% of the catchment, are naturally unsuitable (N) for irrigation as they were water bodies. These LULC classifications provide valuable insights for land use planning and resource management within the catchment, guiding decisions related to irrigation and environmental considerations. The suitability classes were presented in Table below.

Table 4.7: LULC suitability classes

LULC classes	Area (ha)	Percentage (%)	Suitability classes
Agricultural/Crop land	3483	20.23	S1
Open Forest, Shrub land	12,990.8	75.465	S3
Built up, Water body	740.92	4.305	N

4.2.5. Distance from the water sources

In Ethiopia, the majority of communities engage in irrigation activities in close proximity to rivers or lakes. This is because cultivating land near water sources allows for easy access to water, which is crucial for agricultural production and particularly suitable for surface irrigation. The proximity of rivers or water resources is a significant factor that greatly influences the selection of locations for surface irrigation. To visualize this relationship, a river proximity map was created using ArcGIS, employing a multiple-ring buffer technique based on equidistant streamlines as shown in figure (4.6) below.

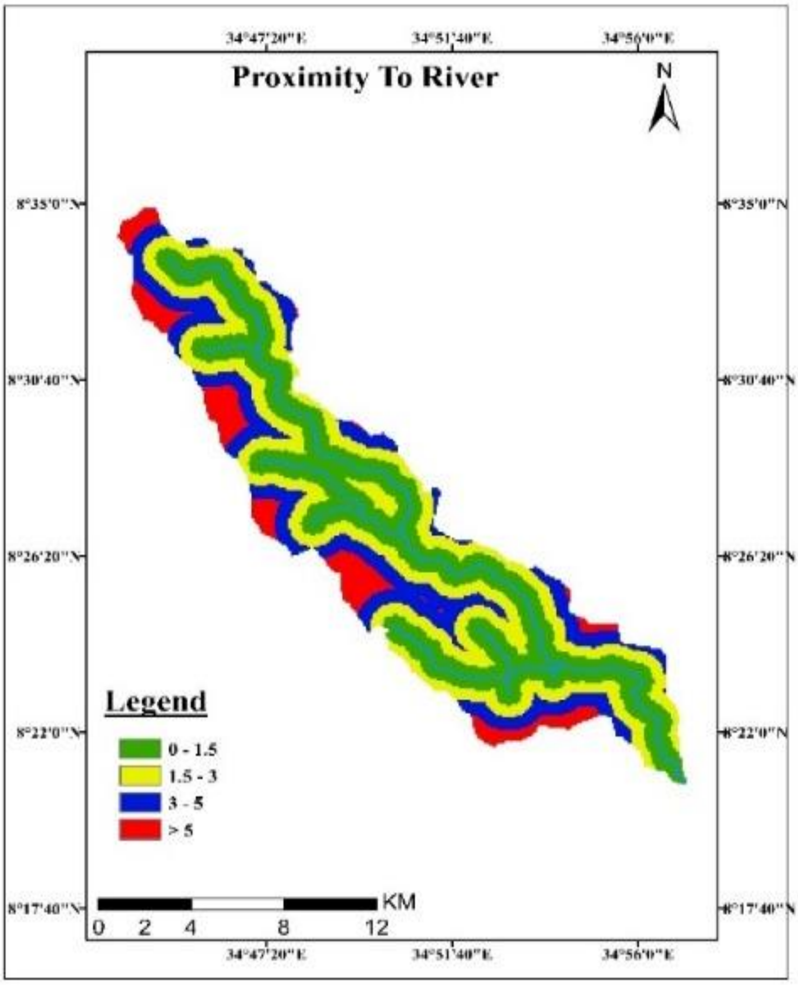

Figure 4.6: River proximity class

Accordingly, 71.25% of the study area covers from highly suitable to moderately suitable of the watershed for surface irrigation development system while, 19.63% of the area covers marginally suitable and 9.12% was not suitable based on distance from the water source.

Table 4.8: River proximity class and range of suitability

River Proximity (km)	Area (ha)	Area (%)	Suitability classes
0–1.5	6867	39.31	S1
1.5–3	5500	31.94	S2
3–5	3377.7	19.63	S3
>5	1470	9.12	N

4.3. Weighting of Factors Using Analytic Hierarchy Process Operation

It is crucial to establish the weights chosen criteria by doing pairwise comparisons in order to find a suitable land for surface irrigation development. These comparisons are based on how important each component is in relation to others, including slope, soil depth, drainage, texture, proximity to rivers, and land use and land cover (LULC). The weighting of these decision factors is determined by considering the importance of each factor for surface irrigation development, the knowledge of experts in the irrigation area, and existing studies on surface irrigation suitability. Slope is deemed as highly important for surface irrigation, as flat land slope is essential for effective surface irrigation. Soil characteristics are also considered significant parameters, as they directly impact water infiltration and retention. Additionally, the proximity of the river to the command area plays a vital role, as a distant river would require substantial investments in constructing conveyance structures. On the other hand, the surface irrigation projects development is thought to place less emphasis on LULC. An Analytic Hierarchy Process (AHP) table was constructed to assign weights to the choice variables based on these evaluations.

Table 4.9: Pairwise comparison matrix of Borta river catchment (PCM)

Factors	Slope	Soil Depth	Soil Drainage	Soil Texture	Proximity	LULC
Slope	**1**	2	3	2	7	5
Soil Depth	1/2	**1**	2	2	2	3
Soil Drainage	1/3	1/2	**1**	2	2	3
Soil Texture	1/2	1/2	1/2	**1**	3	3
Proximity	1/7	1/2	1/2	1/3	**1**	3
LULC	1/2	1/3	1/3	1/3	1/3	**1**
SUM	**2.67**	**4.83**	**7.33**	**7.66**	**15.33**	**18**

Normalizing pairwise comparison matrix of Borta river catchment (NPCM)

The NPCM cell value was obtained by dividing the PCM cell value by the sum of the columns, and the criterion weight was determined by averaging all of the rows, which entails adding the normalized values in each row and dividing the result by the total number of suitability parameters.

Table 4.10: Normalized pairwise comparison matrix

Factors	Slope	Soil Depth	Soil Drainage	Soil Texture	Proximity	LULC	Sum	Criteria weight	Criteria weight%
Slope	0.374	0.414	0.409	0.261	0.457	0.278	2.191	0.365	36.528
Soil Depth	0.187	0.207	0.272	0.261	0.130	0.167	1.224	0.204	20.407
Soil Drainage	0.125	0.103	0.136	0.261	0.130	0.167	0.922	0.153	15.372
Soil Texture	0.187	0.103	0.068	0.131	0.196	0.167	0.851	0.1418	14.187
Proximity	0.053	0.103	0.068	0.043	0.065	0.167	0.50	0.083	8.339
LULC	0.075	0.069	0.045	0.043	0.022	0.056	0.301	0.052	5.165

Consistency analysis

The Analytic Hierarchy Process (AHP) relies on consistent judgements when making pairwise comparisons between different criteria or alternatives. Consistency refers to how logical and internally aligned the comparisons are. A consistency ratio (CR) is used to measure the degree of inconsistency in the comparisons. The CR compares the actual inconsistency to the expected inconsistency if the comparisons were perfectly consistent. Generally, if the CR is below 0.10 or 10%, the comparisons are considered sufficiently consistent for use in the AHP model. This threshold ensures the decision maker's judgments do not introduce too much inconsistency. If the CR goes above the 0.10 threshold, it indicates the comparisons may need to be re-examined and improved to increase consistency. The goal is to make sure the comparisons align logically so the AHP decision model has an acceptable level of consistency in the inputs. To determine whether the calculated values are accurate or not, after normalizing the matrix, the consistency must be calculated. We must sum up each element in each row of this matrix in order to find the weighted sum value.

Table 4.11: Matrix consistency

Factors	slope	Soil Depth	Soil Drainage	Soil Texture	proximity	LULC	weighted sum value	Criteria weighting	$\frac{\mathbf{Ws}}{\mathbf{Cw}}$
Slope	0.365	0.408	0.461	0.2834	0.584	0.258	2.360	0.365	**6.462**
Soil Depth	0.183	0.204	0.307	0.284	0.167	0.155	1.299	0.204	**6.368**
Soil Drainage	0.122	0.102	0.154	0.284	0.167	0.155	0.983	0.154	**6.395**
Soil Texture	0.183	0.102	0.077	0.142	0.250	0.155	0.908	0.142	**6.404**
Distance	0.052	0.102	0.077	0.047	0.083	0.155	0.517	0.083	**6.196**
LULC	0.073	0.068	0.051	0.047	0.028	0.052	0.319	0.052	**6.177**

Where: Ws - weighted sum value and Cw - Criteria weighting

Calculating the consistency measure

(λ_{max}) was calculated by summing all the ratio value and divided by the number of suitability parameters (n).

$$\lambda_{max} = \frac{6.462+6.368+6.395+6.404+6.196+6.177}{6} = 6.334$$

Calculating the consistency index (CI)

Where n-is number of factors

$$CI = \frac{6.334-6}{6-1} = 0.0667$$

Calculating consistency ratio (CR)

CR $= \frac{\mathbf{0.0667}}{1.24} =$ **0.054** this was less than the maximum allowable CR (0.1) so, the assumption is acceptable.

Table 4.12: Percentage of influence for each factor

Factors	slope	Soil Depth	Soil Drainage	Soil Texture	proximity	LULC	Sum
Influence %	37%	21%	15%	14%	8%	5%	**100%**

4.4. Waited Overlay Analysis

Overlay analysis is a spatial analysis technique used to identify suitable areas for a particular purpose by overlaying multiple layers of geographic data. In the context of finding suitable land for surface irrigation, overlay analysis was employed to consider various factors and criteria related to irrigation suitability. By using a weighted overlay analysis of each individual suitability parameter slope, soil depth, soil texture, soil drainage, proximity to a water source, and LULC, the watershed area's suitable land was identified.

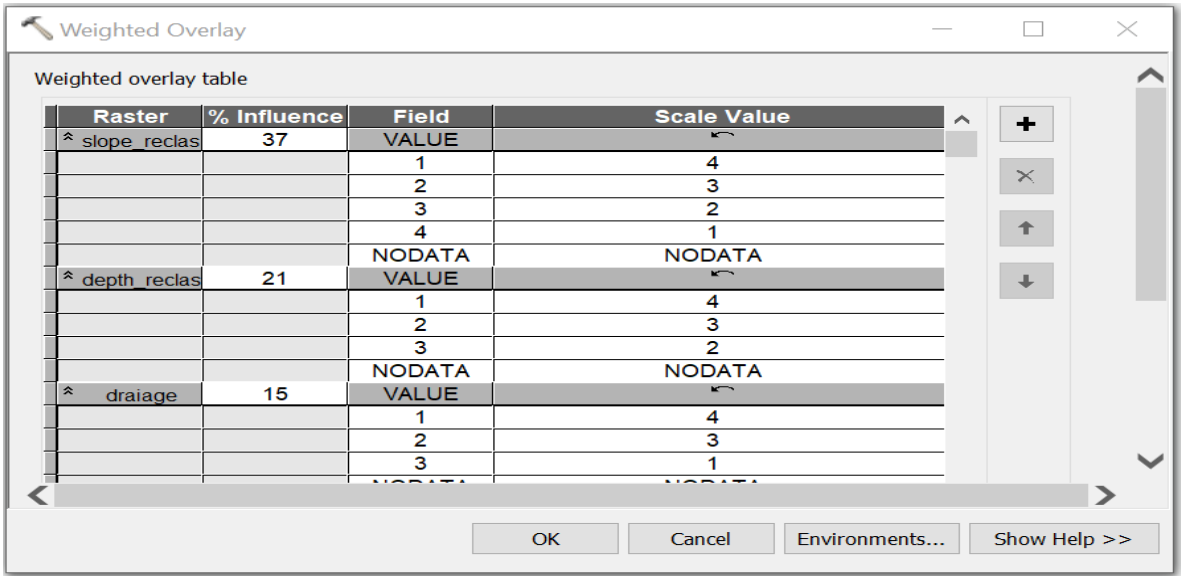

Figure 4.7: Weighting overlay analysis process for selected factors using ArcGIS

According to the qualitative land evaluation for irrigation suitability, which is depicted in the table and figure below, the majority of the study area was determined to be highly, moderately, and marginally suitable for irrigation. Small areas were determined to be highly suitable.

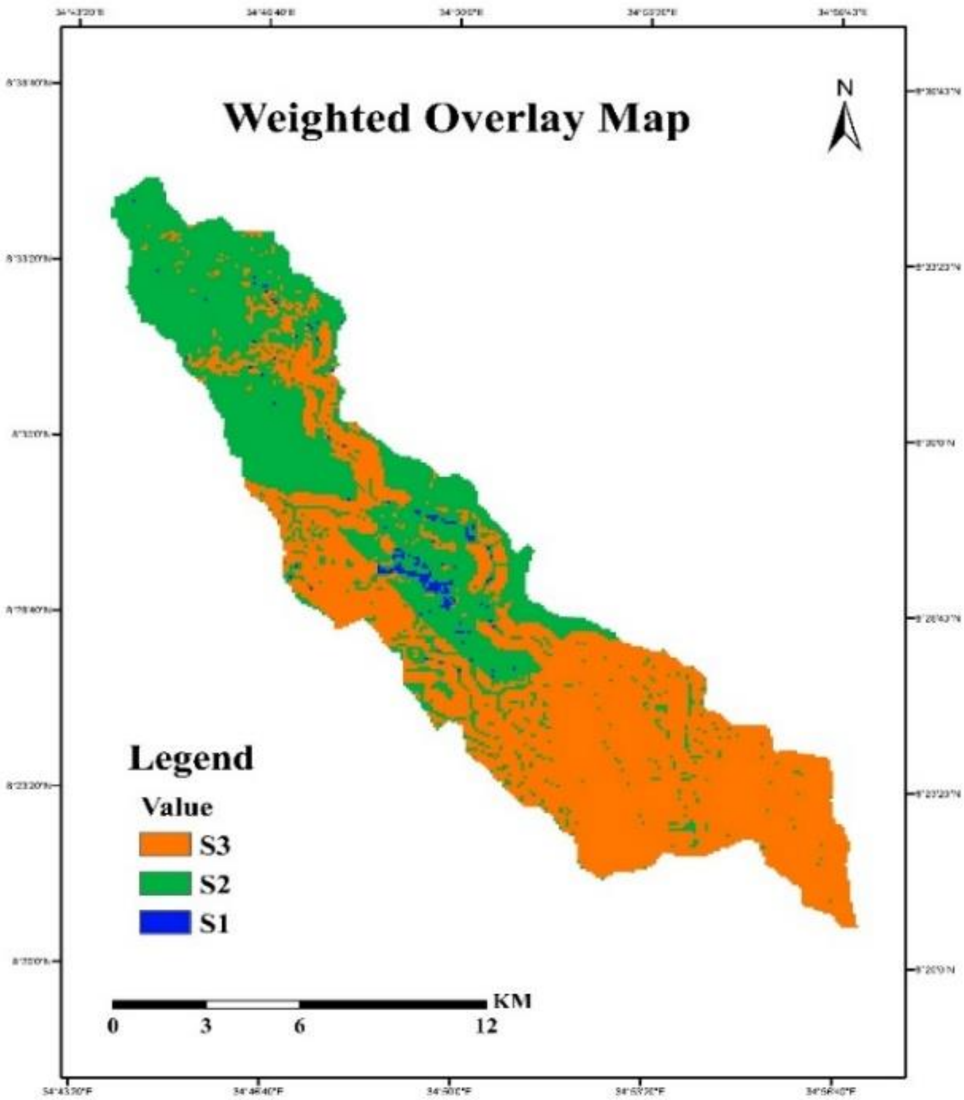

Figure 4.8: Overall suitability map of the study area

The analysis categorized the study area of 17,214.7 ha into three classes: highly suitable (S1), moderately suitable (S2), and marginally suitable (S3). The overlay mapping revealed that only a small area of 216.4 ha (1.26%) was highly suitable for surface irrigation and a larger area of 7,033.3 ha (39.85%) was moderately suitable. The largest portion of 9,965 ha (58.89%) was marginally suitable for irrigation under the criteria used. This overlays suitability mapping quantitatively delineates the spatial distribution of irrigable land classes, from the prime areas meeting all criteria to marginal areas with limitations as shown in table 4.13 below. The overlay analysis gives an impartial evaluation of where surface irrigation could work well based on looking at many geographic and environmental factors together. The different suitability levels and total area for each level identified by the analysis can help to guide thoughtful choices about set up how much land to include in irrigation. The suitability mapping and classes make it easier to make wise decisions about surface irrigation expansion according to the area's physical conditions.

Table 4.13: Areal distribution of suitability classes

Suitability Classes	Area (ha)	Area (%)
Highly suitable(S1)	216.4	1.26
Moderately suitable(S2)	7033.3	39.85
Marginally suitable(S3)	9965	58.89
Total	**17,214.7**	**100**

4.5. Assessment of Water Resource

The study area's available surface water was assessed using stream flow discharge data obtained from the Ministry of Water, Irrigation, and Energy bureau. The mean annual monthly stream flow, as well as the maximum and minimum flow, were all calculated. However, actual irrigable land was computed using average flow data after releasing 25% for ecological purpose. Table 4.14 and fig 4.9 below shows that the Average, maximum and minimum annual flow of Borta river.

Table 4.14: Average, maximum and minimum annual monthly flow (M^3/s)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Av. Flow	0.855	0.796	0.77	0.7	1.5	2.55	3.86	4.5	3.42	2.84	1.03	0.99	**23.811**
Max. Flow	1.221	1.294	2.451	1.534	4.103	4.515	6.39	6.788	5.559	4.746	1.952	1.635	**42.688**
Min. Flow	0.123	0.189	0.132	0.142	0.143	0.237	1.39	2.269	1.875	0.244	0.165	0.163	**7.072**

Total average flow, minimum and maximum flow were added 23.811, 7.072 and 42.688 m^3/s respectively minimum flow is observed in the month of January (0.123) and maximum flow were observed in the month of August (6.788). And the average stream flow of Borta river varied 0.7 m^3/s during April to 4.5m^3/s during August. Borta River is the perennial river with average annual flow of 751Mm^3.

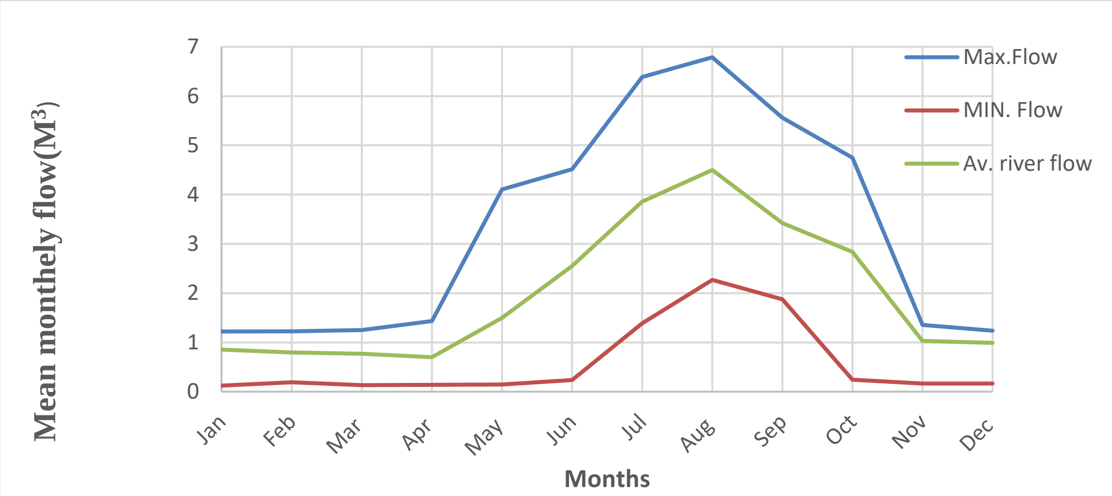

Figure 4.9: Graphical representation of average, maximum and minimum flow

Table 4.15: Average flow after releasing 25% for ecological purpose

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Flow(M^3/s)	0.641	0.59	0.577	0.525	1.125	1.91	2.895	3.375	2.565	2.13	0.7725	0.7425

4.6. Calculation of Crop Water Requirements and Irrigation Water Requirements

The term "irrigation water requirement" denotes the quantity of water that is required to supplement rainfall and sufficiently used to water crops to satisfy their water demands. This guarantees that crops obtain an adequate amount of moisture for their best possible development and productivity in areas where rainfall is inadequate. On the other hand, "crop water requirement" refers to the specified water requirements of a given crop. It includes the overall amount of water required for a crop's growth (gross irrigation water requirement), accounting for things like evapotranspiration (the sum of water loss through plant transpiration and soil evaporation) and other environmental considerations. The amount of water needed by crops varies based on type of crop, development stage, climate, and soil properties.

Reference evapotranspiration (ETO)

The average ETO for the Dambi Dollo station was 3.59 mm/day. It varies from 2.65 to 4.34 mm/day. The maximum ETO was in February and the minimum was recorded in the month of August.

Table 4.16: Calculated ETO values in mm/day for Dambi Dollo station

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
ETo (mm/day)	3.93	4.34	4.3	4.33	3.46	3.12	2.92	2.65	3.35	3.58	3.57	3.54	**3.59**

Effective rainfall (P_{eff})

Using collected average rainfall data, the Cropwat program computed effective rainfall. Effective rainfall in the catchment varied from 23.9mm February to 94.4mm July respectively as shown on table below.

Table 4.17: Effective rainfall (mm)

Months	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Rainfall(mm)	66.5	56.5	95.9	104.9	132.1	136.1	148	120	125	108.6	72	73.8	**1239.4**
Effective Rainfall(mm)	29.9	23.9	52.7	59.9	81.7	84.9	94.4	72	76	62.9	33.6	35	**706.9**

4.6.1. Crop water requirements Calculations

CROPWAT 8.0 model was used to determine Crop water requirements using monthly average value of crop coefficient and ETO for each of the crop, maize, onion and potato. For rainfed farming, the crop season was chosen based on the wet season. After the first phase of cultivation's crops were harvested, land preparation took place, and the second phase of farming and specified irrigation technique followed. In accordance with the local agricultural calendar, the first stage of land preparation began in the middle of May, and crops were harvested starting in the middle of October to the end of November. Then, in early December, the second phase of irrigated agriculture began with the preparation of the land and then, cropping of selected crops began Early in January and the harvesting time varied depending on the crops chosen and the dates of planting.

Table 4.18: Cultivation Calendar for selected Crops

Crops type	Planting date	Harvesting date
Maize	1-Jan	25-Aprl
Onion	10-Jan	14-Aprl
Potato	20-Jan	19-May

The input data used for the calculation of water requirement in the CROPWAT are shown in appendices table 6 and the effective rainfall computed by entering the average rainfall to the model and the entered values are also given in (appendices table 5). Net irrigation requirements of maize, onion and potato at the study area are given in appendices table. The monthly calculated values of ETc for each crop is given in table 4.19 below.

Table 4.19: Crop water requirement of selected crops (mm/month)

Crops	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Total (Growing period)**
Maize	44.7	122.1	158	75.2	0	0	**400**
Onion	61.7	107.2	139.8	60.8	0	0	**369.4**
Potato	34.1	89.9	133.7	134	66.1	0	**457.9**
Total (Monthly)	**140.5**	**319.2**	**431.5**	**270**	**66.1**	0	**1227.3**

Within the watershed, various crops have varying crop water requirements. Crop water requirements for selected crops, Maize, Onion and potato are presented in above Table for each month. From all crops potato has highest crop water requirement which is 457.9 mm/growing period and onion has the lowest water requirement 369.4 mm/ growing period. Total water requirement was calculated as 1227.3 mm/growing period for all crops.

Table 4.20: Command area assigned for selected crops.

Crops	Area (ha)	Area (%)
Maize	2465	34
Onion	2465	34
Potato	2320	32
Total	**7250**	**100**

4.6.2. Irrigation water requirements

- **Gross irrigation water demand**

The estimation of gross irrigation water requirements for selected crops, i.e., Maize, Onion, and Potato, was carried out at identified potential irrigable sites from CROPWAT 8 using Kc (crop coefficient) and ETO (Reference Evapotranspiration). According to FAO calculations, the overall irrigation efficiency declined from 100% to 54%. The gross irrigation water demand of selected crops was given in mm/month and m^3/s in table 4.21 table 4.22 below respectively.

Table 4.21: GIWR for each crop in mm

monthly						Total GIWR/ Growing period
Crops	**January**	**February**	**March**	**April**	**May**	
Maize	101.6	116.8	238.7	53.5	0	510.6
Onion	132.4	112.1	120.8	28.1	0	393.4
Potato	87.2	77.9	111	86.3	22.1	362.4
Total	**321.2**	**306.8**	**470.5**	**167.9**	**22.1**	**1266.4**

Table 4.22: GIWR in m^3/s for each crop for growing period

Crops	month					Total GIWR/	Area
	Jan	Feb	Mar	Apr	May	Growing period	(ha)
Maize	0.1479	0.986	0.96135	0.27115	0	**2.3664**	2465
Onion	0.3944	0.8381	0.7888	0.2958	0	**2.3171**	2465
Potato	0.2088	0.6264	0.696	0.6728	0.116	**2.32**	2320
Total	**0.7511**	**2.4505**	**2.44615**	**1.23975**	**0.116**	**7.0035**	**7250**

4.7. Possible Irrigable Land with Available Flow in the River Catchment

By comparing the irrigation needs of the land that had been determined to be suitable for surface irrigation with the available mean average monthly flows in the Borta River catchment, the possible irrigation capacity of the study area was determined according to area division for each crop based on the approach recommended by (FAO, 1997). Gross irrigation water demand for selected crops such as maize, onion and potato and Monthly streamflow is presented in table 4.24 below.

Table 4.23: Comparing available streamflow and gross irrigation water demand

Month	Jan	Feb	Mar	Apr	May
Maize	0.1479	0.986	0.96135	0.27115	0
Onion	0.3944	0.8381	0.7888	0.2958	0
Potato	0.2088	0.6264	0.696	0.6728	0.116
Total GIWR (m^3)	**0.7511**	**2.4505**	**2.44615**	**1.23975**	**0.116**
Steam flow (m^3)	**0.64125**	**0.597**	**0.5775**	**0.525**	**1.125**

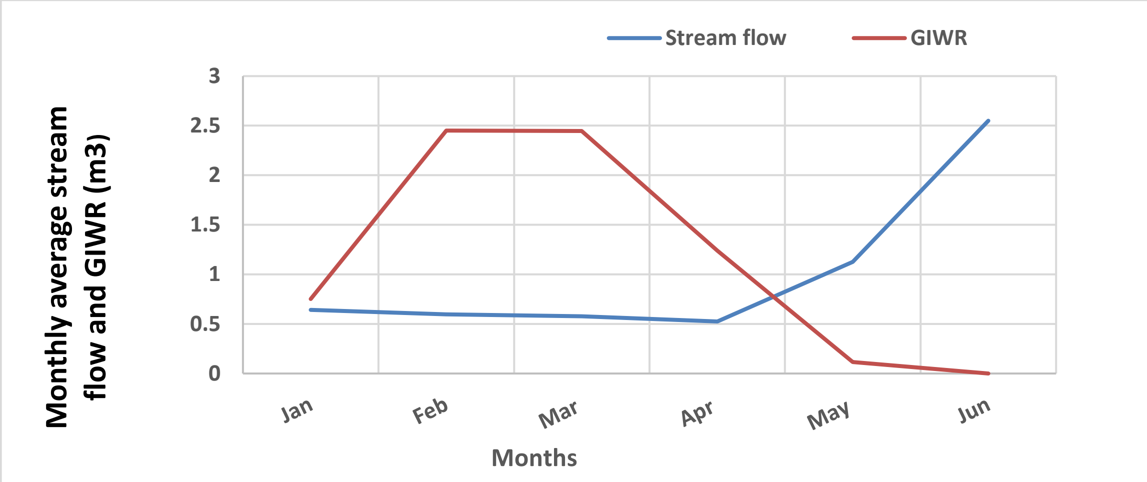

Figure 4.10: Graphical representation of the comparisons of available flow with GIWR.

Based on the available stream flow, it is possible to calculate the effective irrigable area (in hectares) for each month. The crop area assigned to each particular crop was shown in Table 4.24 below.

Table 4.24: Optimal irrigable area (ha) for each crop in each month

Crops	Jan	Feb	Mar	Apr	May
Maize	2142	578	577.32	1190	0
Onion	2142	578	577.32	1190	0
Potato	2016	544	543.36	1120	2320
Total	**6300**	**1700**	**1698**	**3500**	**2320**

The effective irrigable area varied from month to month, as indicated in Table 4.25, however the actual effective irrigable area was the smallest of the month. The combined gross irrigation water requirement for all chosen crops and arable land was 7.0035 m^3/s, however the available streamflow was 3.466 m^3/s during the chosen irrigation months (January to May) after releasing 25% for ecological purpose, which could irrigate 3587.7 ha of arable land. Consequently, 3.534 m^3/s of irrigation water are needed to irrigate the remaining entire 3662.3 hectares of land throughout the growing season. This necessitates the need for storage structure inside the study area to compensate crop water requirement and irrigation water need of all suitable land in the catchment. So, the irrigation potential of the Borta river catchment was found to be 3587.7 ha which accounts for 49.5 % of the total suitable land area of the Borta river catchment.

If we need to start irrigation with effective irrigable area, the irrigation may be unreliable because of the variation of the flow from month to month. So, to start irrigation with available flow in the catchment without any storage, we need to calculate critical command area. The area that was calculated below on table 4.25 are called the critical command area.

Table 4.25: Critical command area that can be irrigated with available flow

Crops	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Irrigable Area (ha)**	**Un-irrigable Area (ha)**
Maize	0.0578	0.2023	0.19652	0.0867	0	**578**	**1887**
Onion	0.0578	0.2023	0.19652	0.0867	0	**578**	**1887**
Potato	0.0544	0.1904	0.18496	0.0816	0.0272	**544**	**1776**
Total	**0.17**	**0.595**	**0.577**	**0.255**	**0.0272**	**1700**	**5550**
Stream flow (m^3)	**0.64125**	**0.597**	**0.5775**	**0.525**	**1.125**		

As we observe from the above Table, from 7250 ha of land that is suitable for surface irrigation in Borta river catchment, we can irrigate 1700 ha of land for the three selected crops with the areal percentage division of crops, i.e.; maize 34% (578 ha), onion 34% (578 ha) and potato 32% (544 ha) in this catchment the selected crops could be supplied with sufficient water throughout the growing period and Irrigation in this case could be reliable.

4.8 Discussion

This comprehensive evaluation of land suitability and water availability provides vital insights to guide sustainable surface irrigation development in the Borta River catchment. The GIS-based multi-criteria analysis effectively delineated the spatial distribution of land suitability classes based on a weighted overlay of factors like slope, soils, land use and proximity to water sources. This revealed that only a small portion of land is highly suitable, with moderate to marginal suitability prevailing across much of the catchment.

The soil chemical analysis also showed no major limitations in terms of salinity, acidity or alkalinity that could restrict crop productivity under irrigation. The analysis provides a strong foundation for planning context-specific surface irrigation projects aligned with the catchment's soil and topography(Design et al., 2019).

The water availability assessment indicated adequate mean annual river flows. However, dry season water scarcity remains a major bottleneck for reliable irrigation, as also evidenced by the gap between irrigation demand and available supplies. To address these challenges, Storing excess wet season flows by constructing small reservoirs or farm ponds could help augment dry season availability. Adopting efficient irrigation techniques like drip or sprinkler systems could also enhance water productivity. Exploring the groundwater potential through hydrogeological studies is advisable, as conjunctive use of surface and groundwater can improve water security(Porhemmat et al., 2018).

The comparative analysis of gross irrigation requirements for dominant crops against the available surface water clearly indicates that current flows are inadequate to meet crop water needs, especially in the dry season. This water scarcity challenge will require a multi-pronged strategy. Increasing water storage in small reservoirs and farm ponds is an obvious solution. Adopting micro-irrigation techniques like drip or sprinklers can significantly enhance water productivity per unit of land efficient water application, also on-farm conservation techniques and groundwater use is essential to bridge the gap between irrigation requirements and available water in the Borta River catchment area. Deficit irrigation schedules can be planned to align water application with crop growth stages (Barragan et al., 2010).

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This study evaluates land suitability and water availability for surface irrigation in the Borta river catchment, located in the Baro Akobo basin of western Ethiopia. GIS-based multi-criteria evaluation and weighted overlay analysis was used to assess the suitability of land considering factors like slope, soil properties, land use/land cover and proximity to water sources. The water availability assessment involved analyzing hydrological data to quantify the surface water resources that could potentially be used for irrigation purposes.

The results of the slope suitability analysis indicated that only around 7% of the catchment area fell under highly suitable to moderately suitable classes while the remaining vast majority was either marginally suitable (9%) or not suitable (84%) based on the slope thresholds. Evaluation of soil characteristics including texture, depth and drainage showed that dominant soil texture in the catchment were clay and clay loam, with largely adequate depth (>100cm) and well drained. In addition, soil sample were collected from representative pits within the catchment for the purpose of testing the chemical properties of the soil such as ($CaCo_3$ content, ph., electric conductivity) of the soil of the study area by laboratory test. As a result of the test the chemical properties of the soil was not limiting factor for surface irrigation entire the catchment, since they fell in the range of highly suitable to moderately suitable.

The land use/land cover assessment revealed that only 20% of the area comprised of croplands that were highly suitable for irrigation. Other land cover types like shrub land and open forests were deemed marginally suitable. In terms of proximity to water sources, about 70% of the catchment area was found to be in the range of highly to moderately suitable.

After combining the individual factor suitability maps using the Analytical Hierarchy Process (AHP) with appropriate weightings, the final land suitability map categorized a portion of the area as highly suitable, a larger portion as moderately suitable, and the majority as marginally suitable.

Regarding water availability, analysis using hydrological data revealed that the average annual flow of the Borta River amounted to approximately 751 million cubic meters. When comparing this available surface water supply with the gross irrigation water requirements for major crops like maize, onion, and potato cultivated in the catchment area, it was evident that it could support irrigation on 3,587 hectares of land. This represents approximately 50% of the suitable land within the catchment area. To facilitate irrigation on the remaining land area, it becomes apparent that the construction of additional water storage infrastructure is imperative.

Generally, while the Borta river catchment possesses moderate potential for surface irrigation development considering land suitability and water availability, there are several limitations that need to be addressed through appropriate planning and investments. Strategic measures like water harvesting, storage and conservation, slope management, soil reclamation and optimizing cropping patterns can help tap the irrigation potential in a sustainable manner.

5.2. Recommendation

Based on the findings and conclusions of this study, the following recommendations were made:

- Construction of water storage and diversion structures like small reservoirs and dams should be explored to store excess water during rainy season and augment dry season flows for expanding irrigation.
- Land leveling and terracing activities could help reduce slope limitations in steeper areas and enhance suitability for surface irrigation.
- Adopting effective irrigation methods like drip or sprinkler systems to enhance water use efficiency.
- Further studies to assess the groundwater potential and prospects for conjunctive use with surface water resources.
- Detailed surveys, feasibility assessments, and pilot projects to identify priority sites for irrigation development in the catchment.
- Awareness creation about optimal crop selection, cropping patterns, and irrigation schedules aligned with soil and water availability.

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APPENDICES

Appendix Table 1. Corrected Monthly Rainfall at Dambi Dollo station (mm)

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1995	12.28	3.9	48.4	84.2	121.8	160.7	125	119.2	154.2	71.6	7.9	0
1996	9.53	2.2	218	281.2	213.8	143.5	133.8	209.4	62.2	5.4	11.1	24.9
1997	3.1	120.7	98.4	95.3	98.47	95.3	161.2	221.9	194.1	176	21.2	30
1998	9.9	11.3	33.8	159.1	187.1	266.4	148.2	112.1	157.4	176	36.7	22.4
1999	0	21.8	47.5	91.2	154.1	159.8	172	205.5	159	106	40.3	43.9
2000	6.3	6.18	53	36.4	39.58	123.1	202.8	144.6	98.1	86.5	29.4	98.4
2001	98.47	88.94	98.4	95.3	98.47	95.3	98.47	98.47	95.3	98.4	95.3	98.4
2002	98.47	88.94	98.4	95.3	98.47	95.3	98.47	98.47	95.3	98.4	95.3	98.4
2003	0	29.9	42.6	107.2	165.8	159.8	252.4	197.3	208.5	53.5	34.2	28.1
2004	25.8	3.1	27.6	171.8	220.3	158	205.1	208.5	206	27.3	143	23.7
2005	155	167.4	180	95.3	155	167.4	192	116	117.2	108	14.2	1.6
2006	24.33	14.8	92	44.7	191.3	188.2	98.47	98.47	95.3	98.4	95.3	98.4
2007	23.2	9.8	9.8	0	4.5	9.8	9.8	9.8	9.8	9.8	7.3	4.5
2008	9.8	9.8	9.8	9.8	9.8	7.3	9.3	9.8	0	4.5	9.8	9.8
2009	9.8	9.8	9.8	7.3	182.2	113.6	194.4	73.9	72.3	31.8	87.3	207
2010	268	60.2	8.4	77.6	126.6	294.8	211.6	215.2	136.6	165	86.4	72.3
2011	17.8	125.9	190	316	71.9	7.5	78.5	103.3	330.8	186	233	116
2012	196.8	59.6	88.6	31.8	85.3	184.4	339.1	95.8	3.2	82.8	57.7	345
2013	181.8	200.3	175	152.1	103	72.3	60.9	58.6	189.1	320	136	3.2
2014	62.4	35.9	324	185.9	242.9	191.1	116.4	128.3	76.1	308	196	215
2015	183.1	115.9	160	66.9	204.5	164.6	201.2	0	164.6	67.6	75.7	9.8
Mean monthly	**66.47**	**56.49**	**95.88**	**104.97**	**132.14**	**136.10**	**148.05**	**120.22**	**125.00**	**108.62**	**72.05**	**73.85**

Appendix Table 2. Dambi Dollo Maximum Temperature

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1995	27	26.69	26.19	24.73	24.6	23.64	21.33	22.3	22.68	24.02	24.91	24.68
1996	24.99	26.03	25.61	25.63	23.14	22.2	21.55	21.3	22.1	23.97	25.39	24.53
1997	24.29	25.71	25.67	24.14	22.5	21.93	20.62	21.3	22.97	23	22.82	23.97
1998	25.26	26.96	26.18	27.55	24.32	22.72	20.97	20.5	22.16	22.35	24.13	25.6
1999	25.59	27.86	28.35	26.88	22.87	22.23	20.36	20.8	22.04	21.67	24.45	24.82
2000	25.82	27.27	28.43	25.18	24.02	22.16	21.23	20.8	22.33	22.21	23.85	24.69
2001	25.33	27.31	26.25	26.76	24.39	21.65	21.4	21.4	22.66	23.31	23.86	24.78
2002	24.5	26.99	26.23	26.41	24.72	21.89	22.17	21.6	22.47	23.4	24.04	23.93
2003	25.85	25.11	24.59	24.59	24.59	24.59	24.59	24.6	24.59	24.59	24.59	24.59
2004	24.98	27	27.62	26.28	24.99	21.94	21.24	22.1	22.25	23.85	23.99	24.68
2005	25.56	28.83	27.66	26.85	24.95	22.38	20.92	22	22.25	22.98	23.92	25.61
2006	27.1	28.19	27.88	27.69	24.27	24.61	21.81	21.4	21.91	22.96	23.71	23.94
2007	24.72	25.8	27.63	26.08	24.46	22.81	21.34	21.4	22.53	24.49	24.7	25.54
2008	25.69	26.64	27.76	24.93	23.61	22.35	20.89	21	22.44	23.72	23.72	24.14
2009	25.22	25.92	26.52	25.8	25	23.54	21.58	21.5	22.45	23.39	24.48	24.05
2010	25.82	26.71	27.21	28.32	24.07	22.78	21.03	21.8	21.85	23.68	23.71	23.58
2011	24.6	27.37	27.05	27.07	24.4	22.36	22.23	21.5	22.54	24.79	24.17	24.65
2012	26.23	28.52	28.19	27.59	24.92	22.79	25.18	24.6	24.59	24.59	24.59	24.59
2013	24.59	24.59	13.44	24.59	24.59	13.43	13.04	23	13.02	22.95	24.59	24.59
2014	25.68	27.65	26.81	25.37	23.69	23.41	21.84	24.5	24.59	33.71	34.37	35.21
2015	27.02	39.56	39.79	36.17	34.16	33.5	32.48	32.3	33.62	35.21	34.97	29
Mean monthly	**25.52**	**27.46**	**26.91**	**26.60**	**24.68**	**22.81**	**21.8**	**22.46**	**22.76**	**24.52**	**25.19**	**25.29**

Appendix Table 3. Dambi Dollo Minimum Temperature

Year	Jan.	Feb.	Mar.	Apr.	May.	Jun.	Jul.	Aug.	Sep.	Oct.	Nov.	Dec.
1995	11.29	12.11	12.97	14.62	14.85	14.43	13.8	13.53	13.5	12.68	13.16	11.96
1996	13.15	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16
1997	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16
1998	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16
1999	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16
2000	12.62	12.75	14.47	14.62	13.24	13.32	12.77	12.55	12.8	12.87	11.77	10.73
2001	9.24	9.36	13.29	14.33	14.6	13.66	13.18	13.87	13.48	12.92	11.07	10.92
2002	11.16	12.73	14.2	14.76	14.8	13.82	13.95	13.19	13.79	12.59	12.02	10.85
2003	10.72	13.05	14.44	14.25	15.32	14.05	13.71	13.79	13.85	12.18	12.18	10.42
2004	11.69	12.1	14.43	14.97	14.84	13.65	13.13	13.32	13.35	12.53	11.9	11.13
2005	15.56	14.46	13.81	15.77	14.4	13.87	13.87	13.65	14.23	12.66	10.83	10.55
2006	14.14	14.79	11.77	12.96	13.59	13.58	14.48	14.31	13.86	13.17	13.16	13.16
2007	10.35	11.24	13.03	13.82	13.69	13.76	10.84	12.68	14.14	15	14.02	13.42
2008	13.31	14.17	12.96	14.49	14.56	14.07	14.24	13.55	13.68	12.77	13.25	14.15
2009	12.92	14.54	14.55	14.08	14.24	13.63	13.61	12.89	13	13.16	13.16	13.16
2010	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16	13.16
2011	13.31	14.16	13.01	14.44	14.55	14.08	14.24	13.6	13.65	12.89	13.1	14.16
2012	12.96	14.49	14.55	14.08	14.24	13.63	13.61	12.89	12.73	12.66	12.72	13
2013	12.73	13.08	13.98	14.05	12.96	14.49	14.08	14.2	13.57	13.66	12.85	12.25
2014	12.34	9.79	12.77	13.01	13.17	13.16	13.16	11.31	10.07	13.89	14.5	14.02
2015	13.75	12.7	13.92	14.32	14	13.84	12.51	13.02	12.1	11.81	11.31	8.5
Mean monthly	**12.56**	**12.92**	**13.52**	**14.012**	**13.95**	**13.66**	**13.38**	**13.25**	**13.22**	**13.01**	**12.70**	**12.30**

Appendix Table 4. Monthly flow Observed for Borta river gauging station (m3 /s) (1995-2015)

Year	Jan.	**Feb.**	**Mar.**	**Apr.**	**May.**	**Jun.**	**Jul.**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**	**annual**
1995	1.815	1.662	1.713	1.046	0.786	0.914	1.39	2.269	4.277	2.429	1.472	0.874	1.72
1996	0.664	1.115	1.136	0.509	0.949	1.577	2.893	2.942	3.021	3.012	1.497	1.023	1.69
1997	0.782	0.569	0.56	0.736	1.387	3.303	4.325	4.331	3.372	3.06	0.893	0.784	2.01
1998	1.262	0.979	0.896	0.802	1.205	1.965	2.779	3.463	3.502	3.23	0.761	0.774	1.802
1999	1.327	1.081	0.876	1.026	1.914	4.515	3.523	2.78	3.54	3.54	1.74	1.635	2.29
2000	1.352	1.051	0.888	1.01	1.421	2.776	4.266	2.676	3.784	3.183	1.526	0.782	2.06
2001	1.29	1.058	0.967	0.913	0.888	1.789	2.585	3.8	3.054	2.567	1.952	0.671	1.79
2002	0.755	0.308	0.284	0.151	0.481	2.182	4.652	4.827	3.452	2.296	1.245	0.793	1.785
2003	0.535	0.34	0.316	0.776	1.348	1.991	5.215	6.78	4.543	3.891	1.484	2.313	2.46
2004	1.646	1.388	0.934	1.334	1.635	3.044	6.39	6.788	3.379	4.746	1.432	1.165	2.82
2005	1.633	1.294	1.297	0.902	1.677	3.143	6.18	4.73	5.559	4.9	0.859	1.51	2.807
2006	1.721	1.54	0.927	0.896	4.103	4.394	5.239	5.402	2.372	3.795	1.011	1.616	2.751
2007	0.108	0.58	0.64	0.142	0.149	0.179	4.35	6.56	4.245	3.45	0.248	0.167	1.735
2008	0.087	0.67	0.31	0.3	0.301	2.14	3.45	5.37	2.56	1.56	0.257	0.163	1.431
2009	0.123	0.81	0.43	0.71	0.91	0.237	3.78	4.45	2.321	2.391	0.264	0.122	1.379
2010	0.07	0.59	0.37	0.23	0.143	3.16	3.89	3.43	3.65	0.244	0.165	0.87	1.454
2011	0.413	0.276	0.302	0.466	1.292	4.13	2.513	4.779	3.692	1.499	0.338	1.568	1.77
2012	0.67	0.214	2.651	0.542	3.909	2.642	4.678	4.278	2.45	0.474	0.262	0.271	1.92
2013	0.214	0.189	0.132	0.441	3.143	4.23	2.13	4.857	1.875	3.41	1.686	1.2	1.9589
2014	0.348	0.53	0.152	0.96	2.391	1.711	2.54	5.246	3.01	2..43	1.25	0.97	1.7948
2015	0.509	0.47	0.324	0.763	1.046	3.516	4.32	4.67	4.254	3.12	1.21	1.511	2.14
Mean monthly	0.855	0.796	0.77	0.7	1.5	2.55	3.86	4.5	3.42	2.84	1.03	0.99	

Appendix Table 5. Effective rainfall calculated by CROPWAT.

Monthly rain - C:\ProgramData\CROPWAT\data\climate\2me.CRM

Station: Dambi dollo   Eff. rain method: FAO/AGLW formula

	Rain	Eff rain
	mm	mm
January	66.5	29.9
February	56.5	23.9
March	95.9	52.7
April	104.9	59.9
May	132.1	81.7
June	136.1	84.9
July	148.0	94.4
August	120.0	72.0
September	125.0	76.0
October	108.6	62.9
November	72.0	33.6
December	73.8	35.0
Total	**1239.4**	**706.9**

Appendix Table 6. Eto (reference evapotranspiration) and Average climatic data.

Monthly ETo Penman-Monteith - C:\ProgramData\CROPWAT\data\climate\hussen.PEM

Country: ethiopia   Station: Dambi Dollo

Altitude: 1764 m.   Latitude: 8.52 °N   Longitude: 34.47 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	12.3	25.7	58	130	8.0	19.5	3.93
February	12.8	27.2	57	138	7.7	20.2	4.34
March	13.6	26.9	60	156	6.1	18.7	4.30
April	14.1	26.3	66	147	7.0	20.3	4.33
May	14.0	24.5	78	121	5.2	17.1	3.46
June	13.7	22.8	82	121	4.8	16.1	3.12
July	13.4	21.9	83	112	4.2	15.4	2.92
August	13.3	22.4	84	130	2.5	13.1	2.65
September	13.3	22.9	78	130	5.3	17.4	3.35
October	12.9	24.3	75	121	6.6	18.7	3.58
November	12.5	24.9	69	112	7.1	18.4	3.57
December	12.1	23.5	63	112	8.0	19.0	3.54
Average	**13.2**	**24.4**	**71**	**128**	**6.0**	**17.8**	**3.59**

Appendix Table 7. Maize monthly irrigation water requirements at Dambi dollo stations.

Crop Water Requirements

ETo station: Dambi Dollo | Crop: maize

Rain station: dambi dollo | Planting date: 01/01

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	1	Init	0.30	1.14	11.4	10.5	0.9
Jan	2	Init	0.30	1.18	11.8	10.0	1.8
Jan	3	Deve	0.48	1.95	21.5	9.3	12.2
Feb	1	Deve	0.79	3.34	33.4	7.6	25.8
Feb	2	Mid	1.09	4.73	47.3	6.4	40.9
Feb	3	Mid	1.20	5.18	41.4	10.1	31.3
Mar	1	Mid	1.20	5.16	51.6	15.0	36.6
Mar	2	Mid	1.20	5.15	51.5	18.6	32.9
Mar	3	Late	1.16	4.99	54.9	19.0	35.9
Apr	1	Late	0.90	3.95	39.5	18.7	20.8
Apr	2	Late	0.62	2.74	27.4	19.3	8.1
Apr	3	Late	0.41	1.67	8.3	11.0	0.0
					400.0	**155.5**	**247.1**

Appendix Table 8. Onion monthly irrigation water requirements at Dambi dollo stations.

Crop Water Requirements

ETo station: Dambi Dollo | Crop: onion

Rain station: dambi dollo | Planting date: 10/01

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	1	Init	0.70	2.66	2.7	1.1	2.7
Jan	2	Init	0.70	2.75	27.5	10.0	17.5
Jan	3	Deve	0.70	2.86	31.5	9.3	22.2
Feb	1	Deve	0.79	3.31	33.1	7.6	25.5
Feb	2	Deve	0.90	3.92	39.2	6.4	32.8
Feb	3	Deve	1.01	4.36	34.9	10.1	24.8
Mar	1	Mid	1.05	4.52	45.2	15.0	30.2
Mar	2	Mid	1.05	4.50	45.0	18.6	26.5
Mar	3	Late	1.05	4.51	49.6	19.0	30.6
Apr	1	Late	1.00	4.39	43.9	18.7	25.2
Apr	2	Late	0.95	4.21	16.9	7.7	7.2
					369.4	**123.5**	**245.1**

Appendix Table 9. Potato monthly irrigation water requirements at Dambi dollo stations.

Crop Water Requirements

ETo station: Dambi Dollo | Crop: potato

Rain station: dambi dollo | Planting date: 20/01

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Jan	2	Init	0.70	2.75	2.8	1.0	2.8
Jan	3	Init	0.70	2.85	31.3	9.3	22.0
Feb	1	Init	0.70	2.94	29.4	7.6	21.9
Feb	2	Deve	0.73	3.18	31.8	6.4	25.4
Feb	3	Deve	0.83	3.59	28.7	10.1	18.6
Mar	1	Deve	0.93	4.02	40.2	15.0	25.2
Mar	2	Mid	1.03	4.42	44.2	18.6	25.6
Mar	3	Mid	1.04	4.48	49.3	19.0	30.3
Apr	1	Mid	1.04	4.56	45.6	18.7	26.9
Apr	2	Mid	1.04	4.61	46.1	19.3	26.8
Apr	3	Late	1.03	4.23	42.3	22.0	20.4
May	1	Late	0.98	3.69	36.9	25.4	11.5
May	2	Late	0.94	3.24	29.2	25.3	1.1
					457.9	**197.6**	**258.4**

Appendix table 10 Irrigation water requirements of selected crop and actual area

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. maize	14.8	97.4	104.5	28.6	0	0	0	0	0	0	0	0
2. onion	42.4	83	86.9	32.3	0	0	0	0	0	0	0	0
3. potato	24.8	65.9	81.1	74	12.7	0	0	0	0	0	0	0
Net scheme irr.req.in mm/day	0.9	2.9	2.9	1.5	0.1	0	0	0	0	0	0	0
in mm/month	27.4	82.4	91	44.4	4.1	0	0	0	0	0	0	0
in l/s/h (% of total area)	0.1	0.34	0.34	0.17	0.02	0	0	0	0	0	0	0
Irrigated area	100	100	100	100	32	0	0	0	0	0	0	0
Irr.req. for actual area in (l/s/h)	0.1	0.34	0.34	0.17	0.05	0	0	0	0	0	0	0
Irr.req. for the study area area in (m^3) for 7250ha	0.7511	2.4505	2.44615	1.23975	0.116	0	0	0	0	0	0	0

Appendix Table 11. Soil laboratory analyses result.

latitude	longitude	Lab No.	Sample code	Ph.	EC (ds/m)	$CaCO_3$ (%)
Zone 1						
8.5616N	34.7383E	3713	P11	6.24	0.156	5.96
8.5372N	34.7313E	3714	P12	5.75	0.0419	5.10
8.5615N	34.7661E	3715	P13	5.59	0.1127	4.46
8.5133N	34.7616E	3716	P14	5.90	0.126	6.05
			average	**5.87**	**0.109**	**5.39**
Zone 2						
latitude	**longitude**	**Lab No.**	**Sample code**	**pH**	**EC (ds/m)**	**$CaCO_3$ (%)**
8.5105N	34.7897E	3718	P21	5.70	0.08	6.33
8.5011N	34.7611E	3719	P22	6.05	0.218	4.96
8.4863N	34.8019E	3720	P23	5.62	0.1301	5.60
8.4592N	34.8014E	3721	P24	5.85	0.1143	4.37
			average	**5.805**	**0.1356**	**5.313875**
Zone 3						
latitude	**longitude**	**Lab No.**	**Sample code**	**pH**	**EC (ds/m)**	**$CaCO_3$ (%)**
8.4364N	34.8527E	3723	P31	5.39	0.0941	6.87
8.4336N	34.8266E	3724	P32	5.45	0.0941	6.24
8.3833N	34.8513E	3725	P33	5.42	0.0779	6.42
8.3847N	34.9012E	3726	P34	5.47	0.1364	6.78
			average	**5.4325**	**0.115225**	**6.57761**

FIGURES IN APPENDIX

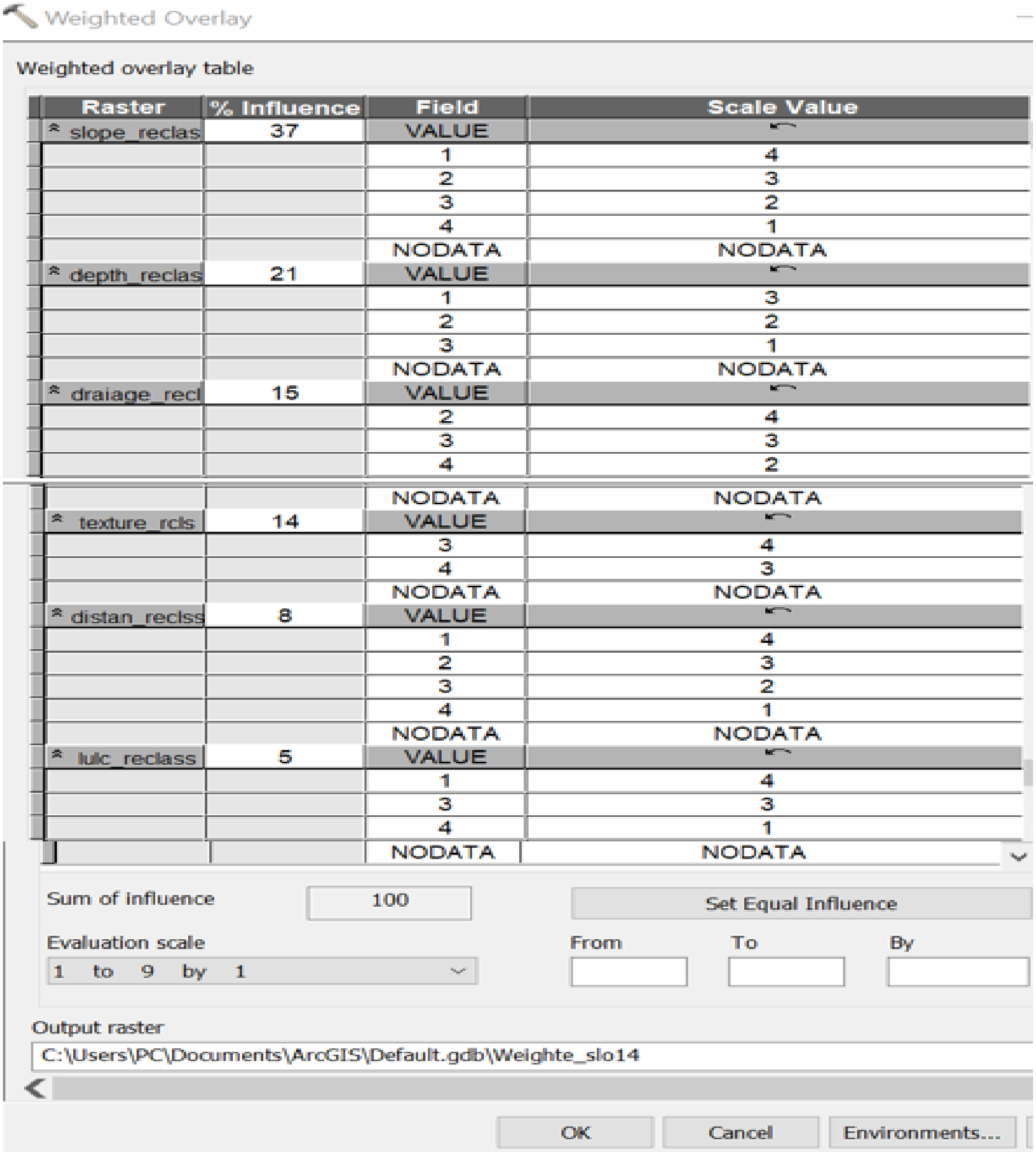

Figure A1: Weighted overlay workspace in ArcGIS for land suitability evaluation

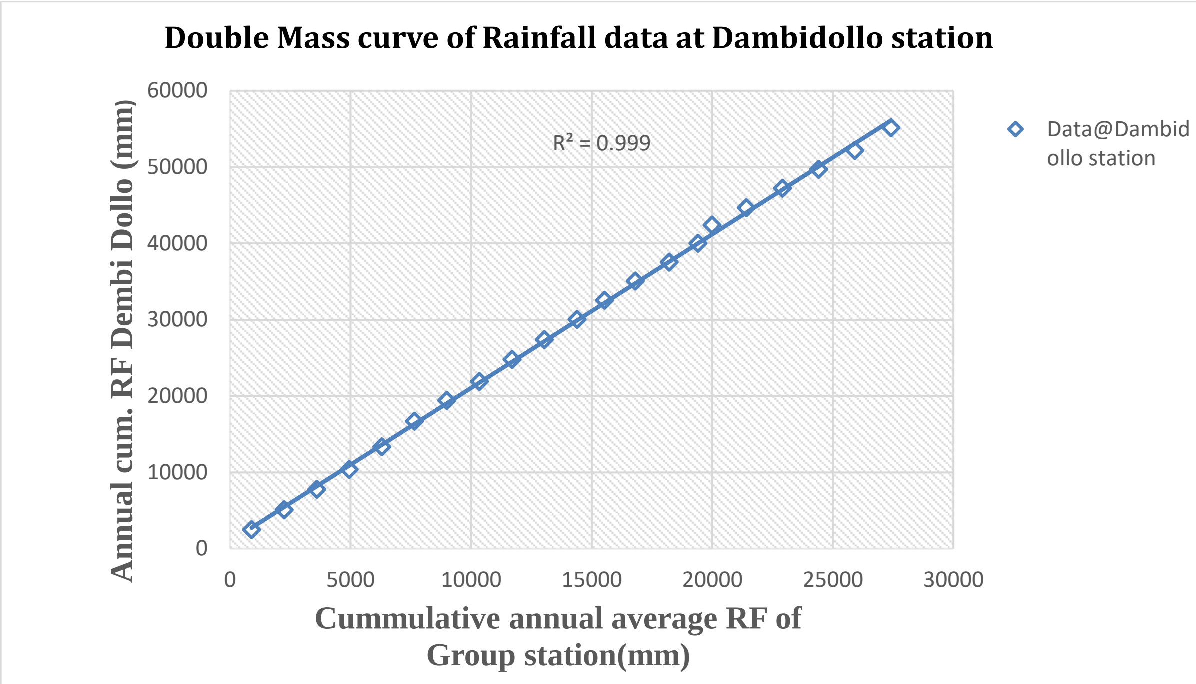

Figure A2: Double mass curve for consistency analysis

Figure A3: Partial view of the study area

Figure A4: Photo that was captured while soil data collection and coordinate of representative soil pits by GPS.