JIMMA UNIVERSITY

SCHOOL OF POSTGRADUATE STUDIES

JIMMA INSTITUTE OF TECHNOLOGY

FACULTY OF CIVIL AND ENVIRONMENTAL ENGINEERING

CHAIR OF HYDROLOGY AND HYDRAULIC ENGINEERING

MASTERS OF SCIENCE PROGRAM IN HYDRAULIC ENGINEERING

GIS-BASED SURFACE IRRIGATION POTENTIAL ASSESSMENT OF WEYIB RIVER SUB-BASIN, GENALE-DAWA RIVER BASIN, ETHIOPIA

BY: RUKIYA GEBRE NEGESSO

A Thesis submitted to the School of Graduate Studies of Jimma University in Partial Fulfillment of the Requirements for the Degree of Masters of Science in Hydraulic Engineering.

September, 2022

Jimma, Ethiopia

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Main-Advisor: Dawd Temam (PhD)
Co-advisor: Mrs. Desu Megra (MSc)

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Thesis Approval Sheet

This is to certify that the thesis entitled "**GIS-Based surface irrigation potential assessment of Weyib river sub-basin**" submitted in partial fulfillment of the requirement for the degree of Master of Science in Hydraulic Engineering.

Rukiya Gebre Signature ------------- Date------------

As members of the Examiner Board of the Final M.sc Open Defense, we certify that we have read and evaluated the thesis prepared by: Ms. Rukiya Gebre entitled: GIS-Based surface irrigation Potential Assessment of Weyib river sub-basin. We recommend that it be accepted as fulfilling the thesis requirement for the degree of Master of Science in Hydraulic Engineering.

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DECLARATION

I, the undersigned, declare that the thesis entitled **“Geographical Information System (GIS)-Based surface Irrigation Potential Assessment of Weyib River Sub-basin”** is my original work and that it has not been presented and will not be presented by me to any other University for similar or any other degree award.

Rukiya Gebre	_______________	_______________
Name of Candidate	Signature	Date

This thesis has been submitted for examination with my approval as university advisor.

1. Main Advisor: Dawd Temam (PhD) __________ ________

Signature Date

2. Co-advisor: Mrs. Desu Megra (MSc) ___________ ________

Signature Date

ABSTRACT

The assessment of the surface irrigation potential process has the integration of information concerning the suitability of the land; water resource availability and climate variation are required in the water requirements of irrigated areas. Ethiopia has huge potential in expanding irrigation using available water resources. But, the country depended on rain-fed agriculture with limited use of irrigation for agricultural production. The major problem associated with rainfall-dependent agriculture in the country is the high degree of rainfall variability and unreliability. However, due to a lack of information related to cultivable and irrigation suitability of the land, its agricultural system does not yet fully productive. A geographic Information System (GIS) can be an effective tool in identifying irrigable land and mapping suitable land for irrigation. Therefore, the objective of this study was to assess the surface irrigation potential of the Weyib river watershed using ArcGIS 10.4.1. The main suitability factors, which were used to identify the potentially irrigable land for surface irrigation, were slope, soil characteristic, land use land cover, and distance from the water source. Irrigation suitability of each physical land parameter is classified based on the FAO guideline for land evaluation into four classes such as S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitable), and N (not suitable) suitability classes, where the final potentially irrigable land was identified by weighting the factors of suitability. Irrigation water requirements of selected crops commonly grown in the area (Wheat, Barley, potato, and Cabbage) were computed from climate, crop, and soil data inputs using CropWat8.0 software, and the volume of minimum flow (90% exceedance flow of Weyib River) were estimated. By weighting values of the seven factors using the Analytic Hierarchy Process and overlaying by weighted overlay in ArcGIS 10.4.1, the irrigation suitability map was developed and the total suitable land for surface irrigation was found to be 427,671.55 ha (99.27 %) of the total area of the watershed was found in a range of highly suitable to marginally suitable whereas about 0.73% of the land was limited for irrigation developments. The river's capacity was insufficient for the irrigation application of the command area, as determined by a comparison between the amount of water needed and the river's monthly flow. Thus, any future planning for surface irrigation may include building a storage reservoir across the river to hold runoff during the rainy season.

Keywords: ***GIS***, Land Suitability, Surface irrigation potential, Weyib River Watershed

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LIST OF ACRONYMS AND ABBREVIATIONS

A.m.s.l	Above mean sea levels
AHP	Analytical Hierarchy Process
BCM/Bm^3	Billion Cubic Meter
CROPWAT	Crop Water Assessment Tool
CWR	Crop Water Requirement
CSA	Central Statistical Agency
DMC	Double mass curve
DEM	Digital Elevation Model
E	East
EMA	Ethiopian Mapping Agency
ESRI	Environmental Systems Research Institute
ET_O	Reference crop evapotranspiration
ET_C	Crop evapotranspiration
EMA	Ethiopian Mapping Agency
FDC	Flow duration curve
GDMP	Genale-Dawa Master Plan
GDP	Growth Domestic Product
GIS	Geographic Information System
GIWR	Gross Irrigation Water Requirement
GLCN	Global Land Cover Network
Ha	Hectare
HWSD	Harmonized World Soil Database
IFAD	International Fund for Agricultural Development
ISRIC	International Soil Reference and Information Centre
ITCZ	Inter-Tropical Convergence Zone
IWMI	International Water Management Institutes
IWR	Irrigation Water Requirements
Km^2	Square kilo meter

LULC	Land use Landcover
M	Meter
MCE	Multi-Criteria Evaluation
Mha	Million hectares
MoA	Ministry of Agriculture
MoWIE	Ministry of Water Irrigation and Energy
MoWRE	Ministry of Water Resources of Ethiopia
N	North
N	Not suitable
NIWR	Net Irrigation Water Requirement
NMSA	National Meteorological Services Agency
OIDA	Oromia Irrigation Development Authority
RS	Remote Sensing
S	Suitable
S1	Highly Suitable
S2	Moderately Suitable
S3	Marginal Suitable
SRTM	Shuttle Radar Topography mission
SWAT	Soil and Water Assessment Tool
UNESCO	United Nations Educational, Scientific and Cultural Organization
USDA	United States Development of Agriculture
UTM	Universal Trans-Mercator

1. INTRODUCTION

1.1 Background

The world's population is rapidly increasing at the moment. The current global population of 7.6 billion people is predicted to grow to around 11.2 billion by the end of 2025. With an increasing population, there will be a significant increase in food demand (United Nations, 2017). FAO researchers looked at agricultural production in over 90 developing countries and found that it increased by 49% in rain-fed agriculture and 81% in irrigated from 1998 to 2030. As a result, an irrigation system is projected to produce a greater amount of additional food (Garuma, 2021).

Most African countries' economies mainly depend on agriculture(IFAD, 2011). Ethiopia's primary economic sector and source of food is agriculture, which heavily depends on rainfall. It contributes 43% of the GDP, 80% of the labour force, and almost 75% of export earnings (Worqlul *et al*., 2017; Araya & Stroosnijder, 2011) &(Mekonen, 2021). Ethiopia's population is estimated 98 million (CSA, 2016). The majority people of Ethiopians live in the highlands, with 85% of the population is live in a rural area and dependent on low-productivity agriculture (Nasir *et al.*, 2020).

Agriculture is a critical component of the country's long-term economic development. Irrigation development has been highlighted as a key tool for promoting long-term economic growth and rural development, as well as a cornerstone of food security and poverty reduction (Asfaw and Gebremedhin, 2015).

Irrigation is a crucial investment in raising rural income by boosting agricultural output. Any country can increase productivity and lessen exposure to climatic volatility by increasing irrigation and managing agricultural water efficiently. The growth of irrigated agriculture depends on the investigation of available water sources and possibly irrigable topography.

Irrigation will help farmers maintain their livelihoods and improve their overall health (Worqlul *et al*., 2015). However, estimated crop production, as practised through rain-fed agriculture, is insufficient to meet the country's food demand. As a result, irrigation has progressed at various scales (i.e. small, medium, or large scale). When the irrigation scheme's construction and function improve, irrigation development improves. Rain-fed smallholder agriculture with poor productivity accounts for over 90% of food production in Ethiopia, making rainfall the single most important factor in the country's food security and economy (Birhanu *et al.*, 2019).

Considering the current rate of population increase and food insecurity, irrigation development is expected to play a key role in increasing economic growth and rural development by improving and stabilizing agricultural production and productivity in the country (Tesfay, 2017). Irrigation development is critical to improving smallholder livelihoods by increasing crop productivity, increasing crop diversity, and lengthening agricultural seasons, according to the country's agricultural development strategy. Proper land use is dependent on the suitability or capability of land and water resources for irrigation development, which might result in a significant rise in food production in many sections of the country (Fasina *et al.*, 2008).

Ethiopia has a land area of 113 million hectares (Mha) and 5.3 million hectares (Mha) of potentially irrigable land; 3.7 Mha from gravity-fed surface water, 1.1 Mha from groundwater and 0.5 Mha from rainwater harvesting (Dagninet & Adugnaw, 2019). However, only 12.1% of the land could be currently irrigated (Birhanu *et al.*, 2019). Long-term daily historical river discharges are used to assess surface water potential and land suitable for irrigation is evaluated using a GIS-based multi-criteria evaluation that considers the interaction of several characteristics such as slope, soil texture, soil depth, soil type, soil drainage, land use/land cover, and distance from the water source to the prospective command area (Worqlul *et al.*, 2015).

A river basin's irrigation potential is determined by its overall suitability, which includes soil qualities, terrain slope, irrigable land availability, distance from the water supply, and the availability of sufficient water resources (amount and quality of water) for irrigation (Birhanu et al., 2019). Therefore, the main objective of this study was to assess surface irrigation potential and identify land suitability for surface irrigation and irrigation water requirements for cultivating some selected crops commonly grown in the study area.

1.2 Statement of the Problem

Agriculture is a vital activity around the world that preserves people's life. It is also Ethiopia's most important economic sector. However, the agricultural sector of the country is highly dependent on rainfall (Mosisa, 2021). Rainfall agriculture is inadequate to supply the world's growing population. Ethiopia has a significant chance for water-led development, but it must address fundamental problems in irrigation system planning and design. The integration of information concerning land suitability, water availability, and climate variables is required in the irrigation planning and design process (Desu, 2020).

Droughts are a common occurrence in Ethiopia because of increased population pressure, uneven regional and temporal occurrence, water resources distribution, and land degradation.

Therefore, the country's ability to produce enough food and maintain food security has grown increasingly more difficult. The current production gaps require extreme measures to improve the productivity of irrigated and rain-fed agriculture if the country is to achieve its stated objectives of food self-sufficiency and food security. Because agriculture is the country's economic engine, all future development trends will be strongly influenced by how we manage the agricultural sector and all other related resources (Ashenafi, 2016).

Regardless of Ethiopia's advantage in terms of potentially vast irrigable land and plentiful water resources. Oromia, in particular, is blessed with enormous water and land resources, but its agricultural system is underutilized due to a lack of information about water availability and land appropriateness. The consequences of unsuitable land use and the inability to utilize land according to its potential suitability remain serious issues (Bayush, 2020).

According to the Genale-Dawa master plan (GDMP, 2007), the study area is one of the three sub-basins of the Genale-Dawa River Basin, which include Genale, Dawa, and Weyib. This area is distinguished by deep and fertile soil, intact natural forest, diverse and huge wildlife, a large number of households, a high population density, and so on. However, now there is a wide reduction of these natural resources, resulting in land degradation, which manifests itself as changes in soil physical characteristics, chemical, and biological degradation, and, as a result, a decline in soil fertility, production, and productivity of land resources.

The majority of the people in the study area live in rural areas, and farmers who live in this area mostly depend on rain-fed agriculture activities. Agriculture is the main source of income for society. The problems occur as a result of a scarcity of irrigation projects in the area. Therefore, using geographic information system (GIS) and CROPWAT software, this study to assess the potential of the catchment's water resources and identify land suitability for surface irrigation and irrigation water requirements for cultivating some selected crops in the area.

1.3 Objectives

1.3.1 General Objective

The general objective of this study is to assess the surface irrigation potential of Weyib river sub-basin using Geographic Information System (GIS) Software.

1.3.2 Specific Objectives

1. To determine the irrigable command area in the study area.
2. To rank the irrigation suitability factors using the Analytical hierarchy process (AHP) method for surface irrigation potential in the Weyib river catchment.
3. To calculate the amount of available surface water potential for surface irrigation and compare it to the irrigation water requirement for selected crops in the study area

1.4 Research Questions

1. How many irrigable command areas are in the study area?
2. What is the best irrigation suitability factor for the surface irrigation potential in the Weyib river catchments?
3. Is there sufficient surface water for selected crops irrigable in the study area?

1.5 Scope of the Study

This study's objectives were to assess the surface irrigation potential of the Weyib river sub-basin, and to determine land suitability for surface irrigation based on suitability factors such as slope, soil depth, soil drainage, soil texture, soil type, land use, land cover, and distance from the water source to the potential command area, and to estimate irrigation potential with available water in the catchment. The Weyib watershed has a drainage area of approximately 4307.985 km^2.

1.6 Significance of the Study

This study examines surface irrigation, site suitability, and the development of a map for the Weyib River watershed using GIS. Irrigation is the most popular way to ensure sustainable agriculture and manage periods of low rainfall or drought. However, agriculture employs around 85% of the country's population; the activity still depends on rainfed. As a result, the expansion of producing crops is not proportional to the growth of the country's population. Ethiopia's rainfall distribution is seasonal and erratic, and the country has the most insecure rainfall regime. Irrigation is the process of applying water to ensure that sufficient soil moisture is available for healthy plant growth. It is used to supplement rainfall during the growing season. On full-season agronomic crops, irrigation is employed to provide a consistent yield year after year. It's also utilized on crops where water stress has an impact on yield quality. As a result, irrigation is critical for the country.

If the irrigation potential of the river basin is assessed and utilized, irrigation will contribute significantly to poverty reduction, food security, and improved quality of life for the country in general and the rural population in particular. The study provided useful information to various stakeholders, including the following: the government institution of the area, contractors, and consultants will benefit from the study as a source of information for irrigation assessment and utilization.

1.7 Limitations of the study

Data accuracy and availability were essential for the thesis. Incomplete and inaccurate data lead to inaccurate outcomes. Although rainfall statistics are the most important part of the information needed for modelling, calculating the water resources of a catchment, and estimating how much water is needed for irrigation, most meteorological station data records from different organizations were inaccurate. There were some missing meteorological data for the research area in the station. The availability of water flow data for the study area in gauging stations with a high proportion of missing data can influence the results if the form is not filled out properly.

2. LITERATURE REVIEW

2.1 Definition of Irrigation Potential

Irrigation potential is defined as the process by which water is diverted from a river or pumped from a well and used for agricultural production (Dr. Peter *et al.*, 2012). In other words, Irrigation is described as the technique of applying artificial water to fields to meet the water requirements required to produce different types of crops and to protect them from the harmful effects of drought or low rainfall (Mesfin *et al.*, 2020).

It assists in the stabilization of food production in several countries by supplementing or replacing the need for natural precipitation for food production (FAO, 1997). On the other hand, defining irrigation potential is not simple and requires several assumptions about irrigation techniques, investment capacity, national and regional policies, social, health, and environmental aspects, as well as international relationships, particularly regarding water sharing. However, knowledge of physical irrigation potential is required to appraise information on land and water resources at the river basin level (Ashenafi, 2016). The amount of land that may be irrigated is determined by physical resources, soil, and water, as well as irrigation water requirements dictated by cropping patterns and climate (FAO, 1986). Therefore, physical irrigation potential is a composite of data on gross irrigation water requirements, irrigation-suitable soil area, and basin-specific water supplies (FAO, 1997).

2.2 Ways of Irrigation Development in Ethiopia

Irrigation development in Ethiopia can be considered a cornerstone of food security and poverty reduction tools as it has the power to stimulate economic growth and rural development. Irrigation development is critical for Ethiopia's long-term agricultural development, which leads to overall development (Asfaw and Gebremedhin, 2015). Irrigated agriculture is used by smallholders, medium-scale farmers, and large-scale farmers. There are a lot of authors such as (Awulachew *et al*., 2007); (Makombe *et al*., 2007); Hagos et al., (2009), and Bacha *et al*. (2011).

During their studies, employed government-based irrigation scheme classification methods to describe them. Irrigation development in Ethiopia is categorized in two ways, according to (Makombe et al., 2007). The first classification is determined by the command area's size. It is divided into three categories.

1. Irrigation systems on a small scale (less than 200 hectares)

2. Irrigation systems on a medium scale (200-3,000 ha)

3. Irrigation systems on a large scale (>3,000 ha)

In Ethiopia, this is the most widely used classification system. As a result, small-scale irrigation projects account for 46% of proposed irrigation projects (Mesfin *et al*., 2020).

The second classification is based on a combination of the establishment's history, time of establishment, management system, and structure type, as follows:

a) **Traditional irrigation schemes**: These are small-scale irrigation systems that often employ diversion weirs made of local materials and require annual maintenance. The canals are usually made of earth, and the schemes are run by the community. Many were built by local communities and have been in use for decades, while others were constructed more recently with the help of nongovernmental organizations (NGOs) and the government.
b) **Modern schemes:** These are small-scale irrigation systems with more permanent concrete diversion weirs that do not need to be rebuilt every year. Concrete is used to construct the primary and secondary canals. They are controlled by the community and were recently built by the government.
c) **Public:** These are large-scale activities that the government constructs and manages. Out-growers (smallholder farmers who have farms near large-scale systems) are sometimes supported by these programs.
d) **Private:** These are privately owned mechanized farm systems that require a high level of operation.

2.3 Irrigation Potential in Ethiopia

Agriculture's water resource management is a significant contributor to Ethiopia's economic and social growth. Irrigation in Ethiopia, if effective, could be a cornerstone of the country's agricultural development, providing up to ETB 140 billion to the economy and perhaps bringing up to 6 million people into food security (Awulachew *et al.,* 2010). Due to a lack of standard or agreed-upon criteria for measuring irrigation potential in Ethiopia, estimations of its potential differ from one source to another. Ethiopians have a large number of water resources that could help the country's socio-economic development. The country's overall land is divided into 12 major river basins based on drainage conditions (Dawud, 2018).

Ethiopia has 113 million hectares of land, with cultivable land ranging from 30 to 70 million hectares. The Ministry of Water, Irrigation, and Electricity (MoWIE) has identified 560 irrigation potential sites on the major river basins at this time. According to the Ministry of Water, Irrigation, and Electricity (MoWIE, 2009), the state has designated 30 large-scale and medium-scale irrigation projects in various parts of the country for development since the 1980s, with a combined command area of over 600,000 ha.

In Ethiopia, where rain-fed production is primarily used, agriculture is the main economic activity. Climate change, in particular the lengthened dry seasons and low rainfall during the agricultural production seasons, provide a challenge to rain-fed agriculture, contributing to food insecurity in the area. Due to these issues, irrigation is a different tactic that Ethiopian smallholder farmers can use to alleviate food shortages and raise their level of living (Yimam *et al.*, 2021).

Agriculture is Ethiopia's most important economic sector, and its performance is a key factor in the country's overall GDP growth rate. Ethiopia has a large agricultural land resource. Around 73.6 Mha (67%) of the country's land could be used for agriculture (Nasir and Feyissa, 2020). A total of 3.7 million hectares of potentially irrigable land has been identified by the USDA (MoWR, 2002).

As a result, by evaluating the available potential of surface water, this study is crucial for understanding what was done in the past, what is happening now, and what will happen in the future in irrigation developments in Ethiopia in general, and in the Weyib watershed in particular. The country's twelve river basins' irrigation potential (Awulachew *et al.,* 2007), is shown in (Table 2.1).

Table 2.1 Irrigation potential in the River Basin of Ethiopia

Basin	Catchment Area (Km^2)	Irrigation Potentials (Ha) (Respective Recent Master Plan Studies)				Irrigation Potential (Wapcos 1995)		
		Small - Scale	Medium-Scale	Large - Scale	Total	Total Drainage Area (Km^2)	Irrigable Area (Ha)	Percentage Irrigable Area of The Country
Abbay	198,890.7	45,856	130,395	639,330	851,581	201,346	1,001,000	27
Tekeze	83,475.94	N/A	N/A	83,368	83,368	90,001	317,000	8.5
Baro- Akobo	76,203.12	N/A	N/A	1,019,523	1,019,523	74,102	985,000	26.5
Omo-Gibe	79,000	N/A	10,028	57,900	67,928	78,213	445,000	12
Rift-Valley	52,739	N/A	4,000	45,700	139,300	52,739	139,000	3.7
Awash	110,439.3	30,556	24,500	79,065	134,121	112,697	205,000	5.5
Genale-Dawa	172,133	1,805	28,415	1,044,500	1,074,720	117,042	423,000	11.4
Wabe - Shebelle	202,219.5	10,755	55,950	171,200	237,905	102,697	200,000	5.4
Denakil	63,852.97	2,309	45,656	110,811	158,776	74,102	-	-
Ogaden	77,121	-				77,121	-	-
Aysha	2,000	-				2,000	-	-
Total	1,118,074.53	3,731,222				982,060	3,715,000	100

Source: - IWMI working paper 123: Water Resources and Irrigation Development in Ethiopia

2.4 Overview of Surface irrigation

The type of irrigation system needed for a given application depends on the type of land, the environment, and the budget. Water availability, soil type, topography, operating conditions, wind, crop type, and water consumption are a few of these factors. Other factors are farm and paddock layout, labour required, capital cost, and energy requirements (Robert, 2003).

The term "surface irrigation" refers to a broad type of irrigation method. Water is introduced and distributed in a field using the surface irrigation method, which uses gravity to move water over the soil's surface. The surface irrigation method entails starting at one field edge and eventually covering the entire area. The soil serves as both a storage medium for water and a conduit for its flow as it distributes and infiltrates (Abdulrahim and Gulma, 2012). The most common surface irrigation techniques are level basins (with or without level furrows), sloping borders and sloping furrows to distribute irrigation water (Fasina *et al*., 2008).

Surface irrigation systems can be as efficient as most other methods. This requires improving the management and control of water, knowing how much water is applied and scheduling applications according to soil water levels and crop needs (USDA, 2006).

According to (Rabia *et al.*, 2013), stated that surface irrigation is the oldest and most common method of applying water to croplands, surface irrigation has evolved into an extensive array of configurations. Efforts to classify surface systems differ substantially, but generally include the following: (1) Basin irrigation; (2) Border irrigation; (3) furrow irrigation, and (4) uncontrolled flooding.

2.5 Land Suitability Classification for Irrigation

The Food and Agriculture Organization's framework for land evaluation (FAO, 1976), which served as the inspiration for this study's concept, defined the process of land suitability classification as the evaluation and grouping of particular land areas based on their suitability for predetermined uses. For a practical alternative for increasing the usage of that property, data regarding the land's soils, geography, and climate are needed to accomplish this goal (Abdulrahim and Gulma, 2012).

On different types of land, land assessment involves a comparison of the benefits obtained and the inputs required. It is an important link in the chain leading to sustainable land resource management by examining the execution and interpretation of fundamental surveys of climate, soils, vegetation, and other features of the land in terms of the need for alternative land uses (FAO,1976).

The physical characteristics of the soil, slope, land use/land cover, distances of the irrigable land from available water sources, as well as topography factors affecting the irrigation technologies chosen, are all taken into consideration for irrigation, according to the (FAO, 2001) for irrigation.

2.5.1 Structure of the Suitability Classification

Framework for land evaluation of the Food and Agriculture Organization (FAO, 1976), the structure of the suitability classification is explained, with four categories of diminishing generalization identifying qualitative, quantitative, and current or potential appropriateness. Within the framework of the many classifications and as applied to various types of land use, each category keeps its core significance (FAO, 1976). Accordingly, the structure of the suitability classification reflects degrees of suitability, as shown in (Table 2.2).

Table 2.2 Categories of the suitability classification

Categories of suitability	Description
Land suitability orders	Reflecting kinds of suitability
Land suitability classes	Reflecting degree of suitability within orders
Land suitability sub-classes	Reflecting kinds of limitations or main kinds of improvement measures required, within classes
Land suitability unit	Reflecting minor differences in required management

The basis of the FAO land evaluation system is land orders and land classes defined by calculated or inferred potential productivity levels (MoA, 2018).

2.5.1.1 Land Suitability Orders

Suitability of the land Orders states whether the land is appropriate or unsuitable for the proposed use. The symbols 'S' and 'N' for suitable and not suitable, respectively, denote two orders.

Order S (Suitable): Land on which long-term usage of the type in consideration is projected to produce benefits that justify the inputs while avoiding the unacceptable risk of damage to land resources.

Order N (Unsuitable): Land with characteristics that appear to prohibit long-term usage of the kind in consideration. For a variety of reasons, land may be designated "unsuitable" for a certain user.

It's possible that the planned use is technically impossible, such as irrigation of rocky steep ground, or that it would result in significant environmental deterioration, such as steep slope cultivation. However, the most common reason is financial: the value of the predicted benefits does not match the expected price of the required inputs (FAO,1976).

2.5.1.2 Land suitability classes

According to the (FAO, 1976). Suitability of the land the different classes represents different degrees of appropriateness. Within the Order, the classes are numbered sequentially by Arabic numbers in order of decreasing degrees of appropriateness. The number of classes in the "Order Suitable" is not defined. The following names and meanings may be applicable in a qualitative classification if three Classes are identified within the "Order Suitable," as is typically recommended

- **Class S1 (Highly Suitable):** Land with no significant restrictions on the long-term application of a given use, or only minor restrictions that do not considerably diminish productivity or benefits, and do not raise inputs over an acceptable level.
- **Class S2 (Moderately Suitable):** Land has moderately severe limitations for sustained application of a given user; the limitations will reduce 18 per cent productivity or benefits and increase required inputs to the point where the overall advantage to be gained from the use, while still appealing, will be appreciably inferior to that expected on Class S1 land.
- **Class S3 (Marginally Suitable):** Land has restrictions that, in the aggregate, are severe enough to prevent a given user from using it for a long time, and will lower productivity or benefits, or increase required inputs, to the point where this investment is only marginally justified.

The association between advantages and inputs is what determines differences in degrees of appropriateness. The advantages could be in the form of things, such as crops, cattle products, or timber, or they could be in the form of services (e.g. recreational facilities). Capital investment, labour, fertilizers, and power are some of the inputs required to achieve such benefits. For example, a plot of land could be classified as Highly Suitable for rain-fed agriculture because the value of the crops produced is greatly above the expenses of farming, but only Marginally Suitable for forestry since the value of timber just marginally outweighs the costs of acquiring it. It is reasonable to predict that, throughout time, the borders of appropriate classes will need to be reviewed and revised in light of technological advancements as well as economic and societal changes (Tesfay, 2015).

There are usually two Classes within Order N (Not suitable)

- **Class N1 (Currently Not Suitable):** Land contains restrictions that may be overcome through time but cannot be addressed with current knowledge at a cost that is currently acceptable; the limitations are severe to prevent successful long-term use of the land in the provided manner.
- **Class N2 (Permanently Unsuitable):** Land with severe constraints that appear to prevent any successful long-term use of the land in the given manner.

2.5.1.3 Land Suitability Subclasses

Land suitability sub-classes represent various constraints, such as a lack of moisture and erosion risks. In classifications for different purposes, the number of sub-classes identified and the limits used to identify them will vary. Sub-classes are denoted by lowercase letters such as S2m, S2e, and S2me. Class S1 does not have any sub-classes. There are two guidelines to follow.

The number of sub-classes should be maintained to a bare minimum to separate lands within a class that are likely to differ significantly in their management requirements or potential for improvement due to different constraints.

2.5.1.4 Land Suitability Units

Sub-divisions of a sub-class are called land suitability units. At the sub-class level, all units within a sub-class have the same degree of appropriateness and the same sorts of limits. This classification is intended to identify land development units with low management requirements. This can demonstrate the high importance of land development projects. The units differ from one another in terms of product characteristics and management requirements. Their identification allows for a more in-depth interpretation at the agricultural planning level. Suitability units are distinguished by Arabic digits after a hyphen, such as S2e-1, and S2e-2. Within a sub-class, there is no limit to the number of units that can be identified (FAO, 1985).

2.6 Irrigation Land Suitability Evaluation Factors

To determine the productivity of the land when it is utilized for certain purposes and under a specific management system, the evaluation of the appropriateness of the land for irrigation considers the entire performance of the land, including landforms, climate, vegetation, and soils. To sustain and develop land usage on a geographical scale, it is essential to evaluate the suitability of the property. In addition to assessing the potential of the land and its long-term use for irrigation, it is utilized to detect regional patterns and levels of bio-physical elements (Hagos *et al*., 2022).

Factors that affect the suitability of an area for surface irrigation were identified based on literature and expert opinion (Kassaye *et al.*, 2019). The key components that influence a given land's irrigation potential are physical and chemical considerations. Physical soil parameters such as soil depth, texture, drainage, fertility, salinity and slope and water resource considerations such as water availability, water quality, and distance to water supply are among the qualities (FAO, 1979).

Soil, topography, drainage, water quality and quantity, and climate are the primary physical elements that determine whether or not a piece of land is suitable for irrigation. Water and climate are distinct from the others in that they are usually consistent across the investigation region (Stanhill, 2002). The physical features of the soil, the distance from available water sources, and the topography conditions of irrigation systems evaluated are all taken into consideration when analyzing irrigation land suitability (Muir *et al.*, 2010). Land use/land cover types, in addition to these characteristics, are recognized limiting considerations in determining the suitability of land for surface irrigation technologies in the study area.

2.6.1 Slope

The slope of surfaces is its incline or gradient, which is often given as a percentage. Because it influenced runoff, drainage, erosion, and irrigation type selection, the slope is significant for soil development and maintenance. The selection of irrigation systems is highly influenced by the slope gradient of the land (FAO, 1999). Slopes of less than 2%, according to FAO standard rules for evaluating slope gradients, are extremely suited for surface irrigation. Slopes larger than 8%, on the other hand, are generally not advised for surface irrigation (FAO, 1979).

For land preparation and water application, the slope gradient has a significant impact on work efficiency and management costs. It plays a vital role in the selection of appropriate irrigation technologies and irrigation systems that are suitable for certain irrigable land. The slope of the irrigable region has a greater impact on surface irrigation than on pressurized (Drip and sprinkler) irrigation methods. If the slope classification is less than 10%, it is assumed to be suitable for surface irrigation. In other regions with sufficient soil and water, available slopes of up to 20% to 30% can be irrigated (Negash, 2004).

Table 2.3 Slope ranges from irrigated land to an interactive multi-criteria analysis

Types of slope	Per cent (%)	Factors of rating
Horizontal	0-2	S_1
Very flat	2-5	S_2
Flat	5-8	S_3
Steep	>8	N_1

Source: FAO, (1996)

Many of the limitations imposed by the slope can be reduced or eliminated by identifying a suitable irrigation system. To save water and labour, increasingly automated irrigation systems (such as sprinkler or drip irrigation systems) are becoming popular. These technologies mitigate the impacts of steep gradients, reduce or eliminate the requirement for most land grading, and typically remove field size constraints. When there are several irrigation systems to choose from, land features may be the most important consideration in deciding which system to select (Meron, 2007).

2.6.2 Soils

When determining whether a piece of land is suitable for sustainable surface irrigation and agriculture, the soil is a key consideration. The ability of the land to produce, how well irrigation works, and how much development can occur (Azemeraw, 2021). When evaluating soils for irrigation, permanent properties that cannot be changed or modified are used. Soil drainage, soil texture, soil depth, soil salinity, and soil alkalinity are examples of such qualities (Fasina et al., 2008). Even though they are similar, distinct types of soil have varied behaviours and physical features. When there isn't enough rain, soil acts as a water reservoir, supplying plant needs during the dry season (Dawud, 2018).

As a result, some soils previously considered to be unsuitable for surface irrigation may be appropriate for spray irrigation or micro-irrigation, as well as certain land-use types. On loam or clay soils, all irrigation methods can be used, but surface irrigation is more commonly found. Clay soils with low infiltration rates are preferably suited to surface irrigation.

To identify the land suitability of the watershed concerning the soil, an overlay analysis is used to evaluate the soil suitability parameters, such as soil texture, depth, and drainage appropriateness. The factors that affect germination, root growth, and erosion processes are all influenced by the physical properties of soil, which also control how air and water travel through it.

2.6.3 Land Use and Land Cover

The terms land use and land cover (LULC) are frequently interchanged. They are, nevertheless, extremely different. Land cover is defined as the observed bio-physical cover of the earth's surface, such as vegetation (natural or planted) and human activities (construction of buildings, roads, etc.), according to the Global Land Cover Network (Global Land Cover Network, 2006); land cover includes water, ice, bare rock, and sand surfaces.

The concept of land use, on the other hand, creates a direct link between land cover and human activity in their environment (for example, commercial forestry, watershed protection/management, national park, wildlife, recreation, grassland, and so on). In this way, definitions of land use or land cover establish a basis for identifying potential irrigation land with accurate and quantitative economic evaluation (Jean Louis, 2009).

Therefore, by combining existing land use/land cover with topography and soil features to assess land suitability for irrigation and assigning land suitability classes, potential sites for increased agricultural production can be identified (Jaruntorn *et al*, 2004).

2.6.4 Distance to water sources

Making sure there won't be a water shortage for irrigation is important. Crop output will suffer, earnings will decrease, and a portion of the scheme's investment will be idle if water is scarce for some of the irrigation seasons. (Rediet *et al*., 2020). The distance to perennial rivers determines a land parcel's appropriateness class for river proximity. By projecting the locations to a Mercator (UTM) Zone 37N, the distance to the existing river was computed using the ArcGIS tool.

2.6.5 Climate

Climate has a significant impact on which lands are suitable for irrigation. Climate influences the qualities of the soil, drainage patterns, distribution of native vegetation, and crop adaptation. The following are some of the most significant climatic factors that affect irrigation suitability: The length of the growing season, temperature, intensity, distribution of precipitation, wind speed, hail and windstorms, humidity, and the number of daylight hours are among the factors that affect plant growth.

2.6.6 Water Availability

Water is the most plentiful substance on the planet, the primary requirement of all living things, and a major force that is continually sculpting the earth's surface. It's also a big part of air-conditioning the earth for human life and influencing civilization's progress (chow *et al*., 1988).

It's critical to ensure that there won't be a shortage of irrigation water. Crop production will decrease, returns will decline, and a portion of the irrigation scheme's investment may sit idle if water is scarce during various parts of the irrigation season (FAO, 2001). Therefore, water availability (amount and seasonality) is a significant component in determining the feasibility of land for irrigation based on the volume of water available throughout the year (FAO, 1985).

Quantifying the amount of water available for irrigation and knowing the precise location to which water can be carried affordably are critical factors in deciding whether or not to extend its use (Kebede, 2010). As a result, proximity to rivers and distance from water sources are useful in reducing the conveyance system (irrigation canal length) and therefore developing the irrigation system economically (Habtamu, 2017).

2.7 Water Resources Assessment

In the central, western, and southwestern portions of the country, there is plenty of water, although the north-eastern and eastern regions of the country are mostly dry. Water distribution and availability are both spatially and temporally unpredictable. As a result, despite abundant water in some areas, the country suffers from severe water scarcity due to a lack of water management infrastructure (Desu, 2020).

2.7.1 Availability of Surface Water Resource

According to (H.J.Ningaraju1and Ganesh, 2016), Water is a priceless gift from nature that must be preserved because it is becoming scarce. As a result of increased water demand brought on by fast population expansion, urbanization, industrialization, and economic development, water scarcity is one of the main water-related concerns that most countries are currently dealing with. The actual availability of water and land is fixed, but their demand is increasing, which is the main difficulty facing planners and managers (Meron, 2007). As a result, the challenge is how to maintain a balance between supply and demand under these challenging and complex circumstances. The efficient and sustainable management of the country's available land and water resources represents the only solution for many countries. The development of water resources is therefore fundamental infrastructure.

In Ethiopia, the land area and water bodies are covered by 99.3% and 0.7%, respectively, of the total area of land, according to the (MoWE, 2013) data. These bodies of water include the 12 largest river basins in the country; 8 of them have visible water flow, one of them is a rift valley filled with water, and the other three basins are in areas of the country that receive insufficient rainfall throughout the year (Dessalegn, 2020). Since the majority of the river basins, except the Awash, are transboundary rivers, 97% of the country's estimated annual stream flow leaves Ethiopia and goes to its neighbours, while only 3% of it stays within the country (Berhanu *et al.*, 2014).

i. **River Basins**

Ethiopia has 12 major river basins. Namely; Abbay, Wabe Shebelle, Awash, Tekeze, Baro-Akobo, Mereb, Rift Valley Lakes, Genale-Dawa, Omo-Gibe, Ogaden, Danakil, and Aysha. The country's surface water potential, as discovered and estimated in various integrated river basin master plans, is 124.4 billion cubic meters of water, although it requires updating and a more thorough examination and an estimated 2.6 to 2.65 Bm^3 of groundwater potential are anticipated to be obtained from these major River basins (Daniel *et al.*, 2020).

At the moment, existing hydro-meteorological networks gather and interpret surface water and meteorological data on a regular schedule. Ethiopia has a huge number of water resources that could play a key part in the country's socio-economic growth. All of

Ethiopia's major rivers begin in the highlands and flow outward via deep gorges in various directions (Dawud, 2018).

ii. **Lakes and Reservoirs**

Ethiopia has twelve foremost river basins(valleys), eleven lakes, nine saline lakes, four crater lakes, and over twelve foremost swamps or wetlands (Gashahun and Fang, 2021). The Rift Valley Basin contains the majority of the lakes. The entire surface area of Ethiopia's natural and man-made lakes is around 7,500km^2 (Awulachew e*t al*., 2007). Fish abound in the majority of Ethiopia's lakes. Except for Ziway, Tana, Langano, Abaya, and Chamo, most of the lakes have no surface water outflows. Chemical concentrations are significant in Lake Shala and Abiyata, and Abiyata Lake is currently being mined for the manufacturing of soda ash. These big lakes have an estimated storage capacity of 84.79 billion cubic meters (Dessalegn, 2018).

iii. Surface water flow (Runoff)

The management of land and water resources in a drainage area depends on the accurate estimation of runoff from rainfall. Changes in soils, land use, slope, and transient variations in soil moisture content all cause runoff to vary geographically. Runoff and rainfall are crucial components that supply more water for the numerous tasks carried out in a watershed. In order to make informed decisions in irrigated agriculture, it is crucial to understand how much surface runoff is produced in a watershed. One of the most crucial occurrences is the link between precipitation and runoff. Rainfall, land use, and soil quality are all thought to be crucial variables in estimating surface runoff (Thakuriah and Saikia, 2014). In engineering design, environmental impact analysis, and water balancing calculations, the estimation of runoff volume is critical.

2.7.2 Ground Water Resources

Always, the local geophysical and climatic conditions have a major impact on the presence of groundwater. A particular aspect of Ethiopia, which is distinguished by a vast heterogeneity of geology, geography, and environmental circumstances, is the difficulty in finding productive aquifers. The country's geology provides usable groundwater and good rainfall transmission to recharge aquifers that give rise to springs and nourish perennial rivers. (Berhanu *et al*., 2014).

Ethiopia's groundwater potential is lower than its surface water resources. However, by many countries' standards, the overall exploitable groundwater potential is large (Awulachew et al., 2007). The potential is estimated to be around 30 to 40 Bm^3 based on available data on groundwater resources (Dessalegn, 2018).

Annually rechargeable resources are predicted to permeate through into the subsurface system for example 13.2 BCM, of which 50% might be extracted. Precipitation and other water bodies recharge groundwater, which infiltrates and percolates deep into the earth. Climate, geographical factors, geology, land use, and land cover all influence groundwater recharge rates (Dawud, 2018).

2.8 Water Resources Assessment for Irrigation Water Requirement

Assessment of water resources can only be done at the basin level (FAO, 1997). One of the paramount factors in whether irrigation can be developed is the availability of water in a particular location and at the required time. Classically approaches are often based on observations of stream flow and/or groundwater availability (Dr. Peter, 2012).

According to the (CA, 2007); river basins are the geographic area contained within the watershed limits of a system of streams and rivers converging toward the same terminus, generally the sea or sometimes an inland water body. Tributary sub-basins or basins more limited in size (typically from 10 square kilometres to 1,000 square kilometres) are often called watersheds (in American English), while catchment is frequently used in British English as a synonym for river basins, watershed being more narrowly defined as the line separating two river basins. An important consideration in water resource assessment is to estimate how much flow is available at the outlet of the river catchment. The volume of water reliably available on an annual or seasonal basis can be determined from the available data in the case of gauged rivers and some approaches are currently available for the prediction of ungauged catchment flows.

Water resource investigations ought to be regarded as a crucial step in the assessment of land resources (FAO, 1985). The success of an irrigation project depends equally on the quality and amount of the water supply as it does on the land and other considerations (Meron, 2007). The CROPWAT 8 program was used to determine how much irrigation water was needed in the command area that might be irrigated.

Water used for irrigation should carry out its required task without having any negative effects on the soil's fertility or the healthy development of plants. Which relates to the general irrigation issues of salinity, acidity, and specific ion toxicity of other elements, and describes the suitability of water for irrigation. (FAO, 1985) and (Meron, 2007)

2.9 Overview of Geographical Information System and Remote Sensing

A Geographic Information System (GIS) is a software program that allows you to capture, store, query, analyze, and display data that is spatially referenced (Goodchild, 2000). Geographically referenced data describes the positions and properties of spatial features on the Earth's surface, including roads, landed property, and plant stands. The ability of a GIS to handle and process spatially referenced data sets it apart from other information systems.

Although work on GIS began in the late 1950s, the first GIS software was not released until the late 1970s, from the Environmental System Research Institute's lab (ESRI). Because of innovations created in the early and late 1950s, Canada was a forerunner in the creation of GIS. Roger Tomlinson deserves a lot of credit for the early development of GIS. The evolution of GIS has changed and altered the way planners, engineers, managers, and others manage and analyze databases (Meron, 2007).

Remote sensing (RS) is a technique that is closely related to geographic information systems (GIS). Remote sensing can give real-time data at scales that are suited for a wide range of applications. As a result, many experts believe that using GIS and RS in research and operational applications can lead to significant advancements. When these two technologies are combined, it can result in a massive increase in information for a variety of people.

The process of obtaining information about an object, area, or phenomenon by analyzing the data acquired by a device, not in direct contact with the object, area, or phenomenon under inquiry is known as remote sensing (Lillesand and Kiefer, 1994). This is accomplished through the observation and recording of reflected or emitted energy, as well as the processing, analysis, and use of that data.

Role of GIS for Land Suitability Analysis

The GIS software is used to enter, store, retrieve, manipulate, analyze, and output spatial data. A significant amount of work goes into gathering the information necessary for the suitability analysis for crop production, and GIS capabilities can play a significant part in spatial decisions. The incorporation of geographic data from remote sensing sources or maps and subsequent conversion into an electronically accessible format are the first parts of a GIS. Assessments of the suitability of a land parcel cannot be excluded based on data from biophysical resources. Large amounts of data can be stored and retrieved more quickly and for less money. Some of the basic applications of GIS are presented below.

Mapping

The most popular way for consumers to interact with geographic information is through a map. The primary use of GIS is mapping, which includes editing tasks as well as map-based query and analysis (Campbell, 1984). It is the primary application in any GIS-related task and the most typical view for a user to interact with a geographic information system (Mamenie, 2017). The map displays geographic information as a set of layers and additional components. The data frame containing the map layers for the provided extent, along with the scale bar, north arrow, title, descriptive text, and symbol legend, are common map components.

Watershed delineation

The area of a catchment or drainage basin that drains into a single common outlet is referred to as a watershed. Delineating a watershed refers to determining its specific boundary or size. ArcGIS, a tool for spatial analysts, offers a hydrology tool that may be used to create watersheds using DEM data as an input. (Winchell *et al.,* 2008). DEM of 30*30 m provides a good terrain representation from which watersheds can be derived using ArcGIS procedures.

Weighted overlay analysis

The weighted overlay analysis is a method for combining various and dissimilar inputs into one analysis by using a common measurement scale of values. The geographic issue has frequently called for the use of GIS to analyze various elements. For instance, weighing variables like slope, soil, and land use/land cover is necessary to choose the best irrigation site (Dao Huy and Yang, 2003)To prioritize the influence of these factor values, weighted overlay analysis uses an evaluation scale from the least suitable factor to the most suitable factor (Tadele and Zewde, 2021).

Weighted overlay only accepts integer raster's as ingredients such as a raster of LULC, soil types and slope. A weighted overlay method along with the analytic hierarchy process provides a very assuring outcome for the site suitability assessment of agricultural land use. The identification of different criteria depended on the majority that influences the product yield of agriculture. The method can be useful for the multi-level hierarchical structure of various constraints and criteria (Malay, 2016)

GIS-based as a Tool for Irrigation Potential Assessment

The tool for input, storage and retrieval, manipulation and analysis, and output of spatial data is GIS. Spatial decision-making can benefit greatly from GIS functionality. Information gathering for the appropriate analysis, and crop production requires a lot of work. The decision-maker should be presented with both opportunities and limits with this information. In the past, many studies have been conducted using the GIS tool to evaluate the potential for irrigation and the availability of water as follows:

Getenet *et al.* (2019) Assessing Suitable Land for Surface Irrigation in Ungauged Catchments: Blue Nile Basin, Ethiopia. They considered multiple factors such as Slope, Soil Drainage, Soil Depth, Soil Texture, Land Use, and River Proximity. Their study shows only 9% of the soil is not suitable for irrigation development and 5% of the land is too steep. In addition, another 4% of the land is urban, forested, or a water body, and cannot be used for irrigation development and showing that the existing water resource potential only irrigates a small portion of suitable land in the district.

Ebrahim & Mohamed, (2017) evaluate land suitability for agricultural planning in the Gelda catchment, northwest of Ethiopia. The study analyzes by combining soil, climate, and topographic factor. The result showed that 76.04%, 69.52%, and 67.79% of the study area are classified as moderately suitable for teff, maize, and finger millet cultivation respectively. And also 20.25% and 63.92% of the catchment are moderately suitable and marginally suitable for cultivation of all selected land utilization types.

Hailegebriel (2007); conducted a study on irrigation potential and crop suitability. His study is entitled irrigation potential evaluation and crop suitability analysis using GIS and remote sensing technique in Beles sub-basin, Beneshangul-Gumuz Region and he found out that 65.7 % of the Beles sub-basin is classified as suitable for surface irrigation. This study demonstrates the application of the combined (GIS, MCDM and AHP) approach to address the complex decisions of mapping the crop and surface irrigation suitability.

2.10 Application of Analytical Hierarchical Process (AHP)

A general measuring theory is the Analytic Hierarchy Process (AHP). From both discrete and continuous paired comparisons, ratio scales are derived using this method. These comparisons could be made using actual measurements or a fundamental scale that expresses the relative strength of preferences and emotions. The AHP is particularly concerned about changes in measurement, dependencies within and across groupings of structural parts, and departures from consistency. Its most extensive uses are in resource allocation, planning, multi-criteria decision-making, and dispute resolution.

The AHP, in its most basic version, is a nonlinear framework for doing deductive and inductive reasoning without the use of syllogisms by taking into account multiple aspects at once, allowing for dependence and feedback, and making numerical trade-offs to arrive at a synthesis or conclusion. AHP is a form of multiple criteria decision-making that was first created by prof. Thomas L. Saaty (1977).

When generating a pair-wise matrix between two or more criteria, a scale value of 1 to 9 is used, with 1 denoting equal significance and 9 denoting extreme significance (Ayla *et al.,* 2016). The potential for surface water was evaluated using AHP, and an appropriate area for irrigation was identified.

Table 2.4 The comparison scale in AHP

Scale	1	3	5	7	9	2,4,6,8
Definition	Equal importance	Moderate importance	Strong importance	Very strong importance	Extreme importance	Intermediate values

Source: Saaty, (1980)

2.11 CROPWAT Model Description

CROPWAT model is a computer program for irrigation planning and management, developed based on the FAO Penman-Monteith method (Smith, 2000). The CROPWAT model is a decision-support system created by the FAO's Land and Water Development Division for irrigation planning and management in water resource development (FAO, 1985). CROPWAT is a practical tool to do standard calculations for reference evapotranspiration, crop water requirements, and crop irrigation requirements, as well as the design and administration of irrigation schemes.

It enables the development of suggestions for improved irrigation techniques, the scheduling of irrigation systems under various water supply situations, and the evaluation of crop production under rain-fed or deficit irrigation settings (Ashenafi, 2016). Calculations of agricultural water requirements and irrigation requirements are carried out with inputs of meteorological, crop, and soil data (FAO, 1985).

3. MATERIALS AND METHODS

3.1 Description of the Study Area

3.1.1 Location

The Weyib river sub-basin is located in Oromia Regional State, Bale zone in the northern part of the Genale-Dawa River basin. Watershed is located in terms of a geographic coordinate system, and lies between 6°30′0″ to 7°30′0″N latitudes and 39°30′0″ to 40°30′0″E longitudes as shown in (Figure 3.1). It covers a total drainage area of 4307.985km^2.

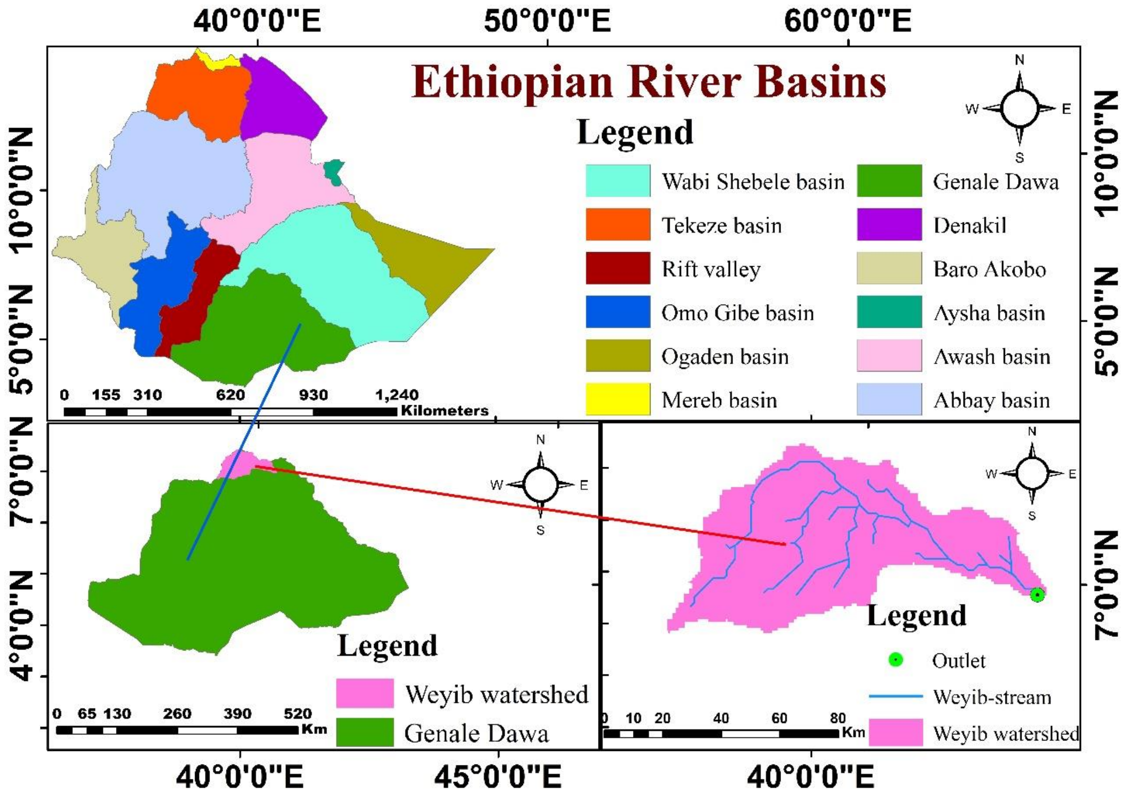

Figure 3.1 location of the Weyib River watershed

The Weyib River originates from the northern flanks of the Bale Mountains extreme points locally called Sannete and first flows generally north-eastward then flows east and south-eastward for the remainder of its course. Finally, it joins with Genale and Dawa rivers near Ethiopia–Somalia border strengthening its journey to the Indian Ocean. The uppermost of the watershed is covered with the afro-alpine ecosystem which is known to be the largest such area in Ethiopia.

3.1.2 Climate

The climate in Ethiopia is geographically quite diverse, due to its equatorial positioning and varied topography. The climatic condition of the country is traditionally classified into five climatic zones based on altitude and temperature variation. Namely; Wurch (cold to moist climate more than 3200m altitudes), Dega (cool to humid climate with 2300- 3200m altitude), Woyna Dega (cool sub-humid at 1500 to 2300m altitude), Kola (warm semi- arid type 500 to 1500m in altitude), and Berha (hot-arid climate <500m altitude) (Berhanu *et al.,* 2014). Weyib Watershed falls into Wurch(cold) and kola (warm semi-arid climate) according to a traditional climate classification system.

3.1.3 Topography

Topography is a major factor affecting irrigation, particularly surface irrigation. It influences drainage, soil erosion, irrigation efficiency, cost of land development, size and shape of fields, etc. The upstream elevation of the watershed is 4235m, in the Bale Mountains and the downstream elevation is 1456m at the watershed outlet at Sofumer (Alemayehu *et al.*, 2015). The upper reaches of the River are fairly forest land with a rugged slope of Bale mountainous ridge, while the lower part of the drainage area is narrowed gorge and is very flat at its lower.

3.1.4 Soils

Soil is a key factor in determining the suitability of an area for agriculture and sustained irrigation (Kassaye *et al.,* 2019). Soil data were a major component in the study of land suitability assessment for irrigation. According to the FAO/UNESCO (1995, 2003), the comprehensive Harmonized World Soil Database (HWSD), the Soil classification system of the study area includes Seven major soil types, such as Eutric Vertisols, Chromic Luvisols, Eutric Leptosols, Eutric Cambisols, Haplic Nitisols, Humic Nitisols, and Chromic Cambisols.

3.1.5 Land Use/Land Cover

Land use/ land cover of the study area is also the factor, which was used to evaluate the land suitability for irrigation. A land use/cover map of the study area was extracted from the land use land cover map developed by the Ethiopian mapping agency. Land use/cover types of the study area were ranked based on their suitability for irrigation potential, working efficiency, costs to land clearing or land preparing for cultivation and environmental impacts. After rank was given for the land use types, reclassified map of the study area was developed.

3.1.6 Irrigation and Agriculture Activities

The Weyib watershed's agricultural economy is mostly centred on small-scale, rain-fed subsistence farming in the country's highlands. Crop production is the major agricultural practice in the study area.

3.2 Materials and Software

Assessment of irrigation potential started by collecting available data from different ministers and agencies such as the Ministry of Water, Irrigation and Electricity (MoWIE), Ethiopian National Meteorological service Agencies (NMA), downloaded HWSD from satellite (http://iiasa.ac.at/2009/world-soil-database) and from online like ArcGIS, CLIMWAT, and CROPWAT setup. The software and materials that can be used to prepare and analyze data were listed below.

Microsoft Word: was used to write the report and prepare the document.

Microsoft Excel: Microsoft Excel is a spreadsheet application for storing and analysing numerical data. The Microsoft Excel pivot table application was used to create the average monthly rainfall and mean monthly maximum and minimum temperature, relative humidity, solar radiation, and wind speed data for CROPWAT8.0 input to calculate reference crop evapotranspiration (ETo). Tables and graphs in the report were created using the Microsoft Excel pivot table program, and the Analytical Hierarchy Process (AHP) is completed using the Microsoft Excel tool.

ArcGIS 10.4.1: This software was used to delineate the watershed, produce streams and slope maps for the research area, and process land suitability criteria such as soil, land use, slope, and distance. It also was used to analyze the information and develop and execute maps from it.

CROPWAT 8.0: was used to determine reference evapotranspiration (ETo), crop water requirement, and irrigation water requirements.

3.3 Methods

3.3.1 Data Collection and Source of Data

Primary and secondary data are critical for any researcher to achieve their research goal. Only secondary data was used in this study. Secondary data was gathered from public and unpublished documents, and reports, as well as information from irrigation authority bureaus at the regional and district levels, accountable organizations, and FAO standards. As a result, the amount of accessible water and land resource potential for surface irrigation must be quantified. Meteorological data, streamflow data, soil data, agronomic data, land use/land cover data, and digital elevation model (DEM) data are examples of secondary data.

Digital elevation model (DEM)

DEM 30m*30m resolution data were obtained from MoWIE GIS database department and were used as input data in ArcGIS. The DEM was used to define the watershed, extract information on the topography or elevation of the watershed, analyze the drainage patterns of the land surface terrain, and derive slope maps of the study area for an analysis of the suitability of irrigation. Additionally, the DEM was used to derive the characteristics of the stream network of the study area.

DEM of the watershed was projected to UTM Coordinate system using Arc Toolbox in ArcGIS10.4.1 and imported to ArcSWAT10.4.1 to start automatic watershed delineation. As (Figure 3.2), shows imported DEM into SWAT. After the projected new SWAT project setup using the “SWAT project setup” in Arc SWAT. The following diagram shows that the characteristics of the elevation of the watershed vary from 4235m to 1456 masl with a coverage area of 4307.985km^2.

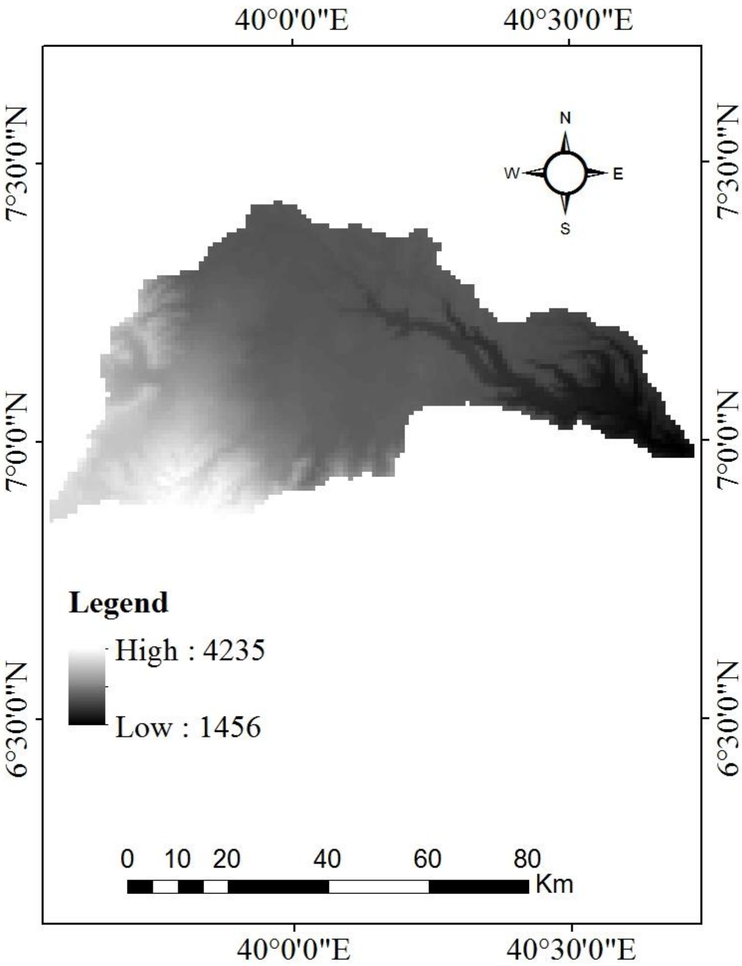

Figure 3.2 Digital Elevation of the study area.

Meteorological data

All climate data for the Sinana, Robe, Agarfa, Dinsho, and Ginir stations were gathered from the National Meteorology Service Agency (NMSA), including rainfall, temperature, relative humidity, wind speed, and sunlight hour. These data were used to quantify the crop water requirements of certain chosen crops that are typically produced in the watershed using the cropwat8.0 programs.

Streamflow data

Data on streamflow in the Weyib River watershed was gathered from the hydrology office of the Ministry of Water, Irrigation, and Electricity. The Weyib River flow data for this study was obtained from 19 years of daily data (1990 to 2008) at the Sofumer gauging station. This data was very essential to assess the available water potential for the area.

Table 3.1 Hydro-Meteorological data and their available years of record

Meteorological data								
Station	**Lat. (ºN)**	**Long. (ºE)**	**Elev. (m)**	**Records year**				
				Rainfall	Temperature	humidity	Wind speed	Sunshine hour
Agarfa	7°15′ 36″	39°49′ 12″	2446	1990-2017	1990-1998	-	-	-
Dinsho	7°6′ 11″	39°46′ 48″	3073	1990-2020	1990-2020	-	-	-
Ginir	7°7′ 48″	40°42′ 36″	1941	1990-2020	1990-2020	1990-2020	1990-2017	2008-2020
Robe	7°7′ 48″	40°03′ 00″	2480	1990-2020	1990-2020	1991-2020	1990-2020	1990-2020
Sinana	7°4′ 12″	40°13′ 12″	2400	1990-2020	1990-2020	2014-2020	1990-2016	-
Hydrological or Stream flow data								
Weyib @ Sofumer	6°54′ 00″	40°50′ 00″	1171	1990-2008				

Soil data: soil data was downloaded HWSD from satellite. This information was used to determine the appropriateness of the soil for surface irrigation.

Agronomic data: Agronomic data was obtained from the Ministry of Agriculture (MoA). Agronomic data include types of crop, and cropping patterns (planting date, growth length, (early stage, medium stage, development stage, and late stage) in days.

Land use/land cover data: Land use/land cover is the most significant geographical factor that defines the catchment. This feature is dynamic since land use can alter both spatially and temporally. Data on land use /cover was used to assess the suitability of the land for surface irrigation. In this research, the 1:250,000 scale land cover map is updated (2017) from the Oromia water work design and supervision enterprises. These data sets were collected from different sources (Table 3.2).

Table 3.2 Summarized data type, software, and Sources used in this study

No	Data type	Sources
1	Meteorological data	National Meteorological Service Agency (NMSA)
2	Hydrological data	MoWIE
3	Soil data(map)	http://iiasa.ac.at/2009/world-soil-database HWSD version 1.2
4	DEM	Ethiopian mapping agency (30mX30m)
5	LULC data	Ethiopia map server organization (2017)
6	ArcGIS 10.4.1 Software	Download from https://soft.hoit.asia/2016/12/arcgis-104.1-desktop-full-crack-download.html
7	CROPWAT8.0 Software's	Download from https://softadvice.informer.com/Cropwat8.0_Software_By_Fao_For_64_Bit.html

3.4 Data Processing and Analysis

Before processing and analysing the collected data, the data have to be checked and errors have to be removed. In processing all the design and analysis, identifying the literature review of the research, and data gathered were analysed to come up with the research output.

3.4.1 Data pre-processing and checking

Collected data can contain errors due to failures of the measuring device or the recorder. Before using the data for a specific purpose, the data should be checked and errors should be removed. checking for missed data and removing errors is very essential. In this study, rainfall data were filled by using the arithmetic mean method and data consistency checking was performed by a double mass curve (Asawa, 2008). The analysis was extended to hydrological and meteorological data to prepare input data for water resources assessment and irrigation water requirement estimation using the CROPWAT model.

3.4.1.1 Filling Missing Meteorological and Flow Data

Before using the climate data and flow data of a station, it is necessary first to check the data for continuity and consistency. The existing missing data were estimated using the data-filling methods. Some of the methods which are used to estimate missing rainfall data are the inverse distance method, normal ratio method, areal precipitation ratio method, arithmetic mean method, and multiple regression analysis methods. For this study, the Arithmetic mean method was used to fill in missing meteorological data and flow data.

To fill in missing rainfall data, normal rainfall is used as the standard of comparison. Normal rainfall is the average value of rainfall at a particular daily, monthly, or yearly over a specified thirty-one-year period. The two most popular techniques for filling in missing rainfall data are the simple arithmetic average method and the normal ratio method. The following equation has been used to determine the percentage difference to use when deciding between the arithmetic mean method and the normal ratio method.

$$\text{percentage difference} = \frac{N_x - N_i}{N_x} * 100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.1$$

Where, N_x.......... the normal annual rainfall amount from the missing data station,

N_i ……. the normal annual rainfall amount from one of the nearby stations.

The method is used for the difference between the normal annual precipitation at nearby gauges within 10% of the annual precipitation of the station with missing data. This technique can be used to compute missing monthly and annual rainfall values. The missing data is estimated by;

$$P_x = {}^{1}/_{M}\,(P_1 + P_2 + P_3 + \cdots + P_m) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.2$$

Where: - Px = missing rainfall data at station x,

P1, P2, P3, and P4 = precipitation at surrounding gauges station,

M = the number of nearby gauge stations

3.4.1.2 Climate Data Analysis

Five meteorological stations of the watershed were selected such as Agarfa, Robe, Dinsho, Sinana, and Ginir. The selected meteorological stations were those found inside the watershed except Ginir station. Robe and Ginir stations relatively have full climate data shown in (Figure 3.3).

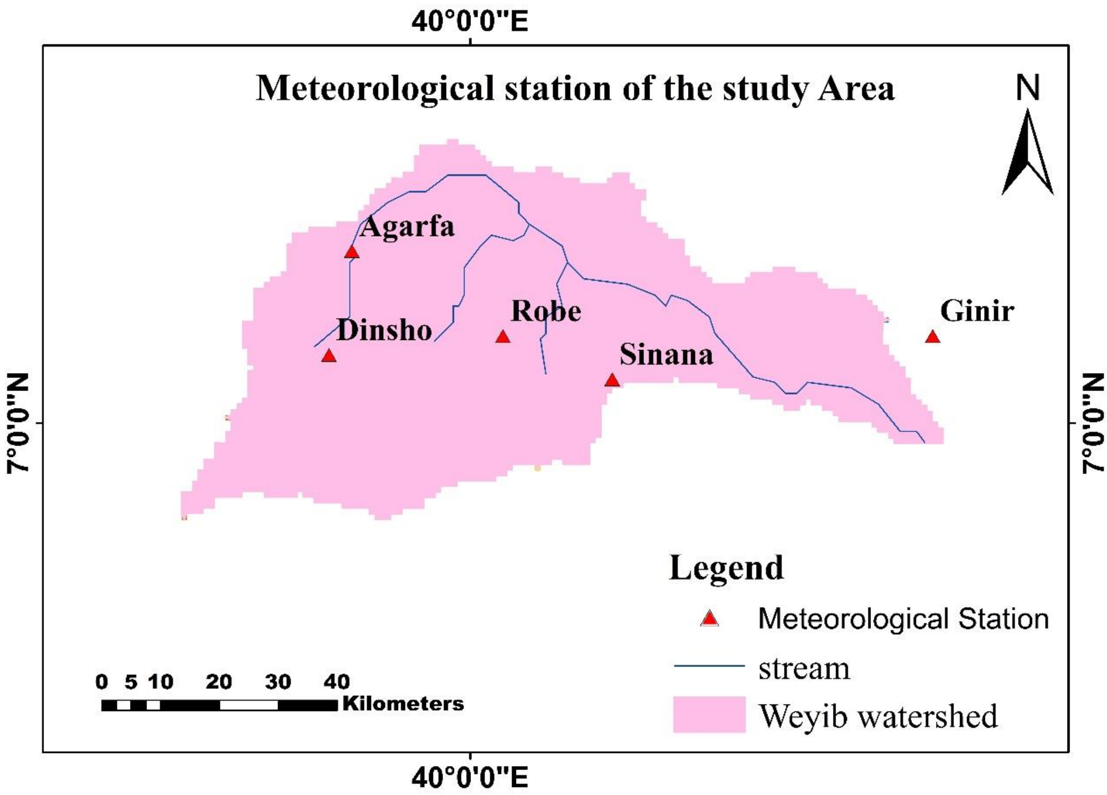

Figure 3.3 Meteorological stations of Weyib River Watershed

Climate data which was used in this study consisted of daily precipitation, maximum and minimum temperature, solar radiation, wind speed, and Relative humidity.

A. Rainfall

The variation in the seasonal distribution of rainfall in Ethiopia can be attributed to the references to the position of the Inter-Tropical Convergence Zone (ITCZ), the relationship between upper and lower air circulation, the effects of topography and the role of local convection currents and the amount of rainfall (Berhanu *et al.,* 2014). The seasonal rainfall distribution within the study area results from the annual movement of the ITCZ. The rainfall pattern of Weyib Watershed follows a symmetric bimodal profile with double peaks in April and August (Abdulkerim and Arup, 2016). Rainfall data for thirty-one years was collected from the National Meteorological Service Agency (NMSA) for the five stations. Namely; Sinana, Robe, Agarfa, Dinsho and Ginir stations.

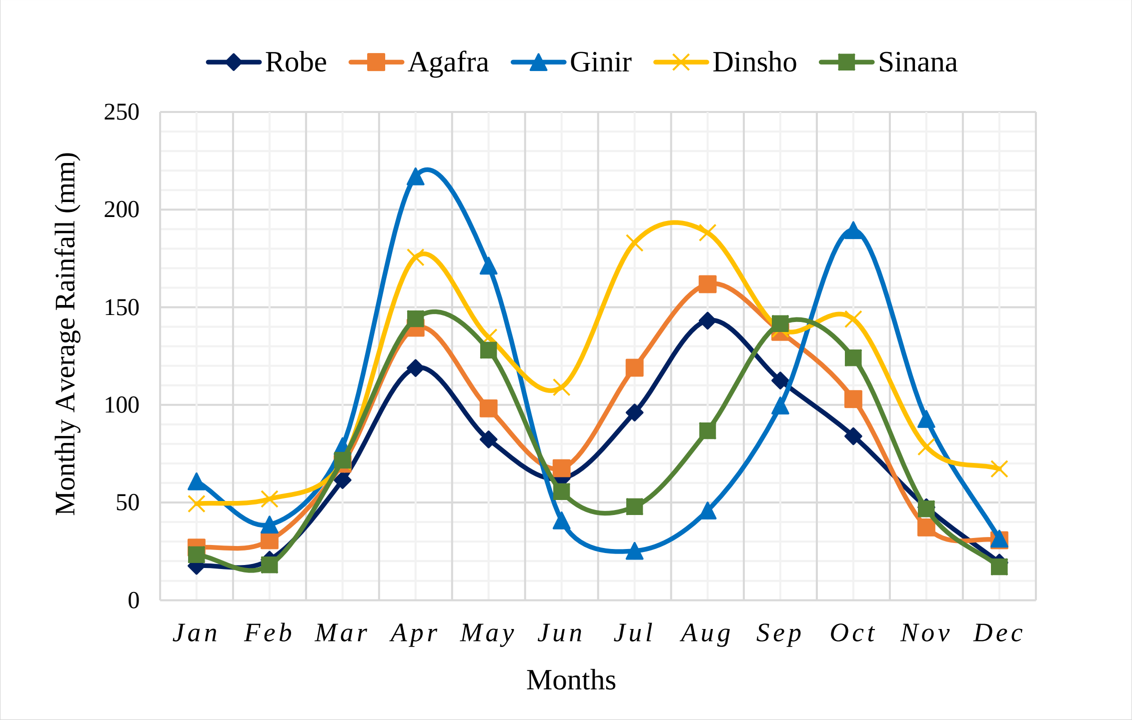

Figure 3.4 Monthly Distribution of Average Rainfall in the Weyib River Watershed

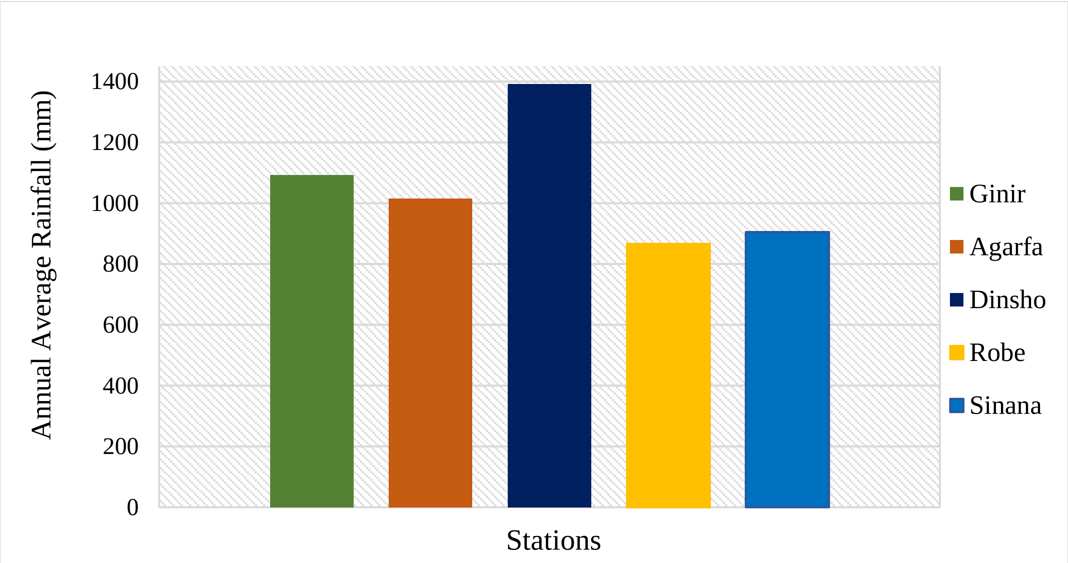

Figure 3.5 Annual average rainfall for all meteorological stations

The Annual average rainfall of 31 years (1990-2020) for Sinana, Robe, Agarfa, Dinsho and Ginir stations was found to be 905.6mm, 866.2mm, 1016.04mm, 1391.5mm and 1092.6mm respectively. The Weyib river catchment receives 1054.4 mm of mean annual rainfall, with a maximum of 1392mm of rainfall in the Dinsho highlands, which is located in the western part of the study watershed.

B. Temperature

The air temperature of the Weyib River watershed was analysed using monthly minimum and maximum data from five stations. The average monthly distribution temperature of the watershed was the maximum and minimum temperature occurs in March (22.58^{0}C) and the month of December (6.66^{0}C) respectively. In the study area, the annual air temperature of the watershed ranges between 4^{0}C and 24^{0}C, and the mean annual temperature is around 14^{0}C. According to (Sissay *et al.*, 2019), the mean annual reference evapotranspiration of the study area is 842.7mm whereas, the actual evapotranspiration is 970.1mm. The mean daily evapotranspiration ranges from 3.1 to 3.9mm/day, with an average of 3.4 mm/day.

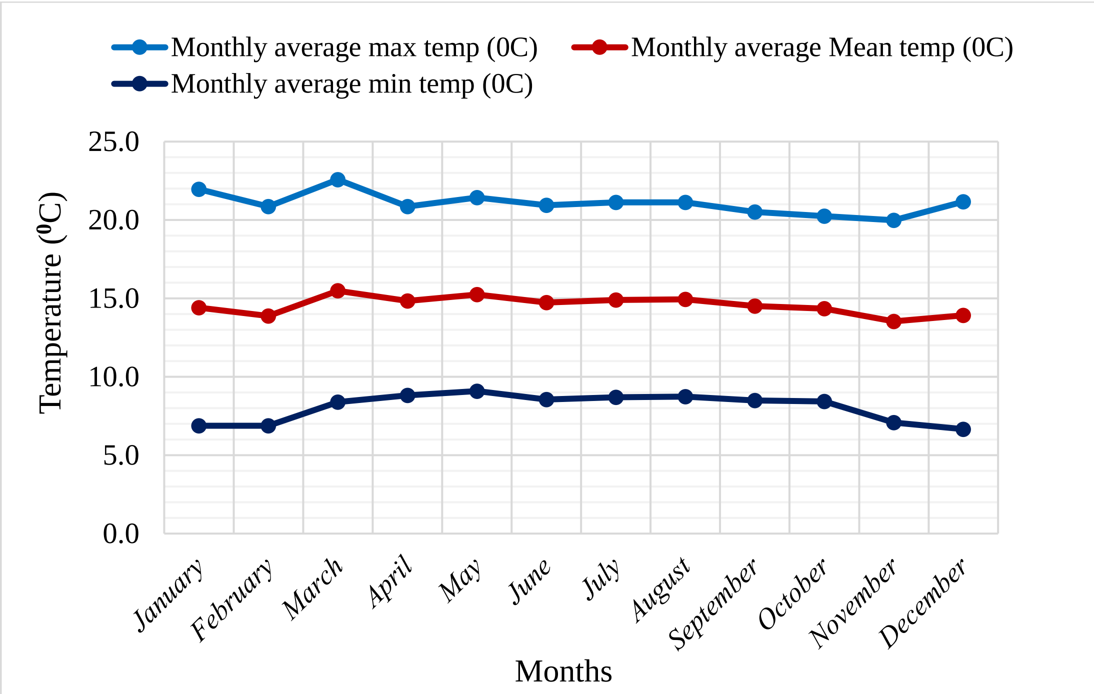

Figure 3.6 Average monthly temperature condition in the Weyib Watershed

C. Wind speed

Wind speed was one of the input parameters that were used for CROPWAT8.0 to calculate ETo. The average wind speed of Robe, Sinana, and Ginir stations were found to be 127.4 km/day, 229.7 km/day, and 155.5 km/day respectively. The selection of irrigation techniques and the rate at which crops transpire depends on wind parameters such as wind velocity, frequency, and direction. At a height of 2 meters, the average wind speed of the robe station was recorded as 127.4 km/day.

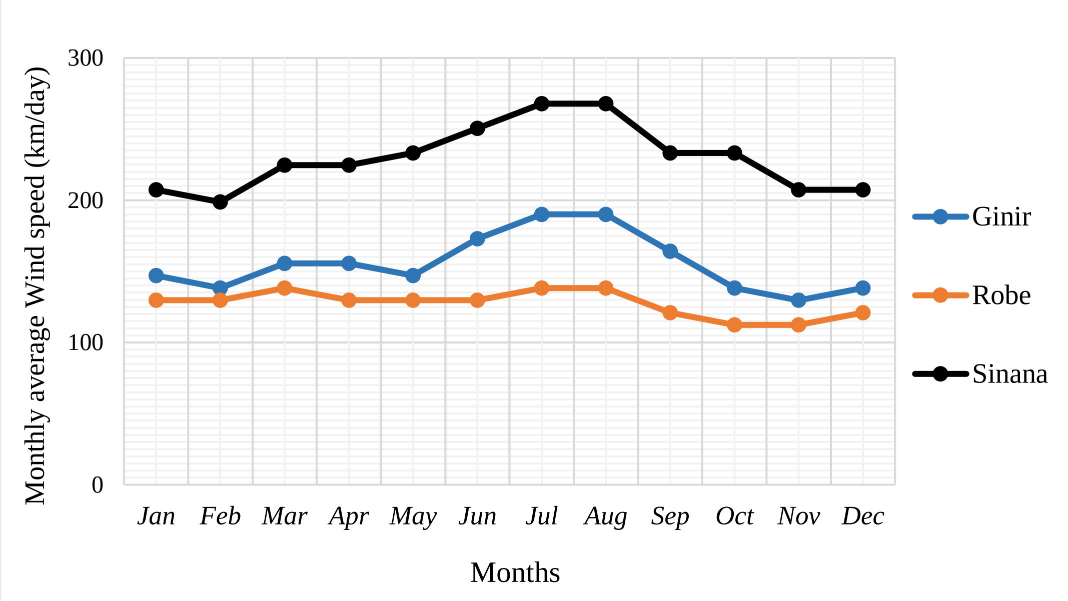

Figure 3.7 Monthly Average wind speed in the study area

D. Sunshine hours

Sunlight hours were the inputs that were used as input for CROPWAT8.0 to calculate ETo. The monthly average maximum and minimum sunshine hours of Robe, and Ginir stations were found to be 8.0 and 8.3 hours in January and 5.4 and 5.6 hours in September respectively.

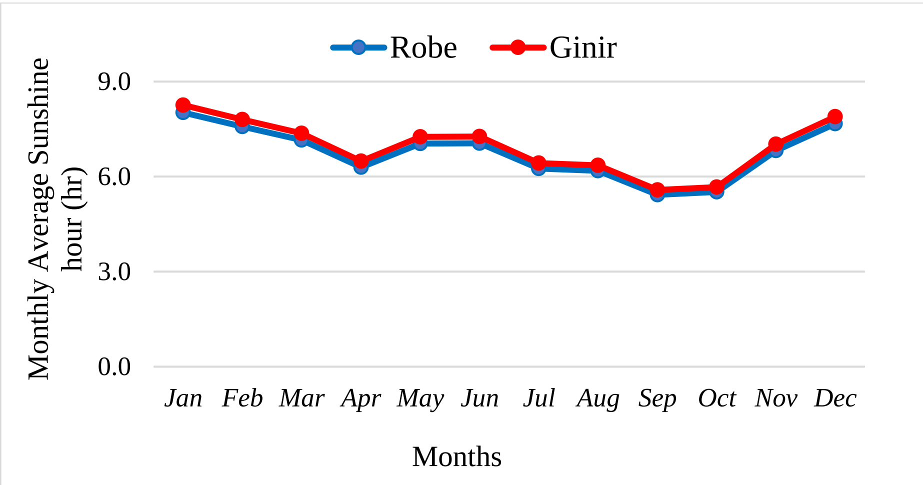

Figure 3.8 Monthly Average sunshine hour in the study area.

At the Robe meteorological station, the average maximum and minimum sunlight hours were 8.0 hours in January and 5.4 hours in September, respectively.

E. Relative humidity

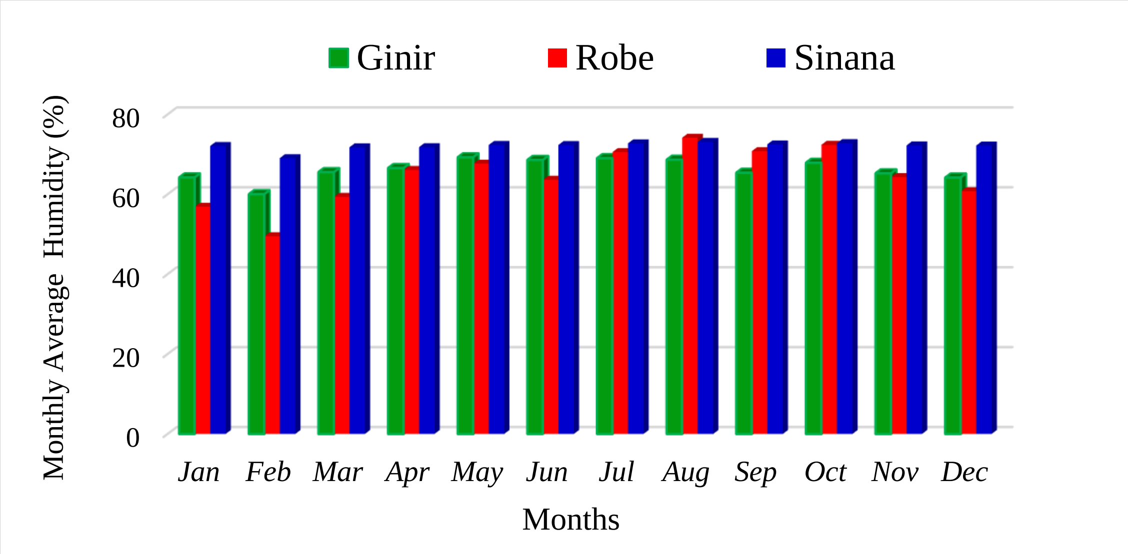

Figure 3.9 Monthly Average Relative humidity in the Weyib Watershed

The monthly average relative humidity of 31 years (1990-2020) for Ginir, Robe, and Sinana stations was found to be about 66.2%, 64.7%, and 72.1% respectively. Relative humidity data was one of the input parameters that were utilized as input for CROPWAT8.0 to calculate reference crop evapotranspiration. According to data collected from the Robe meteorological station over thirty years (1991-2020), the average monthly relative humidity was found to be around 64.7%.

Table 3.3 Meteorological data of Robe station.

Month	Rainfall (mm)	Tmax (°C)	Tmin (°C)	Humidity (%)	Sunshine hour (hr)	Wind speed (Km/day)
January	17.6	22.9	6.3	56.9	8.0	130
February	20.7	21.9	6.5	49.5	7.6	130
March	61.5	23.4	8.4	59.4	7.2	138
April	118.9	21.5	9.5	66.1	6.3	130
May	82.3	22.4	9.8	67.7	7.0	130
June	62.3	22.1	9.2	63.6	7.1	130
July	96.0	22.1	9.4	70.6	6.2	138
August	143.2	21.4	9.4	74.2	6.2	138
September	112.5	20.4	9.0	70.8	5.4	121
October	84.0	20.0	8.8	72.4	5.5	112
November	47.6	20.0	7.0	64.3	6.8	112
December	19.3	21.6	6.1	60.8	7.7	121
Average	72.2	21.6	8.3	64.7	6.8	127.4

Consistency checking for Rainfall

To prepare the rainfall data for further application, their consistency was checked using a double mass curve analysis. Double mass curves are a helpful indicator of data consistency. The consistency of rainfall data was checked by plotting cumulative annual rainfall data against the cumulative annual average at the stations nearby (James K and Clayton H, 1960). To check the degree of consistency provided the value of the coefficient of correlation is as follows.

Table 3.4 correlation coefficients.

Range of correlation coefficients	Description
r = 1	direct linear correlation
0.6 ≤ r < 1	good direct correlation
-0.6 < r < 0	insufficient reciprocal correlation
-1 < r < 0.6	good reciprocal correlation
r = -1	reciprocal linear correlation

Source: (Nemec, 1972)

Rainfall data are somewhat consistent if the periodic data are proportional to an adequate simultaneous period, and these inconsistent data can be modified by proportioning, using a correlation coefficient, between the station (Moutaz Al- Shabbagh, 2001).

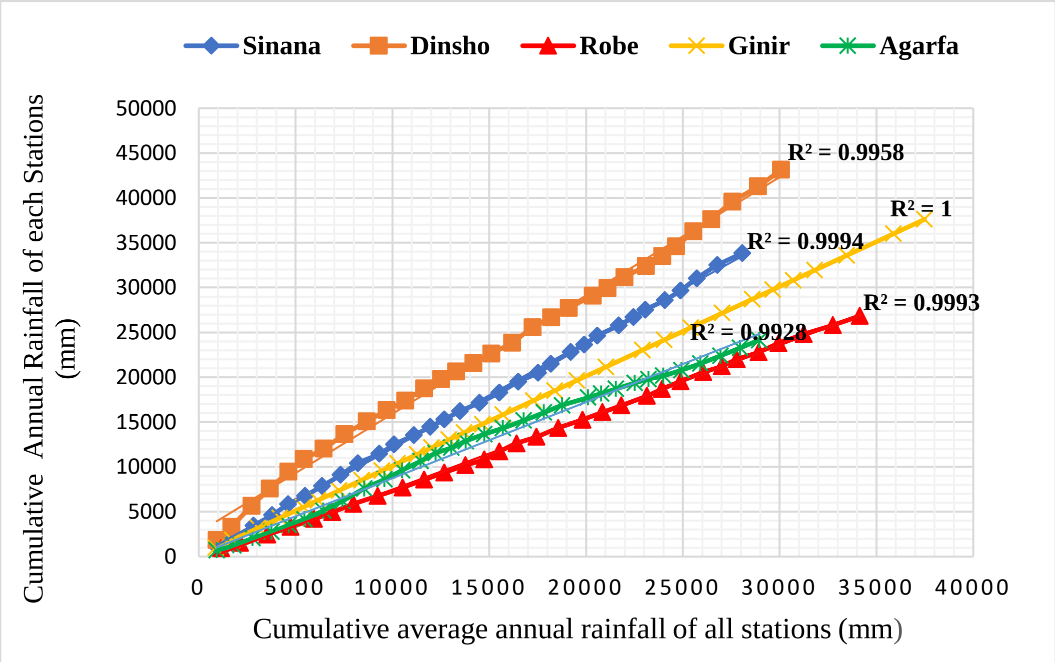

Figure 3.10 DMC of all five rainfall stations.

3.4.2 Delineation of the watershed

The watershed of the research area was defined by the watershed Delineator tool in Arc SWAT 10.4.1 based on an automated process using the watershed outlets established by using "Edit manually," "ADD," and "choose a watershed outlets selection. Additional drainage outlets must be identified to build sub-watersheds. The same technique for defining watershed outlets was used once more to construct the sub-watershed after many nodes or vertices were defined into drainage outlets along the stream arcs.

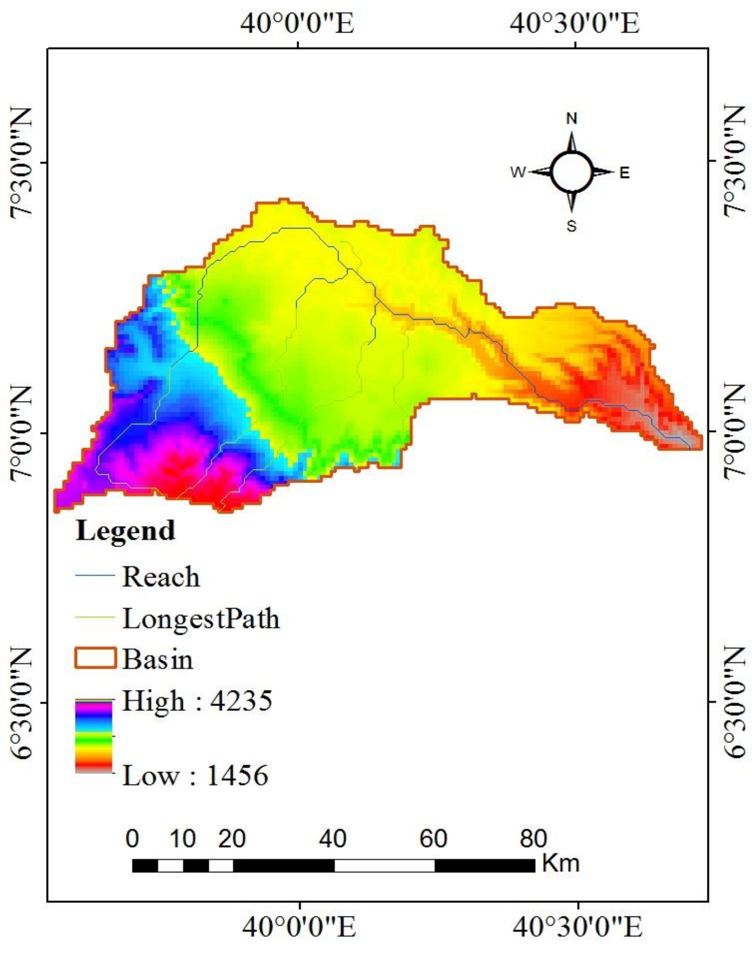

Figure 3.11 Watershed of the study area

3.4.3 Identification of potential irrigable sites

The FAO guidelines and the available information served as the basis for the criterion for identifying potentially irrigable areas. In order to determine whether the land in the study area is suitable for irrigation, the following evaluation factors are taken into account (Biplab *et al.*, 2018). A thorough evaluation of irrigable land and available water resources is necessary for planning and decision-making for new irrigation development projects.

A method was developed for estimating surface water resources and potentially irrigable land in watersheds in the Weyib River by using the ArcGIS tool because the necessary data are typically unavailable in developing countries. The following factors were taken into consideration: soil type, soil's physical characteristics (depth, drainage, and texture), slope, land use, and river proximity (Megersa, 2020). To determine potential irrigable sites, the suitability of each factor was first evaluated individually and then weighted. These procedures were discussed as follows.

3.4.3.1 Slope Suitability Analysis

In the investigation of the suitability of surface irrigation, the slope has been taken into consideration as one of the evaluation characteristics. The Shuttle Radar Topography digital elevation model (SRTM DEM) with 30m resolution was used to determine the sub-basin slope. The "Spatial Analyst" "surface Slope" tool in ArcGIS was then used to create slope maps for the watersheds. Using the "Reclassification" tool, an attribute generalization method in ArcGIS 10.4.1, the slope was categorized into four suitability groups, (FAO, 1999), S1, S2, S3, and N.

Using the "Conversion Tool from Raster," the classified raster data layers were transformed into feature (vector) data layers in order to compute the identified slope's area coverage and conduct an overlaying analysis.

Table 3.5 Classification of slope suitability for surface irrigation.

S. No	Slope (%)	Classes	Factor rating	Description
1	0 – 2	Level	S1	Highly suitable
2	2 – 5	Undulating	S2	Moderately suitable
3	5 – 8	Undulating	S3	Marginally suitable
4	>8	Rolling-hill	N	Not suitable

Source: FAO guideline of land evaluation (FAO, 1999)

3.4.3.2 Soil suitability assessment

Soil is the main factor in determining the irrigation suitability of the study area for surface irrigation. It primarily affects the production capacity, but it also has an impact on costs associated with production and development. Data on the physical characteristics of the soil, including its depth, texture, and drainage, were taken from the FAO/UNESCO global soil map (1995, 2003). It is available in ARC/ INFO format with a scale of 1: 500,000.

For this specific study, four physical properties of the soil were reclassified by the "reclassify" tool in the Spatial analysis of ArcGIS; then those reclassified physical properties of the soil were used as inputs with slope, land use/cover and distance from the water supply for weighting overlay process in ArcGIS to identify irrigable land in the study area by Analytical Hierarchy Process (AHP). In this study only, physical properties not Chemical properties of the soil group were considered.

Soil types suitability assessment

The soil map of the specified study area was obtained from FAO/UNESCO-of soil map. The major soils in the Weyib watershed were found to be Eutric Vertisols, Chromic Luvisols, Eutric Leptosols, Eutric Cambisols, Haplic Nitisols, Humic Nitisols, and Chromic Cambisols.

Eutric Vertisols coverage areas 215576.2ha (50.04%) of the watershed and were characterized as a depth of moderately deep and clay in its texture. Eutric Vertisols are extremely hard when dry and very sticky and plastic when wet which is reflected in their poor workability. When dry and hard, traditional cultivation techniques are unable to plough the land; when wet, the soil is typically too heavy for traditional cultivation, and even under mechanized cultivation traction is poor and the soil tends to smear and compress for the use of Vertisols cultivation, thus only a limited window of opportunity to plough. By surface irrigation, crops such as cotton, wheat, sorghum, and rice can be grown. Vertisols are especially suitable for rice because they are almost impermeable when saturated. As a result, of this, the soil is Highly Suitable (S1).

Chromic Luvisols cover an area of about 107478.5ha (24.95%), were classified as highly suitable(S1), and characterized as well-drained and deep soil. This soil group is commonly dominant on flat to gently sloping topography.

Chromic Cambisols' coverage area is about 5463ha (1.27%) and is categorized as moderately suitable(S2) to having moderate depth, moderate textures, and moderate drainage.

The following soil suitability rating was used based on the FAO guidelines for land evaluation (FAO, 1995). Further, the soil feature layer was converted into a raster layer using the conversion tool "polygon to Raster or Feature to Raster module". The raster soil map of the study area was classified based on the soil type, texture, depth and drainage of the watershed. After classified again change to polygon to calculate area coverage of physical properties of the soil "Editor to merge".

Table 3.6 Classification of soil suitability

Factors	Factors rating			
	highly suitable	moderately suitable	marginally suitable	Not suitable
Drainage	Well drain	Moderately well drain	Imperfectly	poor
Soil depth(cm)	>150	80-150	40-80	<40
Soil Texture	L, CL, C	SC	SL, S	

Sources: FAO guideline of land evaluation (1991, 1995) and HWSD (2009).

3.4.3.3 Land use land cover suitability analysis

The terms land use and land cover (LULC) are frequently interchanged. They are, nevertheless, extremely different. Land cover refers to the cover of the earth's surface, such as vegetation, urban development, water, ice, and bare rock, without reference to how that cover is used. Land use refers to the actual economic activity for which the land is used such as crop production, commercial forestry, national parking, and grassland. The raster Land use/cover map of the study area was obtained from the Ethiopia Land use/cover map of 2017 from the Ethiopia mapping agency. The types of land use/cover in the study area includes cultivated land, open grassland, open shrubland, bushed shrubs grassland, forest land and dense shrub land.

Cultivated Land: is in a sense self-explanatory, being that land, which is being cultivated. Rain-fed, state farms, perennial crops and irrigated lands are sub-divisions of the cultivated class included. This land cover type was classified as highly suitable and covers an area of 229,726 ha (53.33%) of the total area of the catchment.

Grassland: an area covered by grasses and mostly used for grazing purposes. The open grassland is grouped as moderately suitable according to agricultural practice for surface irrigation. It covers around 58791.5ha (13.65%).

Woodland, bushland, and Alpine vegetation: lands covered by small trees, bushes, or a mixture of small trees and small grasses categorized as marginally suitable for surface irrigation. The area coverage was 72430ha (16.81%) of the study area.

Forest land: Forest lands include open woodland and eucalyptus woodland defined as any of numerous often tall trees belonging to the genus Eucalyptus, having aromatic evergreen leaves that are the source of medicinal oils and heavy wood used as timber. Dense shrubland consists of multi-stemmed woody species with a height of more than 2m that are covered densely. It was classified as not suitable for irrigation and covers 69851ha (16.21%).

3.4.3.4 Distance from Water Supply (Source)

By using the buffer's icon in the analysis tool and clipping to the designated study area, straight-line (Euclidean) distance from watershed outlets was determined using DEM of 30 m x 30 m cell size. This allowed us to locate irrigable land close to the water supply. The buffer's clipped map was then transformed to a raster using the conversion tool, and then using the "Classed tool," it was reclassified into a suitable class based on its proximity to the water source. The reclassified distance was utilized for weighing overlay for additional analysis together with other parameters. When determining the buffer distances, the distance between the water source and the command area requires a subjective assessment. The majority of researchers categorized the distance from the source as follows.

Table 3.7 Distance classification.

S. No	Distance (km)	Suitability factor
1	< 1.5	Highly suitable
2	1.5 -3	Moderately suitable
3	3 -5	Marginally
4	> 5	Not suitable

Source: assessment of surface water (Edmealem, 2018)

3.5 Developing Pair-wise Comparison Matrix

According to (Mendoza *et al.*, 2008), Pair-wise Comparison Matrix, often known as AHP (Analytic Hierarchy Process), is a matrix in which the parameters for the Rows and Columns are the same. After the matrix has been set up, a score range of 1 to 9 is chosen and assigned for each factor based on the number of irrigation suitability criteria. The team with the highest score suggests that the row was more significant than the column. A score of 1 was assigned to the matrix's diagonal. Moving on, the value in the corresponding column that was immediately below the diagonal matrix was just the inverse of the scores in the corresponding row. A formula from the matrix goal calculation was used to explain how to calculate the consistency ratio.

$$CR = \frac{CI}{RI} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.3$$

Where: CR = Consistency ratio, CI = Consistency Index and RI = Random Consistency Index.

$$CI = \frac{\lambda_{aver} - n}{n - 1} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.4$$

Where: - λ_{aver} = the average of eigenvalues and n = numbers of criteria or sub-criteria in each pair-wise comparison matrix. The average random consistency index is given in (Table 3.8).

Table 3.8 Random consistency Index

N	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51

3.6 Weighing of Irrigation Suitability Factors to Find Potential Irrigable Sites.

The weighted Overlay tool is one of the most popular overlay analysis techniques to address multi-criteria issues like developing irrigation suitability models and identifying suitable areas for surface irrigation. After determining the suitability of each parameter for irrigation and developing a suitability map layer for each criterion separately, an overlay analysis was performed using the "model builder" tool in the ArcGIS tools box and tools from spatial analysis tool tests to produce a single suitability map of the River catchment.

In order to determine the most suitable area for surface irrigation, a weighted overlay was utilized to combine the irrigation suitability parameters that were taken into consideration in this study, including slope, soil type, drainage, depth, texture, land use/land cover, and distance as shown in the (Figure 3.12).

Figure 3.12 Irrigation Suitability Model flow chart

3.7 Surface water availability

Making a flow duration curve helps us to examine the available flow's 90% time of exceedance flow. FDC offers the percentage of a daily or monthly stream flow's duration that is surpassed over a certain year period (Vogel and Fennessey, 1994). The FDC for this study was created using data from the Weyib river discharge over 19 years (1990–2008).

3.8 Estimation of Irrigation Water Requirements (IWR)

The amount of water required for irrigation includes losses during the conveyance of water from the source to the field as well as water needed for evaporation and transpiration (Evapotranspiration/ ET)(Ahmed *et al.,* 2018). In other words, the amount of water needed by the crop for optimal development conditions without a water shortage is known as the irrigation water requirement, which is stated as the net water requirement for irrigation (Pitojo *et al.,* 2018).

Determining the total amount of water needed from sowing time through harvest is the most crucial aspect of computed irrigation water demand. Various crops require different amounts of water under the same circumstances, and the amounts of water consumed by a given crop vary during its whole life cycle (beginning, development, mid-season, and late-season stages) of the crop period (Mamenie, 2017). A crop requires water initially at a comparatively modest rate during sowing, sprouting, and early growth. In most crops, the rate will rise as the crop grows to its maximum as blooming approaches, then fall as the crop matures (MoA, 2011).

Based on climate data, the selected crops that are commonly grown in the research area had their irrigation water requirements determined. The climatic information about the chosen station was used to determine how much irrigation water was needed for the specified irrigable area. Irrigation water requirement (IWR) was computed as the following equation.

$$\mathrm{IWR} = \mathrm{ET_c} - \mathrm{P_{eff}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..3.5$$

Where: IWR= irrigation water requirement (cm); ET_c = crop evapotranspiration (cm); and P_{eff} = effective rainfall (cm).

Evapotranspiration (ET)

There is no simple method to distinguish between evaporation and transpiration because they happen concurrently. The amount of solar radiation that reaches the soil surface, in addition to the topsoil's water content, is the key factor affecting how much cropped soil evaporates. As the crop matures and its canopy gradually covers more ground area, this percentage falls throughout the growing season. When the crop is tiny, soil evaporation accounts for the majority of water loss; however, once the crop has grown well and has completely covered the soil, transpiration starts to take over.

The standard unit of measurement for evapotranspiration is millimetres (mm) per hour. A cropped surface's water loss rate is expressed as a rate in units of water depth. A growth season of a year, a day, a decade, a month, or even an entire hour might be used as the time unit. The term "crop water demand" refers to how much water is needed to make up for the evapotranspiration loss from a cropped field. Crop water demand refers to the amount of water that must be supplied, whereas crop evapotranspiration refers to the amount of water lost by evapotranspiration, even if the values for both are similar. The difference between the crop water requirement and effective rainfall is represented by the irrigation water requirement.

Factors affecting evapotranspiration

Evaporation and transpiration are influenced by a variety of factors, including environmental factors, crop traits, management, and weather conditions.

i. Weather parameters

The primary weather factors that affect evapotranspiration are solar radiation, air temperature, humidity, and wind speed.

ii. Crop factors

When measuring the evapotranspiration from crops grown in sizable, well-managed fields, the crop type, variety, and growth stage should be considered. Different ET levels are produced in various types of crops under the same climatic conditions by variations in transpiration resistance, crop height, crop roughness, reflection, ground cover, and crop rooting properties.

iii. Management and environmental conditions

Crop development and evapotranspiration may be hampered by factors such as soil salinity, poor soil fertility, sparse fertilizer treatment, the presence of hard or impenetrable soil layers, the lack of disease and pest control, and poor soil management. The variety of management techniques that influence the meteorological and crop elements influencing the ET process should be given considerable thought when determining the ET rate. The microclimate, crop characters, and soil and crop surface wetting can all be impacted by cultivation techniques and the type of irrigation system used. Due to the aforementioned considerations, the associated evapotranspiration ideas are as follows.

Reference Crop Evapotranspiration (ETo)

The reference crop evapotranspiration, represented by ETo, is the evapotranspiration from a reference surface that is not deficient in water. The hypothetical grass reference crop used as the reference surface has a set of features. Climate-related variables are the sole variables that affect ETo. As a result, ETo is a climatic parameter that may be calculated using meteorological data. ETo does not consider crop characteristics or soil conditions; instead, it indicates the evaporating power of the atmosphere at a certain location and time of the year. Additionally, methods for predicting missing climatic factors have been proposed (FAO, 2006).

The reference surface for the FAO Penman-Monteith approach is a hypothetical reference crop with an assumed crop height of 0.12 meters, a set surface resistance of 70 sec/m, and a reflectivity of 0.23 m (FAO, 1998). The reference surface closely resembles a broad expanse of green grass that is consistent in height, actively growing, entirely covering the ground, and adequately watered. Equation 3.4, represents the Penman-Monteith Equation.

$$ET_O = \frac{0.408 * \Delta * (R_n - G) + \gamma * \frac{900}{T + 273} * u_2(e_s - e_a)}{\Delta + \gamma * (1 + 0.34u_2)} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots 3.4$$

Where:

ETo…. reference evapotranspiration (mm/day)

Rn …. net radiation at the crop surface ($MJ/m^2/day$)

G…. soil heat flux density ($MJ/m^2/day$)

T…. air temperature at 2-meter height (^oC)

U_2… wind speed at 2-meter height (m/sec)

e_s… saturation vapour pressure (kPa)

e_a …. actual vapour pressure (kPa)

e_s - e_a … saturation vapour pressure deficit (kPa)

Δ …. slope vapour pressure curve ($kPa/^oC$)

γ … psychrometric constant ($kPa/^oC$)

For daily, weekly, decade, or monthly computations, the equation uses conventional climatological records of solar radiation, air temperature, humidity, and wind speed.

Effective Rain (mm/period): Depending on the crop's root zone depth and soil storage capacity, it's a portion of the rainfall can be utilized by the crop successfully. It influences the net irrigation water requirement and crop water requirements (FAO, 2002). Effective rain can be calculated as the following equation.

$$P_{eff} = a * P_{tot} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 3.5$$

Where:

P_{eff} = is the effective rainfall

a= is a fixed percentage coefficient (specified by the model user), with a typical range of values from 0.7 to 0.9; and Ptot= is the measured total daily rainfall.

Crop evapotranspiration (ETc):- The amount of water that a crop needs to match its evapotranspiration losses and the water it uses for metabolic processes is known as ETc (Megersa, 2020). The crop evapotranspiration under standard conditions, abbreviated as ETc, refers to the evapotranspiration from healthy, disease-free crops that have received adequate fertilization and are grown in large fields with suitable soil water conditions. These crops are also capable of producing their full potential under the appropriate climatic conditions.

By directly incorporating the crop resistance, albedo, and air resistance varies in the Penman-Monteith technique and using climatic data, it is possible to determine crop evapotranspiration, according to FAO, (2002). Then, crop evapotranspiration (ETc) was calculated using (Equation 3.6).

$$ET_c = ET_o * K_c \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots 3.6$$

Where: ETc =crop evapotranspiration (mm/day); ETo = Reference crop evapotranspiration (mm/day); and Kc=Crop coefficient (fraction), varies with a crop growing stages.

Crop Water Requirement (CWR)

Crop water requirements are described as "the depth of water needed to meet the water loss through evapotranspiration (ET) of a disease-free crop, growing in large fields under non-restrictive soil conditions, including soil water and fertility; and achieving full production potential under the given growing environment," (Solomon *et al*, 2019). The

CWR approach primarily relies on calculating crop evapotranspiration (ETc), which is influenced by evapotranspiration and crop attributes. The reference evapotranspiration (ETo) is the rate of evapotranspiration from an extended surface of a green cover, completely shading the ground, and not a shortage of water. The factor that indicates various ET levels for various types of crops under the same environmental conditions is known as the crop coefficient (Kc) (Ahmed, 2018).

The crop water requirement refers to the amount of water that must be supplied (positive sign), whereas crop evapotranspiration refers to the amount of water lost through evapotranspiration (negative sign). The values for crop evapotranspiration (ETc) and crop water requirement (CWR) are identical (except for the opposite sign). Crop features, agricultural methods, and the impact of the climate on crop water loss are properly considered when calculating the amount of water required for crops. The CWR was calculated by the following (Equation 3.7).

$$CWR = (ET_o * K_c) - P_{eff} \quad \dots 3.7$$

Where: - CWR = crop water requirement (mm/day), Kc = crop coefficient,

ETo = reference evapotranspiration (mm/day) and P_{eff} = effective rainfall (mm/day)

Net Irrigation Water Requirement (NIWR):- For each irrigated crop, the total of individual crop water requirements (CWR) was computed (FAO, 2002).

$$\mathrm{NIWR} = \sum_{i=1}^{n} \frac{\mathrm{NIWR_i} * \mathrm{A_i}}{\mathrm{A}} \quad \dots 3.8$$

Where: NIWR = Net irrigation water requirement (mm); Ai= the area cultivated with the crop i (ha); A = the area of the scheme (ha).

Gross Irrigation Water Requirement (GIWR):

The term "gross irrigation water requirement" refers to the sum of the net irrigation water requirement and any additional water needed for leaching over and beyond percolation, as well as any conveyance losses between the source of the water and the field (FAO, 2002). According to (FAO, 2001), by considering an application efficiency of 50% for surface irrigation, the GIWR of crops at the identified potential irrigable site was evaluated. Storage and distribution system losses, application system losses, and conveyance losses are all considered for irrigation efficiency.

$$G\mathrm{IWR} = \frac{\mathrm{NIWR}}{\mathrm{E}} \quad \dots 3.9$$

Where: GIWR = Gross irrigation requirements (mm), NIWR = Net irrigation water requirement (mm), E = Over all irrigation efficiency (%).

The amount of water used effectively for crop development in the field is expressed as a percentage of the amount of water taken in from the water source. Efficiency typically ranges from 40% to 60% under the surface irrigation system according to Ethiopian standards. However, efficiency (E) was calculated at 50% for surface irrigation for estimating the total amount of irrigation requirement in the research area.

Potential irrigable area (A_{irr})

Based on the available water (monthly low flow of the river), the potential irrigable area can be estimated in (Equation 3.10).

$$A(\mathrm{ha}) = \mathrm{Minimum\ flow}\ \left(\frac{\mathrm{m}^3}{\mathrm{s}}\right) \Big/ \mathrm{GIWR}\ \left(\frac{\frac{\mathrm{m}^3}{\mathrm{s}}}{\mathrm{ha}}\right) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ldots\ldots\ldots\ldots\ldots\ldots 3.10$$

Where:- A(ha) = Potential irrigable area (ha); GIRW = Gross irrigation water requirement (m^3/s/ha)

3.9 Conceptual Frame Works for the Study

The overall technique adopted for this can be described by the following flow chart

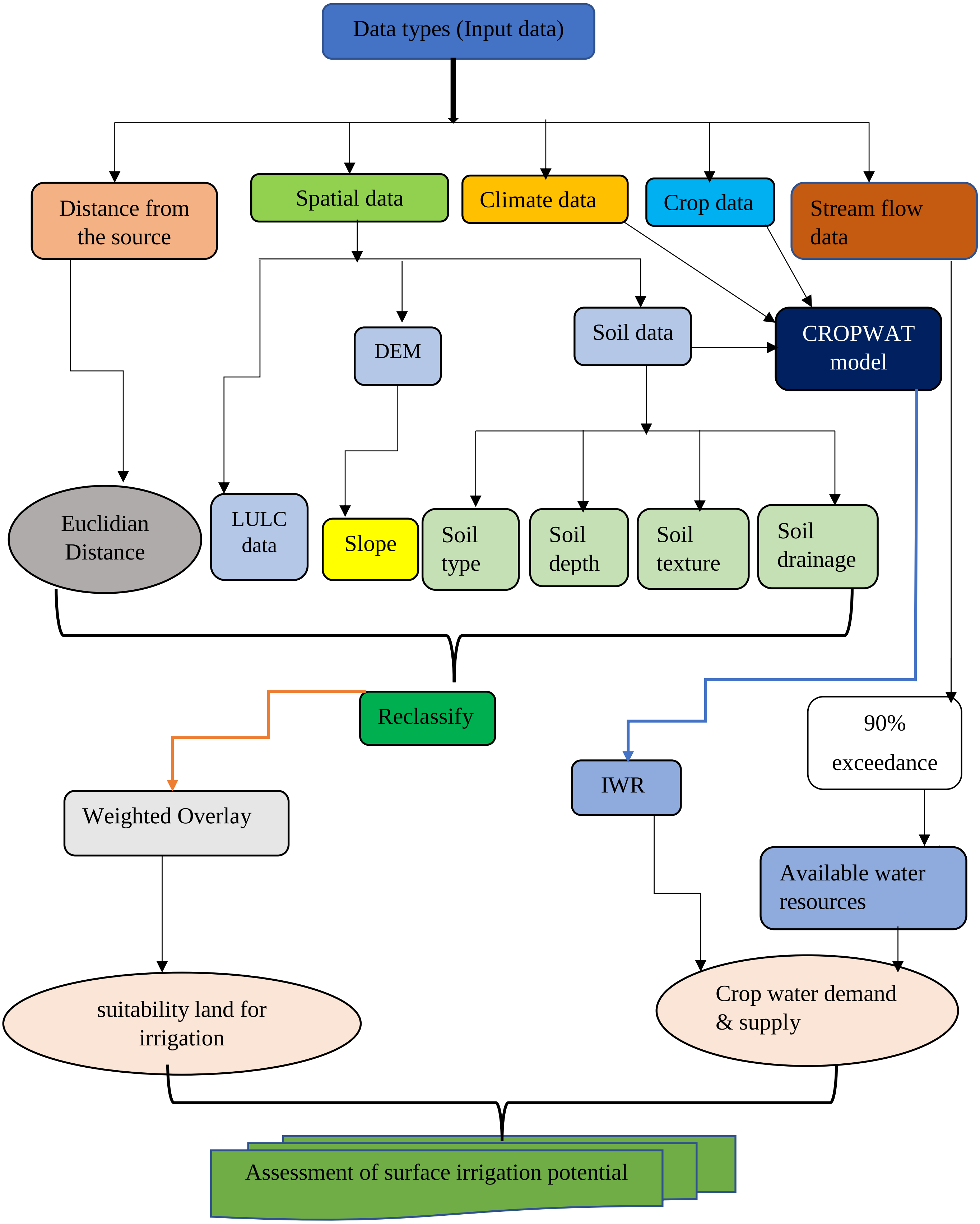

Figure 3.13 General flow chart for the assessment of surface irrigation potential

4. RESULTS AND DISCUSSIONS

4.1 Irrigation land suitability analysis

Physical and chemical factors of the land are the main parameters that determine the irrigation potential of a given land. The suitable land for surface irrigation was evaluated by the irrigation suitability factor such as slope, soil characteristics, land use/cover, River proximity, and water resources factors such as water availability, and water quality (FAO, 1979). The analysis results of surface irrigation suitability evaluation factors are presented in the following section.

4.1.1 Land use land cover suitability

Land use/land cover is one of the potential factors for irrigation land suitability assessment. FAO (1985), Guidelines for land evaluation for irrigation land suitability, land use/land cover influences the cost of irrigation practice to prepare the land for agriculture and tillage practice. The land cover which limits irrigation like the cultivated area very suitable and the other land cover types shrub and bush land can come to suitable for irrigation by removing the cover by high initial investment cost compared with cost-benefit. The land use/ cover type of the study area was ranked based on their importance for surface irrigation potential, costs to remove or change for cultivation, and environmental impacts under the watershed.

According to land use/land cover suitability classification, the land use/cover map of the watershed has different types of land use/cover, which include cultivated (dominantly and moderately) land, grassland, Woodland, bushland, forest, Alpine vegetation, and Swamps land in (Figure 4.1). Cultivated land is the greatest share of land use/cover from all the land cover classes, which covers an area of 229,726ha (53.33%) of the total area of the watershed.

Table 4.1 Classification of land use/cover of the study area

No	Land use/cover	Coverage area (ha)	Coverage area (%)
1	Cultivated land	229,726	53.33
2	Grassland	58,791.5	13.65
3	Bushland	49,186	11.47
4	Woodland	3,514	0.81
5	Forest	64,598	15

6	Alpine Vegetation	19,730	4.53
7	Swamps land	5,253	1.21
Total		430,798.5	100

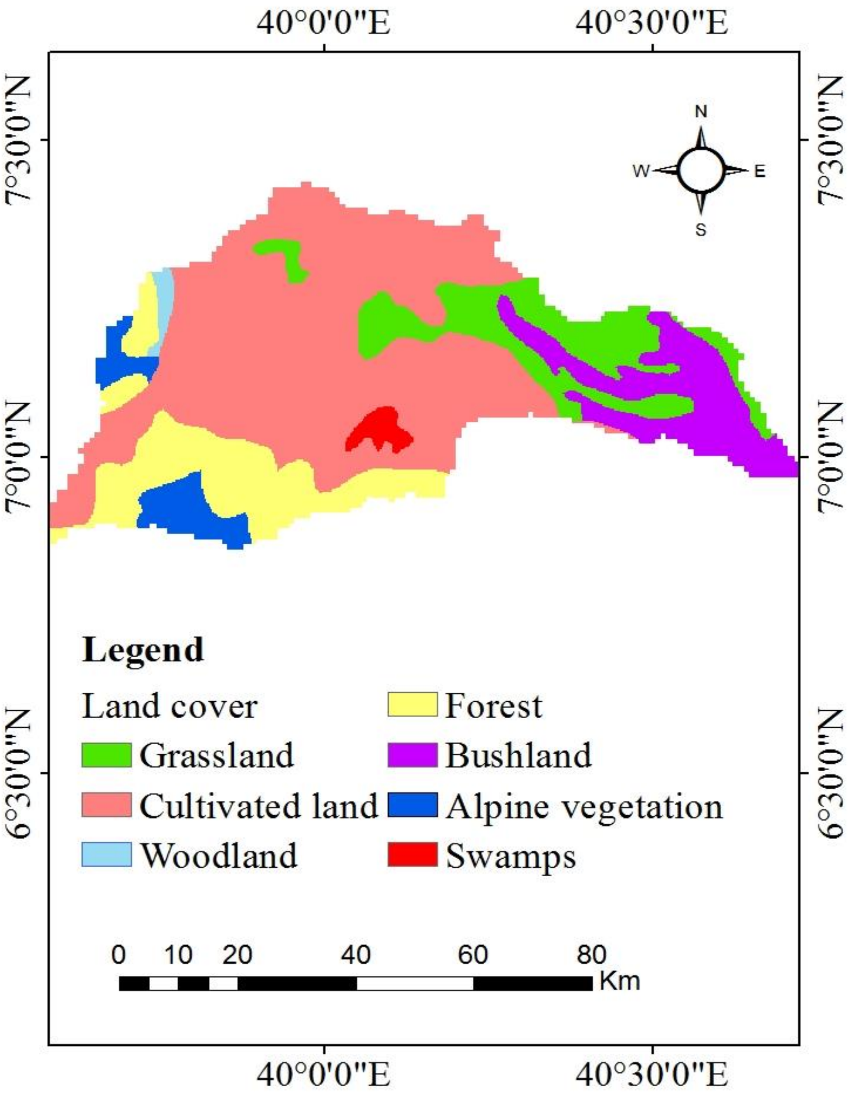

Figure 4.1 Reclassified land use land cover map of the study area.

Generally, the suitability of land use/cover classified from highly suitable to not suitable was considered costs or forces needed to prepare land with different coverage for irrigation and time consumed. The land use type was reclassified into four suitability classes, highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not marginally (N) in (Figure 4.2).

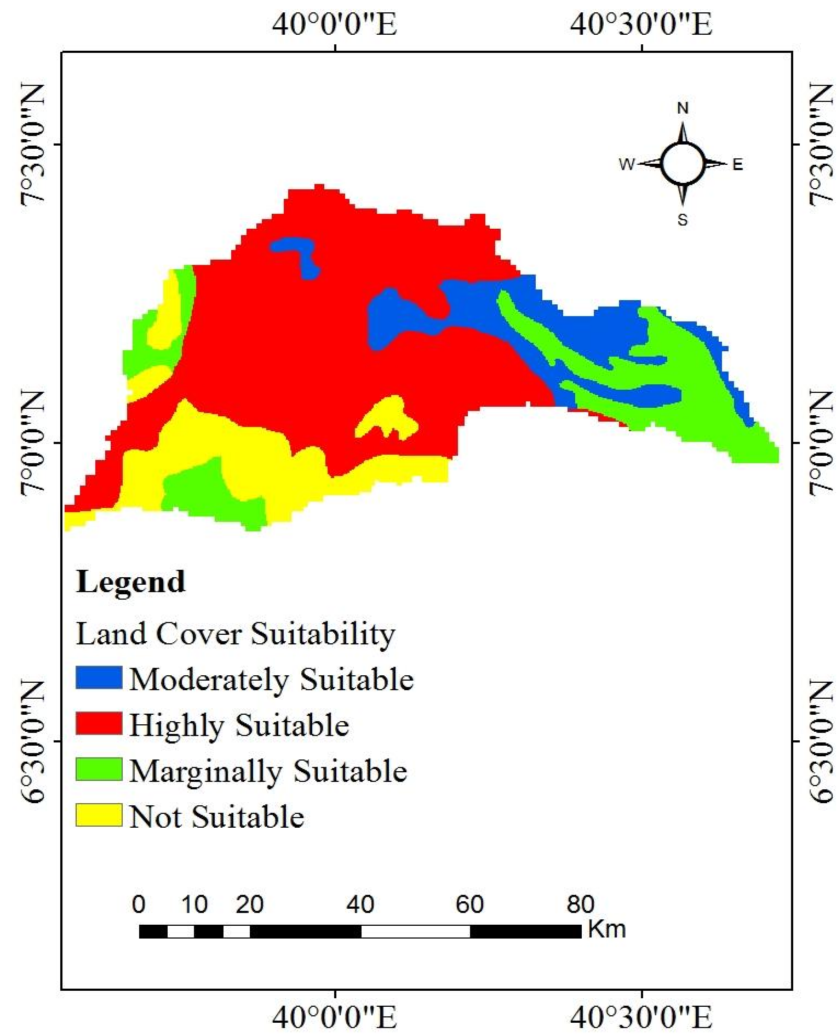

Figure 4.2 Land cover suitability map of the study area.

Table 4.2 Land use/ cover suitability class of study area.

No	Land use/cover	Suitability classes	Area Coverage (ha)	Area Coverage (%)
1	Cultivated land	Highly suitable (S1)	229,726	53.33
2	grassland	Moderately suitable (S2)	58,791.5	13.65
3	Woodland, bushland, and Alpine vegetation	Marginally suitable (S3)	72,430	16.81
4	Forest and Swamps land	Marginally not suitable (N)	69,851	16.21
Total			430,798.5	100

The result from (Table 4.2) showed that 53.33% (covering an area of 229,726 ha) is in the range of highly suitable(S1). cultivated land is very suitable for surface irrigation, and does not need land preparation according to land cover. Around 13.65% (covering an area of 5879.15 ha) is in the range of moderately suitable classes (S2) is covered by grass land, and requires a small amount of land preparation. About 16.81% (covering an area of 72,430 ha) of the catchment is covered by woodland, bushland and alpine vegetation, this type of land requires a high cost for land preparation and is classified under marginally suitable classes (S3) and the remaining land of the catchment,16.21% (69,851 ha) of the area is not suitable for surface irrigation and covered with forest, and swamps land. The result is the irrelevant value when compare with Shaya Watershed that estimated at around 66.43% as suitable land use/cover (Nasir *et al*., 2020). This difference may occur because different watersheds may have different land use/cover types.

4.1.2 Slope suitability

The slope is one of the evaluation parameters in the suitability analysis of the irrigation system. Based on FAO land suitability classification, the slope of the watershed is divided into four classes (S1, S2, S3, and N). The slope map of the study area was derived from the digital elevation model (DEM) and was classified using the “Reclassification” tool, in ArcGIS and divided into four classes for suitability land for surface irrigation, such as 0-2% as highly suitable (S1), 2-5% as moderately suitable (S2), 5-8% as marginally suitable (S3) and >8% as not suitable (N). From reclassified raster slope map of the watershed, the area of each suitable class was calculated.

Table 4.3 Slope classification of the study area

Slope ranges (%)	Area coverage (ha)	(%)	Suitability classes
0-2	170,686.6	39.62	S1(Highly suitable)
2-5	96,657.3	22.44	S2 (Moderately suitable)
5-8	73,967.5	17.17	S3 (Marginally suitable)
>8	89,487.1	20.77	N (Not suitable)
Total	430,798.5	100	

The slope suitability map of the sub-basin and area coverage of each suitability class was described in (Table 4.3). The result from slope suitability analysis revealed that 79.23% of the total area of the basin (covering an area of 341,311.4 ha) is in the range of highly suitable to marginally suitable for surface irrigation systems concerning slope whereas the remaining land of the study area about 20.77% (covering an area of 89,487.1 ha) is not suitable for surface irrigation. Hence, the majority of the study area is highly suitable to marginally suitable for surface irrigation in terms of slope suitability.

As result indicates that most of the area of the Weyib river sub-basin was found to be suitable for surface irrigation regarding its work efficiency and cost for land levelling, canal construction, and value for the pumping system (FAO, 1999). This indicates the study agreed with the study conducted by (Tesfay *et al.*, 2017), in the lowland Gilo Watershed of Surface Irrigation Suitability Assessment using the GIS tool, to consider slope suitability analysis; the result shows that 89.7% of the total area of the lowland Gilo sub-basin was in the range of highly suitable to marginally suitable for surface irrigation systems with respect to slope suitability.

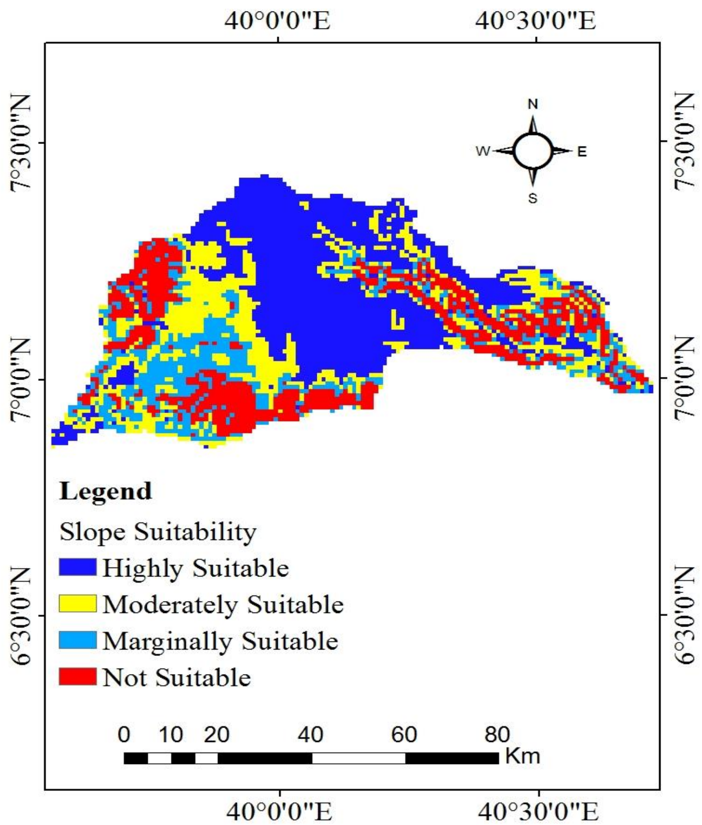

Figure 4.3 Slope suitability map of the study area

4.1.3 Soil suitability

Soil is a major factor in the suitability of land for surface irrigation. Its primary influence is on the productive capacity, but it also influences production and development costs. Soil texture, soil drainage, soil depth, and soil type are the major physical properties of soil that are very important for the evaluation of the irrigation potential of the sub-basin. They affect the root growth of a plant, the infiltration of water into the soil, and the production of crops.

4.1.3.1 Soil type suitability

Soil type was taken as a factor to develop an irrigation suitability map for the study area. The soil map of the specified study area was obtained from the FAO/UNESCO soil map. In the study area, seven major soil types were classified as Eutric Vertisols, Chromic Luvisols, Eutric Leptosols, Eutric Cambisols, Haplic Nitisols, Humic Nitisols, and Chromic Cambisols. The summary of soil type suitability classification is given in (Figure 4.4).

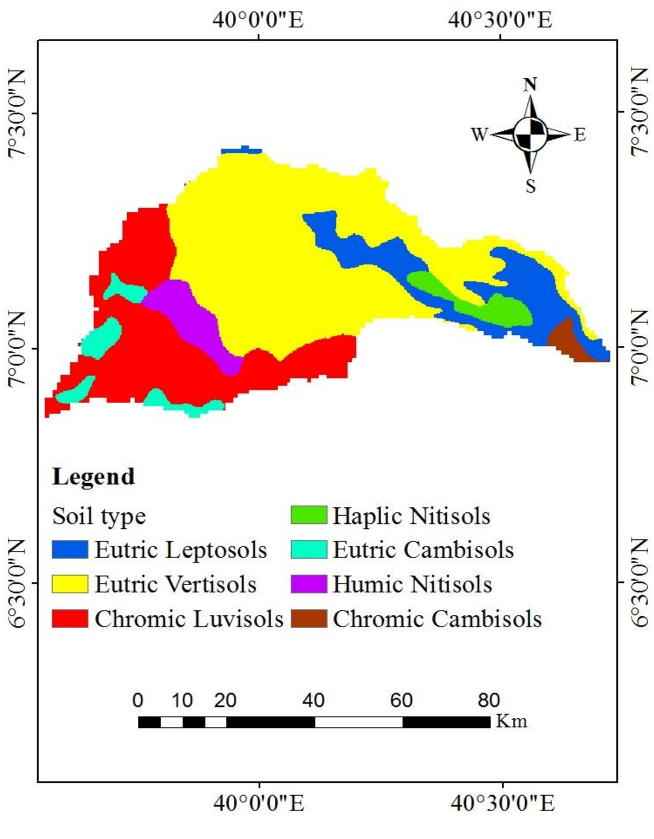

Figure 4.4 Soil types of the Weyib river watershed

Table 4.4 Classification of soil type and its coverage

No	Suitability class	Area coverage (ha)	(%)	Soil type
1	Highly suitability (S1)	335,547.7	77.89	Eutric vertisols, chromic Luvisols and Haplic nitisols
2	Moderately suitability (S2)	5,463	1.27	Chromic Cambisols
3	Marginally suitability (S3)	35,291.5	8.19	Humic Nitisols and Eutric Cambisols
4	Marginally not suitability (N)	54,496.3	12.65	Eutric Leptosols
Total		430,798.5	100	

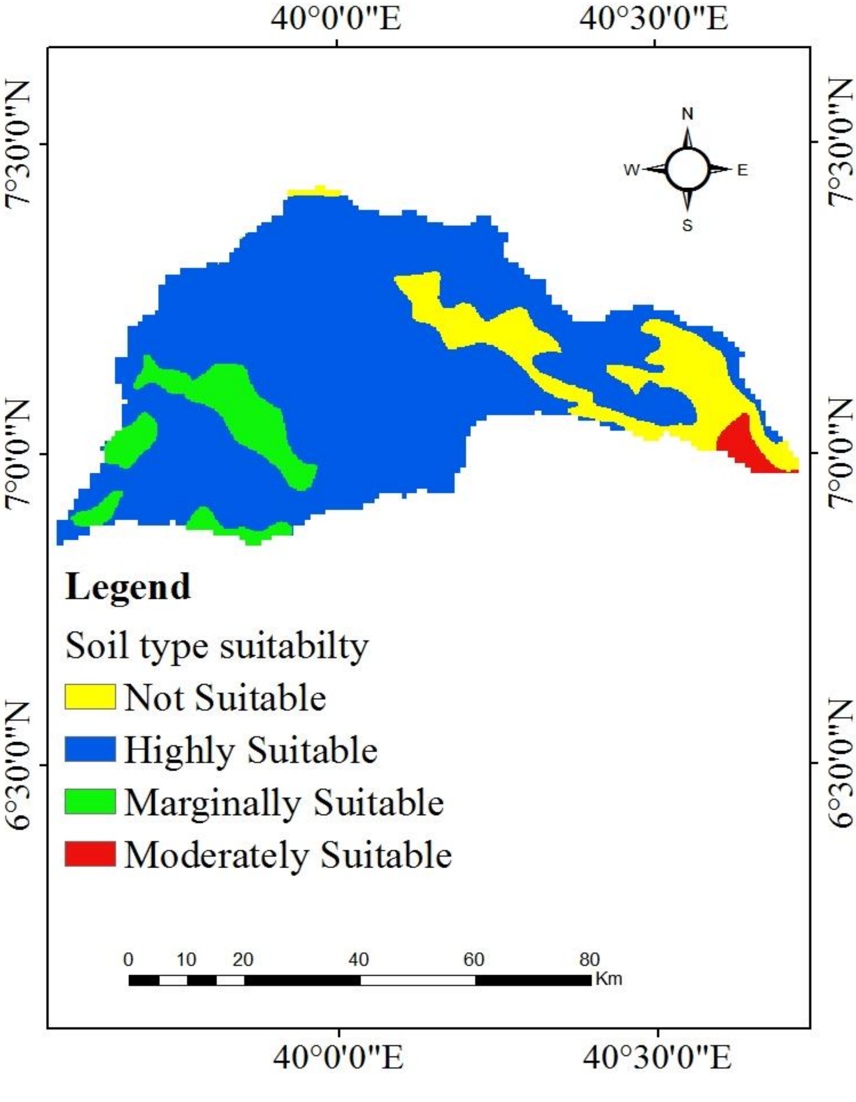

Figure 4.5 Soil type suitability map of the study area

The soil type raster was reclassified using the "Reclassify" tool in ArcGIS. Soil types of the study area were generally classified into four irrigation suitability classes based on soil suitability, such as S1 (highly suitable), S2 (moderately suitable), S3 (marginally suitability), and N (not suitable). Eutric vertisols, chromic Luvisols and Haplic nitisols cover an area of 335,547.7ha (77.89%) of the watershed, they soil with natural fertility and suitability for a wide range of agriculture uses and is very productive, was classified as highly suitable (S1) for surface irrigation.

Chromic Cambisols covering an area of 5463 ha (1.27%) of the study area, has good natural fertility and are considerable for agriculture was classified as moderately suitable (S2) for surface irrigation. Humic Nitisols and Eutric Cambisols soil type that covers an area of 35291.5 ha (8.19%) of the land in the study area were classified as marginally suitable(S3). The remaining soil type Eutric Leptosols which covers an area of about 12.65% (area coverage of 54496.3 ha) of the watershed, with low moisture holding capacity, low production potential, rocky soil, poor fertility and poorly drained was grouped as not suitable in terms of soil type suitability analysis. As result indicates that most of the study area of the Weyib river sub-basin was found to be 87.35% of the total area of the catchment was in the range from highly suitable to marginally suitable for the surface irrigation system.

The study also agreed with the finding of (Megersa, 2020), research conducted on the Gilgel Gibe River watershed; the result indicates that 77.62% of the total area of the river basin was in the range of highly suitable to marginally suitable for surface irrigation development concerning soil type suitability. Generally, the result was irrelevant value because different watersheds have different soil types.

4.1.3.2 Soil depth suitability

Soil depth was considered one of the major factors that determine the selection of land for surface irrigation potential in the study area. Soil depth determines the roots' growth as well as the presence of a volume of water and air in the soil. The depth of the soil layer in the study area was reclassified and divided into four classes (<40, 40-80, 80-150, and >150cm) which are unsuitable, marginally suitable, moderately suitable, and highly suitable for surface irrigation respectively. The soil depth map of the area was analysed on ArcGIS 10.4.1. based on HWSD (2009). The suitability classes of soil depth and their area in the study area are in (Table 4.5).

Table 4.5 Classification of soil depth of the watershed

No	Soil depth (cm)	Suitability classes	Coverage area (ha)	Coverage area (%)
1	>150	Highly suitable (S1)	246,939.7	57.32
2	80 - 150	Moderately suitable (S2)	123,753.3	28.73
3	40 -80	Marginally suitable (S3)	5,529.23	1.28
4	<40	Marginally not suitable (N)	54,576.24	12.67
Total			430,798.5	100

The soil depth suitability analysis result indicates that about (246,939.7ha) 57.32% of the total area of the watershed was categorized as highly suitable, the area which about (123,753.3ha) 28.73% of the watershed was moderately suitable, (5529.23ha) 1.28% of the total area of the catchment was marginally suitable classes and the remaining land about (54576.24ha) 12.67% of the total study area is not suitable for surface irrigation development. Generally, 87.33% of the soil depth in the study area is in the range of highly suitable to marginally suitable and the remaining area around 12.67% of the area is grouped as not suitable in terms of soil depth suitability analysis for surface irrigation.

The result shows that it has some different values when compared with research Conducted on the Shaya River sub-basin in which around 98.69% of the catchment soil depth suitability is classified as highly suitable to marginally suitable for surface irrigation (Nasir *et al.,* 2020).

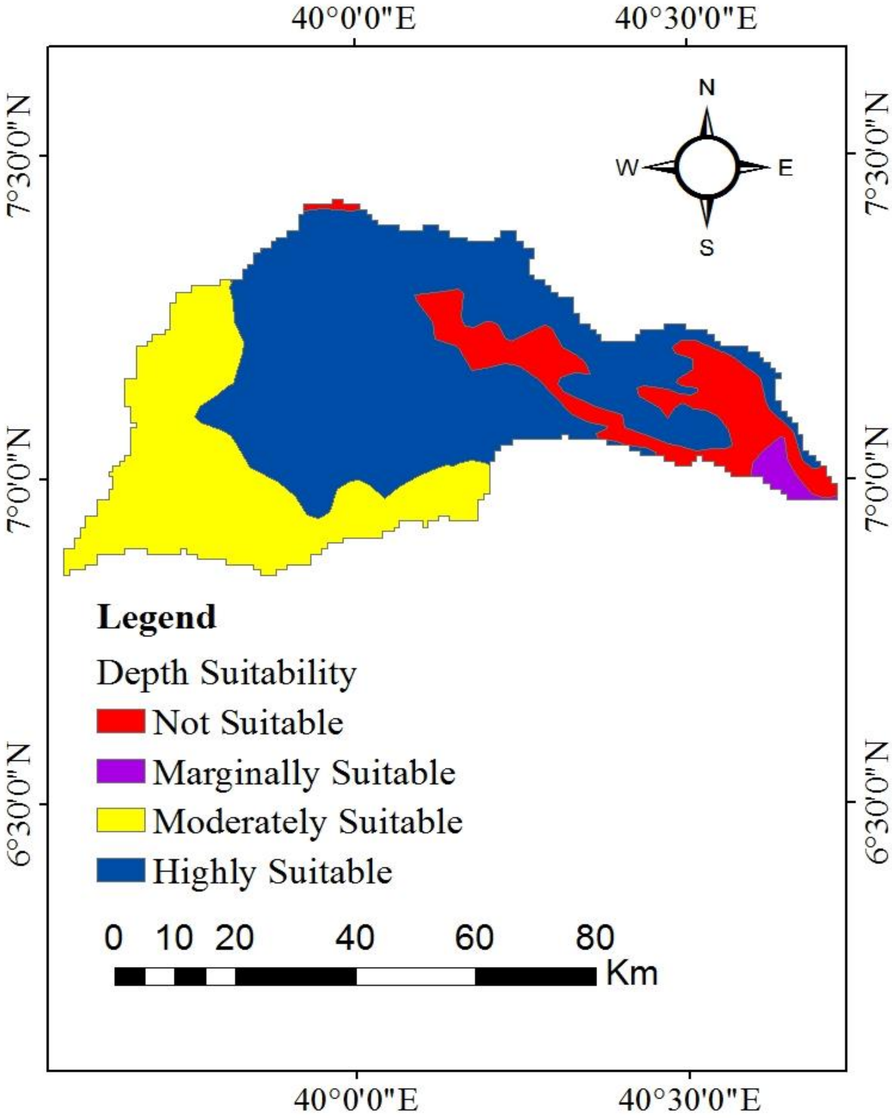

Figure 4.6 Soil depth suitability map of the area

4.1.3.3. Suitability of Soil drainage

Soil drainage is one of the very important parameters of evaluation of the area for surface irrigation. Suitable soil drainage is essential to ensure sustained productivity and to allow efficiency in farming operations. According to FAO evaluation techniques used for the evaluation of permeability of soil properties of the land, soil drainage areas can be classified as well-drained, moderately well-drained, imperfectly drained, and poorly drained. The soil drainage can determine the permeability of the soil for water in the study area. Therefore, the soil drainage properties of the study area were classified into two classes, well-drained and imperfectly drained. In general, well-drained soils are good for agriculture. From reclassified raster soil drainage map of the watershed, the area of each suitable class was calculated and the area covered by each suitability class in hectare and areal coverage in per cent was provided (Table 4.6).

Table 4.6 Soil drainage suitability of the study area.

No	Soil drainage	Suitability classes	Area coverage	
			ha	%
1	Well- drained	S1 (highly suitable)	166,758.1	38.71
2	Imperfectly	S3(marginally suitable)	264,040.4	61.29
	Total		430,798.5	100

The result from soil drainage suitability classification revealed that about 38.71% (covering an area of 166,758.1 ha) of the watershed land was fall under highly suitable (S1) for surface irrigation whereas about 61.29% (covering an area of 264,040.4 ha) marginally suitable (S3), for surface irrigation system concerning soil drainage suitability. The final soil drainage suitability map was developed from reclassified soil raster. Accordingly, most of the study area is covered with marginally suitable soil drainage.

A similar finding was reported by (Birhanu et al., 2019b), in Dirma River Basin; the result was obtained only two soil drainage suitability classes. The classes are highly suitable (well-drained) and moderately suitable (imperfectly drained). The result indicates that about 51.5% (228 km^2) of the area is a highly suitable rating class and the rest 48.5% (213 km^2) is categorized as moderately suitable for surface irrigation development according to (FAO, 1985) guidelines.

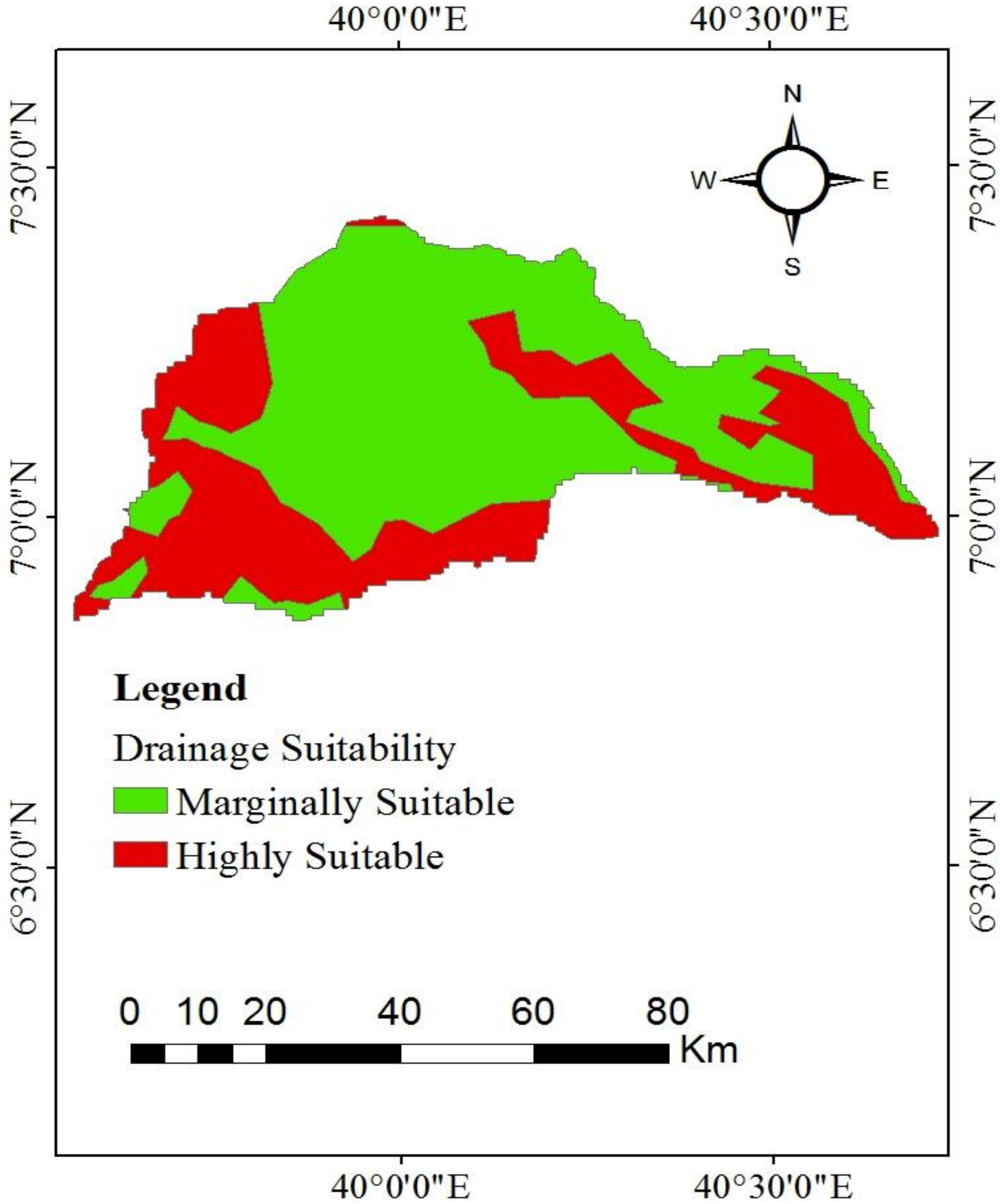

Figure 4.7 Soil drainage suitability map of the study area

4.1.3.4 Suitability of soils texture

According to FAO guidelines for soil evaluation, the soil texture of the study area was evaluated and classified into six classes, such as loam, clay, clay loam, sandy clay loam, sandy loam and sandy soil classes. The soil of all textural classes, except coarse sand, is irrigable if proper methods are adopted. The evaluation of soil textural suitability of catchment for surface irrigation was based on FAO guideline land evaluation (FAO, 1991), and FAO land and water bulletin (FAO, 1997). Textural suitability indicates that loam, clay loam and Light clay soil are the most chemically active soil and categorized as highly suitable for surface irrigation; sandy clay loam soil was evaluated as moderately suitable but sandy loam and sandy soil as marginally suitable for surface irrigation.

Table 4.7 Soil texture suitability classification of the study area

No	Texture	Suitability class	Area (ha)	%
1	L, C, CL	S1 (Highly suitable)	390,048.5	90.54
2	SC	S2 (Moderately suitable)	35,250	8.18
3	SL, S	S3 (Marginally suitable)	5,500	1.28
Total			430,798.5	100

L = (loam), C = (clay), CL = (clay loam), SC = (sandy clay loam) SL = (Sandy loam) and Sand(S).

The soil texture suitability of the Weyib watershed for the development of surface irrigation system is shown in (Figure 4.8) and the area coverage of suitability classes is presented in (Table 4.7), indicating that 90.54% (390,048.5 ha) is highly suitable, 8.18% (35,250.0 ha) is moderately suitable, and the remaining land of the study area is about 1.28% (5,500.0 ha) is marginally suitable for surface irrigation systems. Hence, the majority of the study area is highly suitable to moderately suitable for surface irrigation in terms of soil texture suitability. Due to the suitability range of soil texture currently, 390,048.5 ha of land is highly suitable for surface irrigation purposes.

This study agreed with (Kasye *et al*., 2020), the study was conducted on the Borkena River catchment; the result of the soil textural suitability for surface irrigation, most areas of Borkena River catchment around 73.02% was classified under highly suitable (S1) class, 24.45% of the area was classified under marginally suitable (S3) class and 2.53% of the area was classified under moderately suitable (S2) class according to (FAO, 1997).

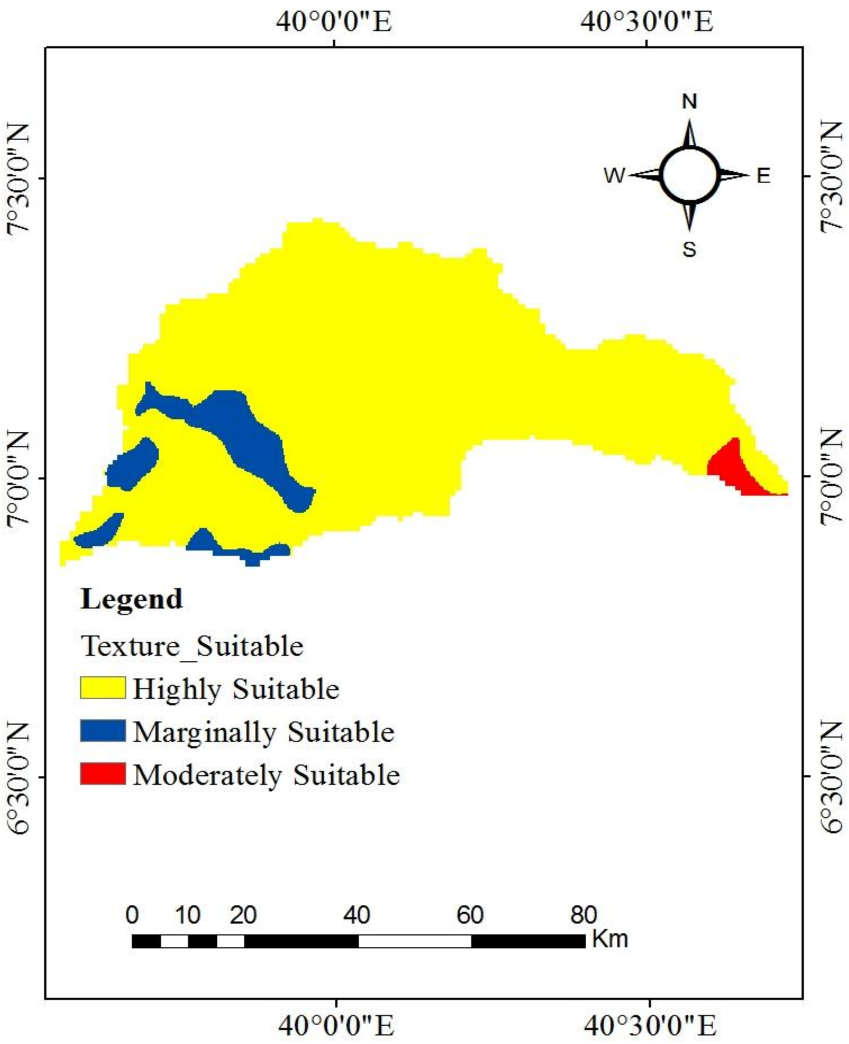

Figure 4.8 Soil texture suitability map of the study area

The final evaluation of soil suitability for irrigation indicating soil type, soil texture, soil drainage, and depth after reclassification is tabulated in (Table 4.8).

Table 4.8 Soil suitability evaluation for surface irrigation

No	Soils type	textures	drainage	depth	Irrigation suitability
1	Eutric vertisols	C	Well Drain	>150	S1
2	Chromic Luvisols	CL	Well drain	80-150	S1
3	Eutric Leptosols	L	Imperfectly	<40	N
4	Haplic Nitisols	L	Well Drain	>150	S1
5	Chromic Cambisols	SC	Well	40-80	S2

6	Humic Nitisols	S	Imperfectly drain	>150	S3
7	Eutric Cambisols	SL	Well Drain	80-150	S3

4.1.4 Suitability of river proximity

Distance from the water source has been considered as one of the evaluation parameters in land suitability for irrigation purposes. Based on the main factors that were considered in the distance suitability classification were; the power and capacity of the pumping engine, the cost of the high-power pumping engines and the cost of construction and maintenance of canals and water lost from canals especially for small-scale and medium-scale irrigation system, the command area was reclassified into four suitability class; highly suitable, moderately suitable, marginally suitable and not suitable. Because of these factors' irrigation suitability is decreased as the distance increase away from the water source.

To identify irrigable areas near the water source, the horizontal distance in a Euclidean from the river was calculated; the spatial proximity to water sources was calculated with ArcGIS spatial layers; the influences of the distance parameters on the suitability of the surface irrigation land were estimated with the clipping feature class. Then converted to raster with the conversion tool and reclassified into the suitability class. The final reclassified result of the distance suitability analysis of the irrigable land was used for weighting overlay for further analysis together with other factors. The suitability classification and area coverage of distance were shown in (Table 4.9).

Table 4.9 Distance classification and its area coverage

Distance(km)	Suitability factor	Area coverage	
		(ha)	%
<1.5	Highly suitable(S1)	105,998.30	24.61
1.5-3	Moderately suitable (S2)	94,732.5	21.99
3-5	Marginally (S3)	90,016.90	20.90
>5	Not suitable (N)	140,050.8	32.50
Total		430,798.5	100

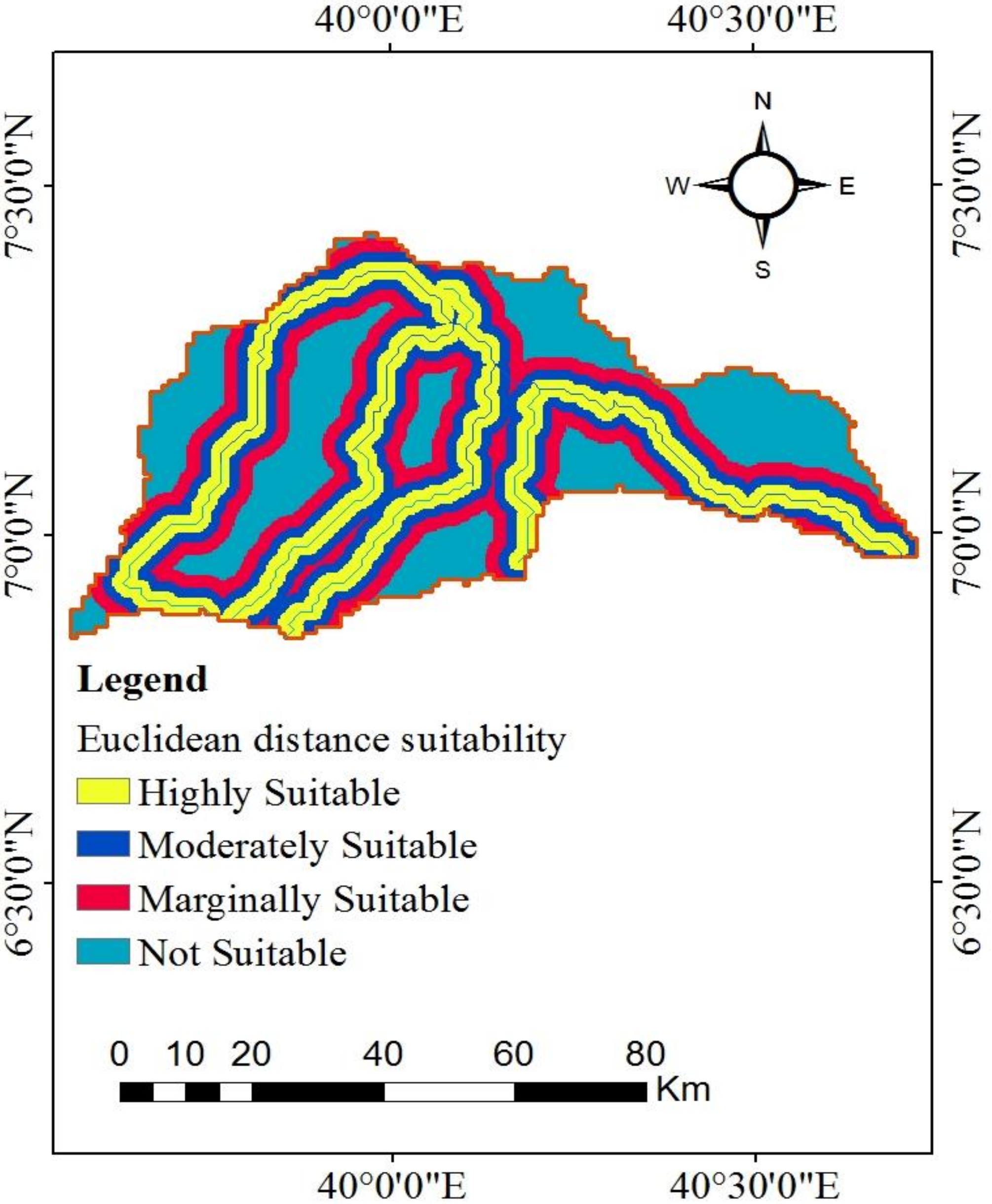

Figure 4.9 Distance Suitability map of the study area

The classification of the river proximity method is differing among different researchers. Because the classification is depending on the catchment characteristics and needs the researcher's decision. The suitability of the study area for the development of a surface irrigation system is shown in (Figure 4.9) and the area coverage of suitability classes is presented in (Table 4.9), indicating that 105,998.3ha (24.61%) of the study area is highly suitable, 94,732.5ha (21.99%) of the watershed is under moderately suitable, about coverage an area of 90,016.9ha (20.9%) of the catchment area is marginally suitable and about 140,050.8ha (32.50%)of the study area is not suitable for surface irrigation development. Hence, the majority of the study area is highly suitable to marginally suitable for surface irrigation in terms of distance suitability.

A result indicates that it has some different values when compared with the study conducted on the Birbir River sub-basin; 96.33% of the study area was classified as in the range of highly suitable to marginally suitable for surface irrigation in terms of distance suitability analysis(Garuma, 2021). This difference value may occur; because different watersheds may have different characterises and also the researcher considered the scale of distance was different from the scale of distance used in this study.

4.2 Weighting of Factors and Identifying Suitable Areas for Irrigation

To reduce the individual biases of factor weighting, the weights in the study were determined by using a pair-wise comparison method as developed by (Saaty, 1980) in the context of the Analytical Hierarchy Process (AHP). All the Weighing irrigation suitability factors including slope, soil, land use land cover, and distance which were selected for the evaluation of land suitability in the study area, were weighted using a pair-wise comparison method. The irrigation suitability parameters are weighted and ranked as follows in (Table 4.10).

Table 4.10 Pair-wise comparison scoring for irrigation suitability factor.

Factor	slope	distance	depth	texture	drainage	soil type	land use/cover
slope	1	3	3	3	3	7	7
distance	0.3333	1	3	3	3	5	7
depth	0.3333	0.3333	1	3	3	3	5
texture	0.3333	0.3333	0.3333	1	3	3	3
drainage	0.3333	0.3333	0.3333	0.3333	1	3	3
soil type	0.1429	0.2000	0.3333	0.3333	0.3333	1	3
Land use/cover	0.1429	0.1429	0.2000	0.3333	0.3333	0.3333	1
Sum	2.62	5.34	8.20	11.00	13.67	22.33	29.0

Then the table was formulated for normalization based on (Table 4.10) by dividing each value of a cell of a column by the total column. The average of each value in a row in this table was the weight of each factor. The weight of the factors was calculated by multiplying the average of each value in a row by 100.

Table 4.11 Normalization value

Factor	slope	distance	depth	texture	drainage	soil type	land use/cover	Weight value	Weighted in (%)
slope	0.382	0.561	0.366	0.273	0.220	0.313	0.241	0.34	34
distance	0.127	0.187	0.366	0.273	0.220	0.224	0.241	0.23	23
depth	0.127	0.062	0.122	0.273	0.220	0.134	0.172	0.16	16
texture	0.127	0.062	0.041	0.091	0.220	0.134	0.103	0.11	11
drainage	0.127	0.062	0.041	0.030	0.073	0.134	0.103	0.08	8
soil type	0.055	0.037	0.041	0.030	0.024	0.045	0.103	0.05	5
land use/cover	0.055	0.027	0.024	0.030	0.024	0.015	0.034	0.03	3

The result of the pairwise comparison matrix showed that the major factors were compared one to one and scored using a scale developed by Saaty (1980). In the weighted overlay analysis, a high weight of percentage influence was given for slope (34%), because the slope affects water flow, fertility of soil profile, depth of irrigation, and drainage of the watershed, and since it is the main determinant factor in the evaluation of the given area for surface irrigation development.

Calculate the consistency ratio by calculating lambda, lambda was calculated by dividing a total value in a row by the value of its weight.

Table 4.12 Computing lambda

Rows	**Total Value**	**Weight value**	**Consistency measure(λ_{aver})**
Row1	2.638	0.337	7.838
Row2	1.850	0.234	7.908
Row3	1.221	0.159	7.696
Row4	0.833	0.111	7.490
Row5	0.596	0.082	7.293
Row6	0.350	0.048	7.299
Row7	0.223	0.030	7.457
Average			7.569

$$\mathrm{CI} = \frac{(\lambda_{\mathrm{aver}} - \mathrm{n})}{(\mathrm{n} - 1)} \quad \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . 4.1$$

Where, CI = consistency index, λ_{aver}= lambda average, and n = number of irrigation factors that computed = 7

$$CI = \frac{7.569 - 7}{7 - 1} = 0.095$$

$$CR = \frac{CI}{RI} \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots \dots 4.2$$

Where: - CR= Consistency ratio, CI=Consistency index, and RI=Random consistency index (RI=1.32) for n = 7 as it was shown in (Table 3.8)

$$CR = \frac{0.095}{1.32} = 0.072$$

The calculation for the consistency ratio was found to be 0.072; this was less than the maximum allowable 0.1. This indicates that the comparisons of each factor were perfectly consistent, and the relative weights were suitable for use in the GIS multi-factor evaluation.

4.3. Weighted overlay analysis of Suitable Land for Irrigation

The total area of the watershed, which is suitable for surface irrigation without affecting crop production, was computed by using overlaying slope, soil type, soil physical properties (textures, depth, and drainage), land cover/use, and river proximity from available water in Arc GIS 10.4.1 as shown in (Figure 4.10) and (Table 4.13).

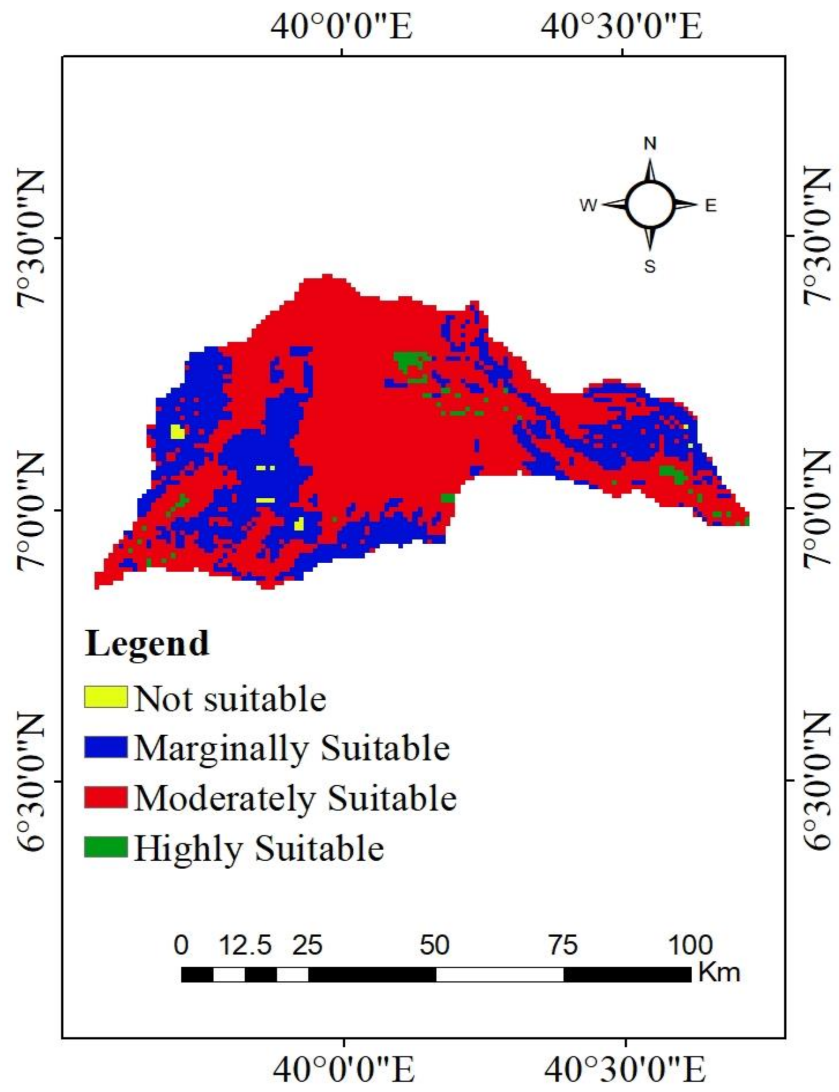

Figure 4.10 Overall Suitability map of the study area for surface irrigation

Table 4.13 Final Suitable land for surface irrigation of the study area.

No	Rating factors	Area coverage (ha)	Area coverage (%)
1	Highly suitable (S1)	8,118.27	1.88
2	Moderately suitable (S2)	282,402.15	65.55
3	Marginally suitable (S3)	137,151.13	31.84
4	Not suitable (N)	3,126.95	0.73
Total		430,798.5	100

The weighted overlay analysis of surface irrigation suitability revealed that 1.88% (coverage of an area of 8118.27ha) of the total area of Weyib river covered in a highly suitable class, 65.55% (coverage an area of 282402.15 ha) was covered in moderately suitable class, about 31.84% (a coverage area of 137151.13ha) of the watershed was covered in a marginally suitable class. The total area of suitable land for surface irrigation was found to be 427,671.55ha (99.27%) was the range of highly suitable to marginally suitable and the rest of the land of the watershed about 3126.95 ha (0.73%) was limited to irrigation developments. The map of suitability and unsuitability land was presented in (Figure 4.10) after filtering, "spatial Analyst Tools" to the majority Filter". The area coverage was shown in (Table 4.13).

The result shows that it is an irrelevant value when compared with research Conducted on the Shaya sub-basin which 66.43% of the catchment drainage is classified as highly suitable to marginally suitable (Nasir *et al.*, 2020). Although both sub-basins are located in the Genale Dawa river basin the result is not the same because the researcher considered not only physical properties but also the chemical properties of the soil.

4.4 Irrigation Water Requirement for Suitable Irrigable Land

The stream flow of the river and gross irrigation water requirements of wheat, barley, potato, and cabbage for the potentially irrigable site indicate that the irrigation needs for, potato, and cabbage crops exceed the minimum flow discharge in all cases in (Table 4.14). Thus, the existing water resources can irrigate only a small portion of the irrigable land. The irrigation efficiency for the study area was found to be 50%.

4.5. Irrigation Potential of Weyib River Watershed

After evaluating of the suitability land for irrigation, it is very necessary to examine the Surface water availability for crop production in the study area. The annual average streamflow of Weyib river at the gauged station was estimated to be 253.84m^3/s or 670.08Mm^3. Irrigation potential refers to areas suitable for irrigation vs. surface water availability. The irrigation potential of the river watershed was obtained by comparing irrigation water requirements of the selected crops commonly grown in the study area; such as Wheat, Barley, Potato, and cabbage; in considering the identified suitable land for surface irrigation and the 90% dependable minimum monthly streamflow of Weyib river which was developed from flow duration curve analysis.

The potential irrigable area was computed by dividing the 90% dependable monthly flow of Weyib River by the Gross Irrigation Requirement for each month.

Table 4.14 Comparison of GIWR, and 90% exceedance flow of Weyib River

Month	**Types of crop**				**NIWR (l/s/h)**	**GIWR ($m^3/s/h$)**	**90% exceedance flow (m^3/s)**	**Potentially Irrigable Area (ha)**
	Wheat	Barley	Potato	Cabbage				
January	91.9	54.9	19.2	110.5	0.25	$5.0*10^{-4}$	0.829	1,658.0
February	6.3	0	0	42.6	0.04	$8.0*10^{-5}$	0.794	9,925.0
March	0	0	0	0	0	0	0.649	-
April	0	0	0	0	0	0	1.265	-
May	0	0	0	0	0	0	2.321	-
June	0	0	0	0	0	0	1.429	-
July	0	0	0	0	0	0	1.549	-
August	0	0	0	0	0	0	6.007	-
September	0	0	0	0	0	0	4.378	-
October	0	4.8	29.2	10.2	0.03	$6.0*10^{-5}$	5.303	88,383.33
November	38.8	72.1	76.8	53.3	0.21	$4.2*10^{-4}$	2.140	5,095.24
December	110.0	108.6	97.9	98.6	0.37	$7.4*10^{-4}$	1.313	1,774.32

The potential irrigable area was assigned for each crop based on their productivity and profitability in the farming system in the watershed based on the Minimum available water. The potential irrigable area of each month is varying throughout the month due to variations in minimum flow. Due to the insufficient available water, most irrigable area is not irrigated. As shown in (Table 4.14), the maximum irrigation water requirement was found in December, which was 0.37 l/s/ha, whereas the minimum available water flows in the month was found to be 1.313m^3 /s, the command area that can be irrigated using the available flows in the study area was 1774.32 ha.

The minimum irrigation water requirement found in October, was 0.03l/s/ha, whereas the minimum available water flows in the month were found to be 5.303m^3 /s, then, the command area that can be irrigated using the available flows in the study area was 88,383.33 ha.

In January, February and November months, the Weyib river irrigation potential area is only 1658.0ha, 9925.0ha and 5095.24 ha of a suitable area can be irrigated within the minimum available water flow of the river respectively. From the suitability map of the Weyib river watershed, most of the area was identified under highly to marginally suitability classes. But to the identified suitability area the mean monthly flows of the Weyib river are not sufficient to irrigate the whole suitable area, especially in the dry months, where the irrigation water requirement of the specified major irrigated crops was high and effective rainfall was very low in those months.

Generally, when GIWR and 90% available dependable flow of the river was compared, the potentially irrigable land that can be irrigated without delivery of storage structures was found to be around 106,835.89 ha (24.79%) from the total of 427,671.55 ha of potential suitable land for surface irrigation.

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusion

The assessment of surface irrigation potential study was conducted for Weyib River sub-basin which is located in the Bale Zone, Oromia Regional State, Ethiopia. The watershed delineation procedure occurs in a sub-basin that covers a total area of 4307.985 km^2. It had been done to assess and estimate suitable irrigable land and irrigation potential of the Weyib River in the study area and generate the final suitability map.

The study's primary considerations for determining whether an area would be suitable for irrigation included slope, soil (soil type, soil texture, soil drainage, and soil depth), land use/cover, and distance from a water source. According to FAO guidelines, the suitability of irrigation land was classified as highly suitable (S1), moderately suitable (S2), marginally suitable (S3), and not suitable(N). Based on the analysis, 79.23 % of slope, 87.35 % of soil type, 87.33% of soil depth, 100% of soil drainage,100% of soil texture, 83.79 % of land use /cover and 67.5% the distance from the water supply of the study area were identified to be in the range of highly suitable to marginally suitable for irrigation.

The irrigation suitability map was created by weighting the values of these constraint data sets using weighted overlay in ArcGIS, and the suitable land of surface irrigation was 8118.27 ha (1.88%) of the total area of the Weyib river was covered in a highly suitable, 282402.15ha (65.55%) covers moderately suitable, about 137151.13ha (31.84%) of the watershed was covered in a marginally suitable. The total area of potential suitable land for surface irrigation was found to be 427,671.55ha (99.27%) range highly suitable to marginally suitable and the rest land of the watershed about 3126.95ha (0.73%) was limited to irrigation developments.

The FAO-Penman-Monteith methods were used to determine the irrigation water need based on data from the meteorological station. The CropWat8.0 model was used to determine the specified crops' irrigation requirements. In December the maximum water irrigation demand, was 0.37 l/s/ha, while the lowest monthly water flow was estimated to be 1.313 m3/s. then, the command area that can be irrigated using the available water flow in the study area was 1774.32 ha. The potentially irrigable land that can be irrigated without delivery of storage structures was found to be around 106,835.89 ha (24.79%) from the total of 427,671.55 ha potential suitable land for surface irrigation.

5.2. Recommendation

Irrigation is thought to be a crucial investment for raising rural income by boosting agriculture productivity. However, this is possible by analyzing the land and the water resources that are accessible for irrigation. As a result, the research area's identified surface irrigation potential for river catchments can help with policy decisions during the building of irrigation projects in the Bale zone.

According to the land evaluation, the river Sub-basin's physical land quality has a large potential for surface irrigation. In this study, the appropriateness of the land for surface irrigation was assessed by taking into account only some variables, such as the physical characteristics of the soil, (soil depth, soil texture, and soil drainage), as well as the distance from water sources, slope, and land use/cover. For irrigation, the chemical characteristics of soils are particularly crucial. Future research should evaluate the chemical characteristics of the soil in the watershed area.

To obtain sound and beneficial results, it is necessary to evaluate the impacts of additional aspects, such as water quality, environmental concerns, economic situations, and social conditions. Due to a lack of available socioeconomic and environmental data, these aspects were not considered while evaluating the site for this study. To determine the land suitability for irrigation in the study area, further research will consider additional criteria.

Only river flow in the study area is insufficient to meet agricultural water demand, thus any future planning for surface irrigation may include building a storage reservoir across the river to hold runoff during the rainy season.

The assessment of surface water availability was the main emphasis of this investigation. The quantity of surface water is not just used for surface irrigation, so estimating the potential for groundwater is also a critical step in the development of irrigation systems. As a result, further research will demonstrate taking into consideration estimates of the amount of groundwater that can be used for irrigation development in the study area.

In this study, only surface irrigation was taken into consideration while analyzing the appropriateness of the land for irrigation. Additional research is advised to improve the appropriateness of the land for irrigation by taking drip and sprinkler irrigation technologies into account.

I advised that farmers use certain agricultural techniques in the study area to maximize their net benefits and, thus, increase their revenue, Wheat crops should be produced to a large extent because it is a beneficial crops.

This study, only considered major crops when estimating the irrigation water requirements of the designated command areas. But to determine the gross irrigation requirements of identified potential irrigable land in the study area, future research should choose several types of crops.

Finally, further research advised improving the irrigation potential of the Weyib river watershed.

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APPENDICES

Appendix Table1: Agarfa Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	0.50	98.00	48.60	259.57	48.60	43.30	110.94	157.30	52.20	106.60	36.42	31.43	993.46
1991	10.50	49.00	0.00	132.00	115.41	71.70	151.00	129.90	69.10	3.60	6.90	0.00	739.11
1992	70.20	39.80	0.00	16.20	88.40	60.70	94.50	147.45	256.50	152.40	55.50	60.00	1041.65
1993	47.10	179.90	0.00	145.90	104.40	58.30	38.50	132.90	114.50	136.40	4.10	2.50	964.50
1994	0.00	0.00	39.20	178.90	68.60	107.90	156.30	176.60	103.00	77.80	101.80	12.20	1022.30
1995	0.00	27.90	58.50	144.90	31.10	33.20	191.80	121.50	87.50	133.30	10.30	29.95	869.95
1996	0.00	42.40	134.70	148.70	235.20	185.50	109.00	110.40	221.00	28.10	36.30	40.10	1291.40
1997	18.00	0.00	172.60	317.60	70.90	84.70	144.90	99.23	328.60	102.81	37.82	29.25	1406.41
1998	132.60	61.70	106.50	166.20	134.80	79.60	151.30	481.40	239.40	231.40	70.50	0.00	1855.40
1999	14.20	0.00	155.50	74.38	109.80	147.47	267.10	108.30	173.10	339.50	0.00	9.70	1399.05
2000	0.00	0.00	58.30	133.80	206.90	47.40	107.00	308.00	174.60	237.10	18.00	72.40	1363.50
2001	0.00	29.96	168.80	143.70	172.50	100.50	137.30	269.50	131.30	131.40	50.70	22.20	1357.86
2002	41.60	0.00	105.30	212.20	91.80	71.80	78.80	108.50	164.80	117.40	0.00	228.50	1220.70
2003	2.20	0.00	17.20	194.30	61.20	72.40	156.90	89.90	88.80	46.70	26.10	50.60	806.30
2004	53.30	0.00	23.10	205.80	28.50	57.10	128.10	110.80	264.90	80.00	30.70	22.20	1004.50
2005	98.90	3.20	94.70	157.70	176.90	31.60	141.50	86.20	113.30	99.50	40.50	0.00	1044.00
2006	4.30	53.50	44.80	135.60	90.40	37.10	81.30	97.10	137.25	36.85	35.76	81.21	835.17
2007	26.87	55.20	55.00	152.20	58.70	98.80	184.00	412.81	133.00	59.10	57.80	0.00	1293.49
2008	25.12	30.38	67.51	143.28	99.93	67.59	121.60	157.70	139.32	103.08	39.53	31.15	1026.19
2009	28.80	31.54	70.49	143.16	97.35	69.32	56.00	102.20	74.40	95.88	44.70	89.90	903.75
2010	139.40	98.70	190.10	201.50	150.00	39.40	107.40	139.40	55.10	45.90	1.80	0.00	1168.70
2011	0.00	0.00	3.50	49.60	137.10	67.66	80.10	69.10	73.50	43.30	70.50	0.00	594.36
2012	0.00	0.00	37.60	133.00	67.20	23.40	71.30	145.10	139.36	60.20	11.40	10.00	698.56
2013	10.90	0.80	200.60	73.70	20.40	18.70	122.50	245.30	83.40	59.40	59.10	0.00	894.80
2014	0.00	12.40	22.00	18.80	53.50	45.50	54.90	97.00	80.10	127.30	41.90	3.50	556.90
2015	0.00	0.00	25.10	49.00	75.10	65.40	48.80	67.40	70.40	49.60	43.80	0.30	494.90
2016	29.40	10.20	31.60	101.70	51.23	44.80	119.59	160.83	146.10	80.40	78.80	0.00	854.65
2017	0.00	18.30	28.80	75.30	105.40	68.38	120.40	156.18	137.48	100.55	36.95	31.40	879.14
2018	26.37	29.48	68.37	139.36	99.99	67.21	117.55	158.53	136.15	99.83	37.00	32.33	1012.18
2019	28.27	31.43	68.71	139.14	96.76	66.42	120.81	154.10	137.46	102.64	36.50	31.40	1013.63
2020	26.79	28.37	67.59	136.40	97.91	63.46	121.59	155.67	135.42	104.44	37.17	30.46	1005.26
Aver.	26.95	30.07	69.83	139.47	98.26	67.62	119.12	159.88	137.45	102.98	37.37	30.73	

Appendix Table 2: Ginir Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Annual
1990	5.9	61	87.9	260.4	184.6	13.7	15.4	3.5	68	99.6	86.4	7.4	893.8
1991	0	41.2	110.8	180.8	156	12.7	56.4	22.7	44.5	61.2	28.4	58.2	772.9
1992	84.8	17.6	80.2	227.2	171.1	38.7	23.5	44.6	99.6	190.6	154.7	68.5	1201
1993	73.8	118	0	143.6	151.9	40.4	25	43.8	99.7	187	92.7	30.3	1006.5
1994	60.8	39.8	80.5	227.2	163.2	35.6	28.3	25.8	63.3	197.2	125	36	1082.7
1995	0	8.6	193.3	161.8	82.5	25.7	12.1	2.7	30.7	142.6	16	7.7	683.7
1996	29.2	0	87.8	288.1	270.5	80.4	23.4	46.5	56.7	84.5	22.9	4.9	994.9
1997	0	0	27.5	158.2	34.3	71.3	12.3	22.9	105.7	301.6	241.3	71.2	1046.3
1998	201	96.5	18.6	188.8	137.5	36	39	9	53.1	146.1	25.7	1.3	952.1
1999	0	0	125.8	151.5	72.8	18.3	45.8	26.7	95.4	163.1	26.5	0	725.9
2000	59.8	39.2	22	229.7	97	29.7	0	55	85.7	229	40.8	23.5	911.5
2001	0	0	60.9	66.1	101.3	36.6	1.1	57.3	114.5	182.6	17	22.5	659.9
2002	44.5	0	127.5	133.1	43.5	24.6	6.3	0	122	242.9	26	41.1	811.5
2003	1.1	0	10.3	159.8	105.5	53.9	17.1	68.6	32.4	103.3	68.5	93.1	713.6
2004	85.8	0	3.9	218.9	79.5	2.7	0	18.1	93.7	183.9	78.1	76	840.6
2005	6.4	0	57.5	200.2	190.7	39.6	25.8	46	106	185.7	97.2	0	955.2
2006	5.2	31.8	81.1	346.8	139.6	77.6	3.2	16.7	126.8	404.3	82.2	102	1417.3
2007	0	0.3	45.1	263.1	107.5	56.2	21.9	53.4	128.8	191.3	138.7	0	1006.3
2008	8.7	0	0	220.7	95.1	4.2	40.5	52.3	96.6	294.3	206.8	0	1019.2
2009	38.9	406	19.1	245.9	113.1	22.2	5.4	2.7	225.2	159.8	83.4	39	1360.7
2010	0	109	312	315.2	547.8	25	50.2	15	105.8	181.3	39.5	0	1700.6
2011	3	2	0	109.1	214.6	79.9	39.7	63.3	139.9	145.3	173.9	35.3	1006
2012	0	0	5.6	150.8	219.9	34	2.9	232.2	284.3	157.3	110.5	46	1243.5
2013	56	0	238.5	385	219	3.5	94.2	49.1	45.4	93.2	157.6	109	1450.1
2014	0	0	155.7	194.3	283.7	5.5	14	127.9	125.8	318.2	180.7	0	1405.7
2015	0	0	100.6	114.8	164.8	74.5	14.7	2.5	105.6	287.6	81.1	5.7	951.9
2016	6.5	13.4	14.5	284.2	141.8	52	12.5	41	72.3	209.4	65.4	33	946
2017	0.6	121	117.4	117.4	220.6	0	62.1	44.5	75.8	156.2	93.5	0	1009.1
2018	0	80	125.7	532.5	231.5	66	24.4	8.5	91.5	197.5	126.3	2	1485.8
2019	1083	15.5	54	80.5	305.1	146	23.5	49.9	101	193.8	95.2	31.4	2178.9
2020	35	0	82.5	371.3	265.5	63	43.2	170.6	94.5	186	94.1	32.2	1437.9
Mon aver.	61	38.7	78.9	217	171.3	41	25.3	45.9	99.7	189.6	92.8	31.5	

***Appendix Table 3*:** Dinsho Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	17.3	163.4	113.8	191.5	37.9	42.6	224.7	545.8	284.2	145.8	57.4	33.5	1857.9
1991	0.0	0.0	46.4	337.0	270.3	176.2	189.0	87.4	154.9	127.8	2.8	65.0	1456.7
1992	0.0	70.7	66.2	194.4	324.3	293.7	135.4	218.9	334.7	414.4	229.6	74.6	2356.9
1993	136.8	180.3	7.0	281.6	147.6	184.4	290.2	210.7	147.0	289.6	23.1	5.9	1904.2
1994	0.0	7.2	51.2	383.7	404.1	103.2	329.4	290.5	91.1	21.8	145.3	57.8	1885.3
1995	0.0	69.9	218.6	254.0	115.9	65.9	187.9	163.7	88.6	162.6	14.6	50.2	1391.9
1996	33.4	14.1	83.8	222.7	115.7	96.7	225.0	135.0	146.0	47.1	52.1	2.5	1174.1
1997	27.8	0.0	101.0	190.9	63.7	85.1	124.7	201.5	193.3	316.5	226.1	77.1	1607.7
1998	114.6	26.0	92.2	122.9	85.6	61.0	143.0	285.8	194.2	265.9	53.6	0.0	1444.8
1999	24.6	5.8	162.7	104.7	93.5	84.1	187.0	218.0	136.5	151.3	33.4	36.1	1237.7
2000	2.9	0.0	45.1	174.4	73.2	47.1	184.2	228.0	94.6	169.4	18.5	48.7	1086.1
2001	0.0	175.1	101.2	103.4	147.0	193.9	314.0	88.7	58.8	105.4	34.0	9.8	1331.3
2002	0.0	2.8	156.6	117.3	201.7	44.9	88.5	89.1	71.5	99.4	6.3	164.0	1042.1
2003	8.4	0.0	14.9	167.3	37.8	86.9	150.4	145.6	132.1	44.7	36.6	50.8	875.5
2004	27.9	20.9	23.7	196.6	61.0	55.4	142.1	98.5	106.5	67.0	59.8	39.1	898.5
2005	53.9	19.0	81.0	196.7	147.4	57.5	96.8	131.9	93.1	153.4	65.0	2.0	1097.7
2006	6.0	58.3	43.4	219.9	77.4	39.8	174.1	197.7	98.4	141.1	100.1	49.9	1206.1
2007	2.0	183.5	32.1	251.0	66.2	86.2	170.7	153.0	187.7	197.6	194.5	194.6	1719.3
2008	202.6	22.9	0.0	0.0	95.8	109.3	200.8	188.1	116.4	88.9	57.7	0.0	1082.6
2009	76.5	172.8	29.5	126.1	97.2	16.7	106.4	185.7	69.6	78.7	43.9	66.5	1069.6
2010	3.6	137.8	222.1	195.0	118.3	47.7	308.3	158.7	89.1	77.0	20.0	2.5	1380.1
2011	0.0	0.0	0.0	9.5	144.0	198.1	116.1	165.2	72.9	57.1	73.0	0.0	835.9
2012	0.0	0.0	45.8	234.4	96.5	52.4	248.9	158.8	150.1	135.8	56.6	26.5	1205.8
2013	196.4	33.5	9.4	204.5	184.6	53.0	142.9	140.7	116.0	110.8	80.8	2.4	1275.1
2014	0.0	16.0	123.2	126.0	121.8	91.7	117.5	208.1	98.8	131.5	37.8	2.5	1074.9
2015	0.0	0.0	59.0	72.7	109.0	140.5	72.3	114.7	154.3	76.1	77.8	195.1	1071.5
2016	197.2	22.6	20.0	194.3	199.4	194.3	198.7	200.0	76.2	210.5	42.4	121.2	1676.8
2017	0.0	21.8	25.3	58.9	170.4	39.3	140.6	257.4	203.1	73.1	195.4	197.6	1382.9
2018	200.3	176.8	194.2	229.9	75.6	249.8	267.9	173.1	157.0	101.7	9.6	107.1	1942.9
2019	0.0	6.5	33.2	89.0	198.0	189.4	199.2	196.2	192.6	199.7	193.4	202.6	1699.9
2020	200.8	0.0	0.0	194.0	94.4	193.2	197.1	197.3	194.7	198.9	194.5	199.3	1864.2
Mon. aver	49.5	51.9	71.1	175.6	134.7	109.0	183.0	188.2	138.8	143.9	78.6	67.3	

Appendix Table 4: Robe Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	38.6	85.3	69.5	101.0	39.0	45.4	57.7	174.1	150.6	86.6	46.5	12.6	906.9
1991	4.1	26.0	72.1	62.7	83.5	34.5	101.0	53.9	82.8	27.1	54.0	10.3	612.0
1992	49.2	32.5	27.1	93.1	107.6	64.3	52.2	184.9	115.2	104.7	58.7	45.0	934.5
1993	43.4	68.7	0.0	118.4	86.9	59.3	58.0	168.1	130.8	100.7	7.3	0.5	842.1
1994	0.0	0.0	28.6	137.2	73.9	55.1	97.2	171.2	111.0	130.1	74.8	6.3	885.4
1995	0.0	17.1	38.2	155.0	51.4	18.8	157.1	123.7	111.8	70.7	2.6	16.7	763.1
1996	29.5	33.5	106.1	174.6	69.1	110.0	108.7	83.8	98.8	29.9	69.8	9.7	923.4
1997	6.3	0.0	88.8	134.2	50.6	59.2	75.7	82.0	118.4	127.2	109.9	43.9	896.2
1998	77.6	34.4	38.3	95.0	58.4	53.0	100.7	92.0	136.5	196.7	51.7	1.9	936.1
1999	10.3	34.5	123.7	97.2	65.9	41.7	147.3	121.2	114.1	95.5	25.7	1.4	878.5
2000	15.1	0.0	13.9	71.9	132.6	43.5	44.1	245.7	84.8	95.3	32.3	9.5	788.7
2001	22.2	10.9	118.1	58.9	76.8	77.8	107.8	119.9	122.6	70.0	16.2	17.9	819.1
2002	29.4	2.5	89.8	46.4	54.3	35.6	67.7	69.9	117.2	42.2	7.3	86.6	648.9
2003	15.5	0.0	55.6	163.0	68.2	99.0	103.1	146.7	97.5	49.2	37.2	56.4	891.4
2004	55.5	10.2	45.5	107.4	26.0	63.7	130.1	233.8	134.2	65.6	14.6	13.8	900.4
2005	16.1	12.5	30.4	155.5	148.3	72.7	47.9	64.8	99.6	38.7	39.6	0.0	726.0
2006	12.8	33.1	59.5	200.8	72.4	58.4	91.5	178.7	90.4	113.5	26.1	48.2	985.4
2007	0.0	40.6	93.6	103.5	86.1	56.9	140.2	168.1	110.2	56.9	72.4	0.0	928.5
2008	5.1	0.0	41.0	94.6	87.4	68.8	82.3	168.2	88.5	85.5	102.7	3.6	827.7
2009	30.2	8.3	31.6	106.1	48.7	41.1	66.4	134.3	107.1	79.3	57.1	38.2	748.4
2010	4.4	136.8	158.2	162.2	110.8	70.1	104.8	164.0	85.9	73.1	2.5	0.2	1073.0
2011	0.0	0.2	20.0	70.9	125.1	39.5	133.5	133.0	152.9	36.3	57.8	0.0	769.2
2012	0.0	0.0	8.8	149.0	69.0	34.1	139.0	233.7	137.5	67.5	4.4	12.3	855.3
2013	12.4	0.0	114.4	71.3	115.6	79.5	149.9	186.8	59.1	97.3	119.8	3.4	1009.5
2014	0.0	7.0	33.4	73.7	116.9	37.5	71.3	87.8	97.2	102.2	37.7	6.6	671.3
2015	1.7	0.0	39.7	52.0	195.2	63.4	62.7	150.1	98.3	58.0	48.2	2.6	771.9
2016	38.5	0.0	70.4	139.6	76.0	78.0	101.3	72.4	74.3	53.9	70.5	23.9	798.8
2017	0.0	15.2	33.3	110.9	110.5	89.6	53.9	178.2	256.6	109.1	20.8	4.8	982.9
2018	0.0	30.5	154.2	334.0	36.7	87.4	44.0	170.1	44.6	91.2	30.7	3.5	1026.9
2019	0.0	0.0	9.0	70.5	64.6	104.4	165.9	150.3	136.6	185.3	84.9	27.7	999.2
2020	27.3	3.0	95.2	176.6	45.2	89.5	114.3	127.7	122.4	66.0	91.8	91.4	1050.3
Aver.	17.6	20.7	61.5	118.9	82.3	62.3	96.0	143.2	112.5	84.0	47.6	19.3	

Appendix Table 5: Sinana Meteorological station corrected monthly rainfall (mm)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	11.7	69.1	134.1	164.9	112.0	22.7	14.9	86.3	134.2	110.5	28.9	17.9	907.2
1991	36.8	27.6	170.0	95.5	147.9	37.1	54.5	69.0	184.6	36.1	18.3	19.8	897.2
1992	83.3	25.1	14.3	87.9	135.2	74.0	74.8	102.5	137.6	143.1	68.0	79.7	1025.5
1993	70.9	82.2	0.0	161.5	242.0	40.5	36.4	80.6	151.2	80.6	4.6	5.1	955.6
1994	0.0	0.0	19.6	106.0	149.6	36.6	45.9	102.5	94.3	155.4	109.8	14.3	834.0
1995	0.0	7.3	95.6	160.5	142.0	66.7	22.6	75.4	122.1	150.4	11.3	10.4	864.3
1996	0.7	1.9	145.2	120.9	100.9	55.4	51.4	87.8	146.7	126.4	24.3	16.4	878.1
1997	22.8	0.0	32.6	133.3	103.6	46.2	83.9	49.6	206.2	225.3	46.8	19.0	969.2
1998	159.0	14.0	78.9	144.2	73.3	38.3	96.4	61.1	129.1	95.1	0.0	0.1	889.5
1999	0.2	4.8	132.1	73.3	237.7	77.6	75.5	98.0	244.1	167.4	1.2	0.0	1111.9
2000	24.1	18.6	14.0	245.7	60.6	22.0	14.3	41.8	112.6	128.8	51.3	22.8	756.7
2001	0.7	6.4	74.8	145.1	163.7	79.1	64.5	67.2	197.3	156.4	41.2	32.4	1028.7
2002	71.3	0.0	164.0	79.4	72.3	20.0	68.1	18.6	136.8	99.2	26.8	80.7	837.1
2003	3.0	5.7	57.2	134.2	62.2	65.0	60.4	90.2	101.4	77.3	56.9	17.3	730.8
2004	51.1	11.9	68.1	161.5	108.8	19.8	29.7	73.6	132.5	64.6	41.8	39.5	802.8
2005	33.6	17.0	52.7	118.7	275.7	57.9	51.0	85.2	142.8	125.9	45.2	0.0	1005.6
2006	13.9	43.8	79.0	197.0	106.2	34.8	29.7	115.9	116.1	209.2	30.3	51.7	1027.6
2007	3.2	7.2	76.1	195.5	116.3	86.8	75.7	90.9	110.1	139.0	87.3	0.0	988.1
2008	8.9	0.0	148.1	148.1	182.4	14.5	40.5	62.5	224.0	104.3	74.0	5.0	1012.3
2009	3.1	0.0	45.4	182.8	101.6	15.4	16.6	62.3	160.4	33.9	21.0	31.1	673.6
2010	0.0	82.7	146.8	264.6	97.4	12.0	71.6	97.4	191.1	52.8	8.1	0.0	1024.5
2011	0.2	0.0	0.0	104.1	173.2	42.4	23.5	119.8	125.4	35.4	68.0	0.0	692.0
2012	0.0	0.0	0.3	153.3	103.5	28.1	11.2	113.4	163.1	54.9	44.4	6.6	678.8
2013	47.8	0.0	109.6	195.6	107.4	195.6	128.7	23.1	86.4	164.7	35.1	0.0	1094.0
2014	0.0	0.0	0.0	86.4	98.0	55.2	4.7	179.0	133.1	185.0	26.3	0.0	767.7
2015	2.0	0.0	66.8	30.3	33.6	28.0	16.4	39.2	93.3	171.5	112.0	19.8	612.9
2016	30.8	15.0	25.0	149.7	128.8	54.7	27.9	97.3	80.1	276.9	107.8	8.3	1002.3
2017	0.0	16.6	53.8	112.9	80.1	24.6	2.5	105.5	147.1	160.4	106.4	0.0	809.9
2018	0.0	84.8	103.1	230.1	118.7	21.0	0.0	71.5	123.3	65.5	23.5	0.0	841.5
2019	23.1	17.8	47.3	141.0	210.9	138.6	47.0	82.9	137.8	125.8	83.4	16.7	1072.4
2020	22.6	0.0	69.3	145.9	126.9	214.2	145.6	242.0	125.0	125.9	46.3	17.0	1280.7
Aver.	23.4	18.1	71.7	144.2	128.1	55.6	47.9	86.8	141.6	124.1	46.8	17.1	

Appendix Table 6: Mean monthly streamflow of Weyib river at Sofumer station (m^3/s)

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	8.93	8.62	8.90	9.00	9.03	4.36	5.15	22.73	9.63	15.52	3.04	2.91	107.83
1991	1.03	0.92	1.77	6.90	10.02	3.82	13.21	5.32	5.14	5.30	5.24	5.39	64.06
1992	0.86	2.32	0.75	1.25	4.92	3.01	7.20	57.35	20.39	46.85	23.29	13.07	181.24
1993	8.99	18.56	3.25	6.08	18.87	10.73	12.61	19.04	13.94	19.29	15.34	1.82	148.51
1994	1.09	0.81	0.83	2.63	3.76	2.60	16.90	59.05	20.15	19.77	25.03	5.26	157.89
1995	1.51	1.41	1.89	18.11	8.62	36.18	3.48	35.09	44.84	57.77	6.30	4.37	219.56
1996	49.32	20.36	1.74	5.15	20.56	20.68	28.16	34.37	19.05	10.87	2.36	1.47	214.10
1997	1.14	0.81	1.01	7.09	6.10	3.19	8.35	11.05	11.58	60.70	40.71	20.86	172.57
1998	13.71	4.73	2.94	6.21	10.56	6.20	24.63	33.23	26.94	115.49	27.18	2.09	273.90
1999	1.72	1.34	3.70	5.79	7.81	10.97	107.86	101.25	84.77	126.45	63.01	39.07	553.73
2000	38.61	37.09	35.39	42.78	62.08	42.69	57.40	95.82	75.12	123.23	83.07	56.76	750.03
2001	39.59	37.19	41.20	77.98	62.24	55.09	63.87	93.48	112.70	105.98	65.90	30.85	786.08
2002	1.95	1.01	2.48	12.81	5.01	4.15	2.28	9.80	3.19	9.47	5.37	5.52	63.06
2003	4.56	0.83	1.72	17.93	4.21	3.01	13.46	62.87	62.01	9.96	3.36	6.53	190.47
2004	1.64	1.35	0.72	9.92	5.34	1.34	3.81	18.38	16.30	18.71	3.95	2.18	83.63
2005	0.85	1.65	1.59	2.13	34.99	4.57	10.66	23.27	18.58	37.84	8.67	1.11	145.89
2006	0.92	0.79	1.00	12.47	12.07	2.27	13.99	90.12	25.15	18.14	17.60	16.92	211.44
2007	36.19	22.09	34.71	36.69	36.22	33.97	12.71	24.16	103.94	23.46	36.59	36.80	437.52
2008	5.02	3.45	1.16	1.67	8.17	11.22	5.16	5.20	5.14	5.01	5.11	5.20	61.50
Mean	11.45	8.7	7.724	14.87	17.4	13.69	21.626	42.188	35.713	43.673	23.22	13.588	**253.84**
Vol (Mm3)	30.68	21.1	20.687	38.55	46.6	35.48	57.923	113	92.568	116.97	60.18	36.394	**670.08**

Appendix Table 7: Monthly average Wind speed in m/s for Robe Meteorological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	1.75	1.78	1.88	1.68	1.20	1.34	1.35	0.98	0.97	1.58	1.44	1.65	17.58
1991	1.81	1.77	2.00	1.77	1.85	1.62	1.56	2.14	1.85	1.81	1.66	1.93	21.77
1992	1.92	1.73	2.22	1.94	1.79	1.91	2.24	1.98	1.81	1.44	1.47	1.55	22.00
1993	1.65	1.85	2.25	1.99	1.73	2.05	1.89	2.23	1.89	1.64	1.66	1.94	22.75
1994	2.11	1.91	2.33	1.68	1.71	2.01	2.01	2.39	1.86	1.52	1.38	1.73	22.65
1995	1.74	1.68	2.05	1.65	1.89	1.99	2.29	2.33	1.58	1.30	1.38	1.64	21.53
1996	1.77	1.91	1.94	1.69	1.69	1.48	1.67	1.61	1.48	1.52	1.36	1.72	19.84
1997	1.74	1.95	2.22	1.41	1.95	2.06	2.01	2.04	1.80	1.29	1.14	0.05	19.66
1998	1.41	1.42	1.94	1.71	1.64	1.87	1.85	1.99	1.79	1.05	0.30	0.37	17.33
1999	1.67	1.66	1.47	1.48	1.67	1.79	0.95	1.98	1.43	1.16	1.30	1.46	18.03
2000	1.58	1.64	1.80	1.60	1.45	1.68	1.57	1.47	1.22	1.10	1.05	0.98	17.13
2001	1.51	1.39	1.52	1.50	1.50	1.48	1.51	1.50	1.46	1.52	1.47	1.49	17.86
2002	1.36	1.58	1.62	1.45	1.64	1.50	1.35	1.14	1.53	1.09	1.15	1.16	16.57
2003	1.57	1.32	1.37	1.35	1.29	1.24	1.55	1.39	1.35	0.97	1.01	1.16	15.59
2004	1.43	1.39	1.64	1.30	1.86	1.83	1.63	1.45	1.09	0.84	0.89	1.21	16.54
2005	1.42	1.52	1.79	1.36	0.98	1.31	1.55	1.47	1.25	0.93	1.07	1.46	16.11
2006	1.51	1.39	1.52	1.50	1.51	1.48	1.51	1.49	1.48	1.49	1.49	1.51	17.88
2007	1.51	1.37	1.52	1.46	1.53	1.48	1.50	1.50	1.48	1.52	1.47	1.50	17.85
2008	1.51	1.37	1.51	1.47	1.51	1.47	1.50	1.51	1.46	1.51	1.51	1.49	17.81
2009	1.51	1.38	1.50	1.50	1.51	1.47	1.52	1.50	1.47	1.52	1.48	1.51	17.86
2010	1.49	1.38	1.50	1.47	1.49	1.49	1.50	1.52	1.48	1.50	1.49	1.51	17.81
2011	1.51	1.38	1.51	1.49	1.51	1.48	1.49	1.51	1.49	1.52	1.48	1.51	17.87
2012	1.51	1.37	1.50	1.49	1.51	1.48	1.50	1.50	1.48	1.51	1.48	1.52	17.83
2013	0.88	1.05	0.87	0.74	0.85	0.89	0.78	0.84	0.65	0.58	0.58	0.73	9.43
2014	0.85	0.88	1.08	1.48	1.52	1.49	1.51	1.49	1.47	1.53	1.48	1.49	16.28
2015	0.86	0.90	1.05	0.93	0.79	0.88	1.00	0.92	0.69	0.52	0.55	0.74	9.82
2016	1.51	1.39	1.48	1.48	1.51	1.47	1.52	1.49	1.47	1.51	1.46	1.51	17.80
2017	1.50	0.89	0.59	0.38	1.51	1.49	1.51	1.52	1.47	1.50	1.48	1.51	15.35
2018	1.52	1.36	1.50	1.49	1.50	1.47	1.52	1.54	1.45	1.52	1.48	1.51	17.85
2019	1.51	1.37	1.50	1.47	1.50	1.48	1.49	1.52	1.49	1.51	1.48	1.50	17.84
2020	1.52	1.36	1.50	1.48	0.78	0.62	1.52	1.52	1.47	1.51	1.48	1.50	16.25
Mon. Aver	1.52	1.46	1.62	1.46	1.50	1.53	1.56	1.60	1.45	1.34	1.29	1.37	

Appendix Table 8: Monthly average Sunshine hour in (hr.) for Robe Meteorological station

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	8.79	5.52	6.66	6.11	8.23	8.36	6.88	6.11	5.84	7.04	6.95	8.86	85.35
1991	8.13	7.07	7.33	6.90	7.31	7.74	6.24	6.34	5.80	6.93	6.81	7.97	84.57
1992	6.54	5.61	8.20	6.65	7.10	7.42	6.06	4.94	5.66	4.71	6.21	7.12	76.24
1993	6.10	5.57	6.05	5.81	6.08	5.87	6.06	6.06	5.90	6.12	5.89	6.10	71.61
1994	6.08	5.57	6.15	5.94	6.08	5.89	6.11	6.11	5.92	6.09	5.85	6.09	71.88
1995	9.88	7.45	5.98	5.26	8.30	8.66	5.89	6.99	5.67	3.76	8.23	7.86	83.93
1996	7.11	8.65	6.73	6.10	6.11	4.99	6.42	6.35	5.65	6.87	7.39	8.84	81.21
1997	7.74	9.58	7.75	4.73	7.67	7.16	6.36	6.05	5.90	5.18	5.53	7.04	80.69
1998	6.83	7.64	7.65	6.76	7.19	8.15	6.01	6.31	4.70	4.14	7.59	9.97	82.93
1999	9.40	8.79	5.78	7.66	8.13	8.46	5.73	7.91	5.95	4.89	8.22	9.29	90.21
2000	8.97	9.91	9.66	6.90	7.30	7.41	7.33	6.17	5.38	5.13	7.67	9.00	90.83
2001	9.33	8.55	6.58	7.00	7.63	7.36	7.20	6.46	6.47	5.48	7.70	8.92	88.68
2002	8.38	9.43	7.04	6.68	7.74	7.64	7.53	6.12	5.68	5.04	8.07	6.23	85.59
2003	8.94	9.04	8.13	6.67	8.35	6.42	6.09	6.10	5.55	6.24	6.86	8.20	86.58
2004	8.12	8.85	8.04	5.89	9.17	7.19	7.25	7.18	5.17	6.85	7.62	8.10	89.41
2005	8.50	8.71	8.24	6.56	5.89	7.93	7.21	7.78	5.86	6.13	8.35	10.51	91.68
2006	9.39	7.73	7.46	6.74	7.47	7.64	6.45	5.86	4.79	3.99	6.85	6.29	80.65
2007	7.35	7.09	8.75	6.22	7.58	7.53	6.08	5.94	5.00	5.37	6.68	9.44	83.03
2008	8.80	9.21	9.62	5.61	7.34	6.51	6.85	5.97	5.55	4.91	7.70	6.61	84.68
2009	6.69	5.77	6.98	5.71	8.28	8.10	6.14	7.13	5.82	6.01	5.97	5.16	77.75
2010	8.24	5.08	5.17	6.26	6.76	7.57	6.19	5.81	4.74	4.56	7.65	8.22	76.26
2011	9.15	8.63	7.93	7.39	5.82	7.39	6.51	6.31	5.35	6.48	5.90	9.36	86.22
2012	10.21	9.70	9.34	6.16	7.47	6.72	4.89	5.19	3.49	5.21	6.76	8.33	83.47
2013	9.01	8.30	6.10	6.12	6.20	5.99	4.69	5.22	5.36	4.61	6.24	9.13	76.98
2014	8.81	6.56	6.34	6.57	6.19	7.50	5.43	5.96	4.73	5.18	5.93	6.06	75.26
2015	10.03	8.84	7.93	7.36	6.13	6.76	7.84	7.14	5.40	5.05	6.63	7.38	86.48
2016	6.08	5.54	6.00	5.89	6.08	5.97	6.10	6.04	5.94	6.09	5.89	6.13	71.76
2017	6.08	7.68	6.03	5.88	6.09	5.96	6.04	5.20	4.38	5.07	5.97	6.11	70.49
2018	6.07	5.59	6.05	5.93	6.11	5.84	6.02	5.68	6.37	5.59	6.60	6.11	71.97
2019	6.04	5.54	6.05	5.88	6.06	5.86	6.05	6.07	5.92	6.04	5.93	7.29	72.75
2020	7.90	7.72	6.08	5.75	6.50	6.77	4.08	5.10	4.25	6.13	5.90	6.05	72.23
Month. Aver	8.02	7.58	7.16	6.29	7.04	7.06	6.25	6.18	5.43	5.51	6.82	7.67	

Appendix Table 9: Monthly average minimum temperature for Robe Meteorological station

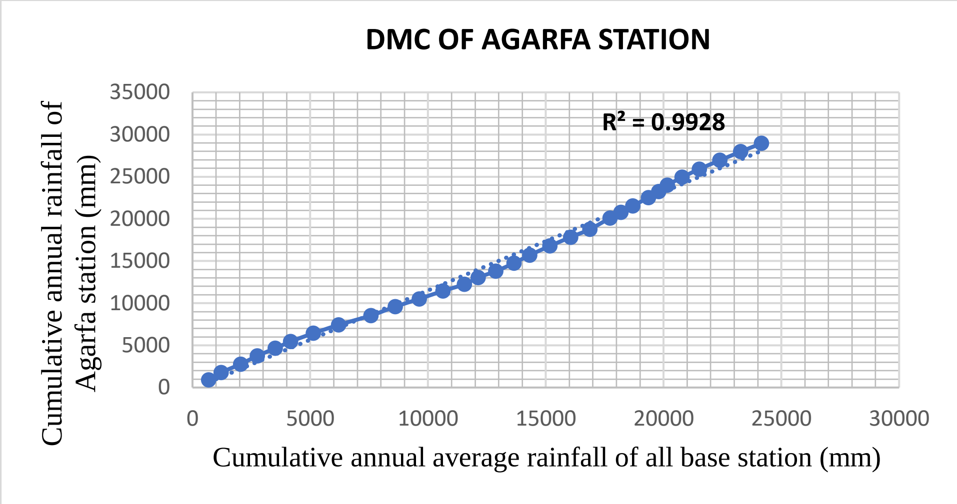
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	5.2	7.6	8.0	8.8	8.5	7.6	8.6	9.1	8.2	7.6	6.1	4.8	7.5
1991	5.8	6.5	8.3	9.1	9.3	8.4	9.1	8.9	7.7	7.2	6.5	5.8	7.7
1992	6.5	7.3	7.7	8.9	9.1	8.5	8.2	8.8	8.3	9.1	5.5	6.9	7.9
1993	7.0	6.2	5.5	8.2	9.3	8.6	8.4	8.4	8.1	8.4	5.7	4.8	7.4
1994	4.7	5.5	7.7	8.9	9.0	9.0	8.8	8.6	8.6	8.1	7.0	4.9	7.6
1995	4.4	6.2	8.7	9.2	8.6	8.2	9.0	9.2	8.4	9.0	5.2	5.5	7.6
1996	7.0	5.6	8.3	9.1	9.3	9.2	8.8	8.7	8.7	7.5	5.9	4.8	7.8
1997	6.1	4.9	7.7	9.6	8.8	8.0	9.0	8.8	8.3	9.8	9.0	8.0	8.2
1998	8.6	7.4	8.9	9.5	10.4	9.4	9.3	10.0	9.2	10.0	5.9	4.4	8.6
1999	5.6	5.8	9.2	9.0	8.9	8.2	9.1	8.3	8.5	9.4	5.8	5.5	7.8
2000	5.4	5.8	7.3	9.0	9.8	8.6	9.0	9.1	8.6	9.8	7.1	6.4	8.0
2001	5.6	5.9	8.8	9.8	9.8	8.9	9.2	9.5	9.2	9.0	6.6	6.3	8.2
2002	7.0	5.8	9.8	9.9	10.1	9.4	9.5	9.6	9.0	9.3	6.9	9.2	8.8
2003	6.8	7.3	9.5	9.9	10.3	10.0	10.1	10.0	9.6	8.5	7.4	6.5	8.8
2004	8.1	6.9	8.6	10.3	9.8	9.5	9.1	9.7	9.4	8.2	7.1	6.8	8.6
2005	6.7	6.7	9.5	9.9	11.1	9.5	9.5	8.9	9.5	9.0	6.2	5.1	8.5
2006	6.5	7.6	8.8	9.7	9.6	9.4	9.9	9.5	9.4	9.8	7.7	7.8	8.8
2007	7.0	7.9	8.3	9.8	10.5	9.9	9.8	9.6	9.6	8.1	7.3	5.3	8.6
2008	6.9	6.0	7.8	9.4	9.2	9.1	9.6	9.8	9.4	9.4	6.9	6.1	8.3
2009	7.4	6.4	8.8	10.0	10.3	9.6	9.9	9.6	9.9	8.8	6.2	9.4	8.8
2010	7.0	9.3	10.2	10.2	11.1	9.8	9.9	9.8	8.4	9.2	5.5	5.5	8.8
2011	5.7	6.0	8.1	8.7	10.3	9.7	9.9	9.6	9.3	7.8	8.1	5.2	8.2
2012	5.6	5.6	7.6	9.6	9.5	8.5	9.1	9.3	9.0	7.4	6.5	5.7	7.8
2013	4.1	5.4	7.8	9.2	9.2	9.2	9.3	9.7	8.6	8.9	7.8	4.4	7.8
2014	5.9	7.2	8.4	8.9	10.0	9.6	10.0	9.7	9.1	9.5	7.4	5.2	8.4
2015	4.7	6.0	8.0	9.3	10.1	9.9	10.0	9.2	9.4	9.8	8.0	7.2	8.5
2016	8.2	6.5	10.0	10.5	9.9	9.4	9.8	9.9	8.5	7.0	9.5	5.9	8.8
2017	7.9	6.7	8.3	9.3	10.2	9.5	10.2	10.2	9.9	10.3	7.2	3.8	8.6
2018	5.0	6.4	9.6	10.1	10.2	9.4	9.4	9.7	9.0	9.0	7.4	6.1	8.5
2019	5.4	6.3	8.9	9.5	10.2	10.5	10.0	10.5	9.4	9.0	8.5	8.4	8.9
2020	7.5	7.6	7.9	9.9	9.6	9.9	10.8	10.1	9.6	9.2	7.7	7.9	9.0
Mon. aver	6.3	6.5	8.4	9.5	9.8	9.2	9.4	9.4	9.0	8.8	7.0	6.1	

Appendix Table 10: Monthly average maximum temperature for Robe Meteorological station

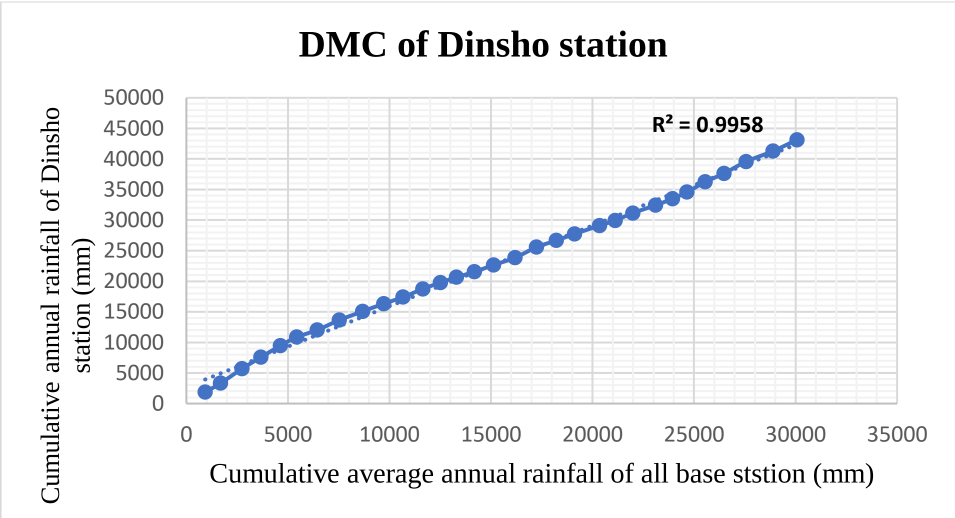
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	21.7	20.0	21.5	20.5	22.9	23.0	22.5	21.4	20.2	19.8	19.5	21.5	21.2
1991	23.3	21.1	23.4	20.8	22.1	22.8	21.6	21.4	21.0	20.8	21.0	22.3	21.8
1992	22.1	21.7	24.6	22.0	21.7	21.1	21.7	19.8	19.3	18.8	18.6	20.1	21.0
1993	20.8	18.5	22.6	20.7	21.2	21.4	22.2	21.4	20.1	19.5	19.7	21.9	20.8
1994	23.3	22.2	24.0	21.3	21.7	22.0	21.7	20.8	19.6	19.0	18.7	21.3	21.3
1995	22.9	21.4	22.2	20.6	22.4	22.8	21.8	21.3	20.4	19.4	20.2	22.4	21.5
1996	22.6	22.9	22.9	20.6	20.8	20.3	21.2	21.5	20.4	20.1	20.5	21.8	21.3
1997	23.3	22.1	24.4	20.7	22.1	22.5	21.8	22.2	20.9	19.5	19.2	20.6	21.6
1998	21.4	20.8	23.4	22.7	22.7	23.1	22.4	20.9	20.0	19.6	18.8	21.4	21.4
1999	22.8	21.7	21.0	20.8	21.6	22.1	21.2	21.0	20.0	19.2	19.3	21.3	21.0
2000	22.8	22.2	24.5	21.7	21.9	22.0	22.9	21.1	20.1	19.4	19.7	21.9	21.7
2001	23.2	21.8	22.3	20.7	22.7	21.6	22.1	21.1	20.1	20.1	19.6	22.0	21.4
2002	22.1	21.8	22.5	21.2	23.4	22.9	23.6	22.2	20.5	20.0	21.3	21.3	21.9
2003	22.7	22.5	24.2	22.2	22.9	21.2	21.3	20.8	20.3	20.1	20.3	20.7	21.6
2004	22.5	21.7	23.5	20.8	23.8	21.9	22.2	21.8	20.2	19.7	20.7	22.3	21.8
2005	23.0	22.6	24.2	22.4	21.3	21.0	21.7	22.9	21.6	20.5	20.7	22.3	22.0
2006	23.3	21.6	23.7	21.0	21.7	22.2	22.0	21.1	20.1	20.0	19.5	20.3	21.4
2007	22.4	21.2	23.8	21.2	22.6	22.0	21.3	21.1	20.5	18.9	19.2	21.6	21.3
2008	22.7	22.1	24.7	20.0	22.0	21.2	21.8	20.6	20.7	19.9	19.5	22.0	21.4
2009	22.6	22.0	23.9	21.4	23.0	23.4	22.9	21.5	20.6	20.7	20.9	21.5	22.0
2010	22.7	20.9	21.3	21.4	22.5	22.2	21.5	21.9	20.3	20.4	20.5	22.3	21.5
2011	23.3	22.5	24.3	23.7	22.3	22.4	22.5	21.1	19.9	19.9	19.9	21.7	22.0
2012	23.7	22.9	25.1	21.7	22.3	22.5	22.4	21.6	20.1	20.2	20.8	22.4	22.1
2013	23.7	22.9	23.2	21.7	22.7	21.7	21.7	20.6	20.4	20.0	20.1	21.8	21.7
2014	23.2	21.9	23.7	21.7	22.6	22.5	23.0	21.7	19.9	19.5	19.5	22.0	21.8
2015	23.6	23.0	23.8	22.6	22.6	22.2	23.6	22.7	21.3	20.8	20.3	22.7	22.4
2016	23.4	23.2	25.2	22.1	22.6	22.1	23.1	21.9	21.1	21.1	20.6	21.2	22.3
2017	23.5	22.0	25.1	21.8	22.4	22.8	22.9	22.0	20.6	20.9	19.4	20.9	22.0
2018	23.6	21.8	21.1	20.0	22.5	21.8	22.2	22.1	21.0	21.3	20.7	22.8	21.7
2019	23.9	22.8	25.5	23.5	23.4	22.0	21.9	21.3	20.9	20.2	20.1	21.2	22.2
2020	22.8	22.5	20.9	22.2	24.6	22.3	21.1	21.2	20.6	21.1	20.5	20.9	21.7
Mon. aver.	22.9	21.9	23.4	21.5	22.4	22.1	22.1	21.4	20.4	20.0	20.0	21.6	

Appendix Table 11: Monthly average Relative humidity in % for Robe Meteorological station

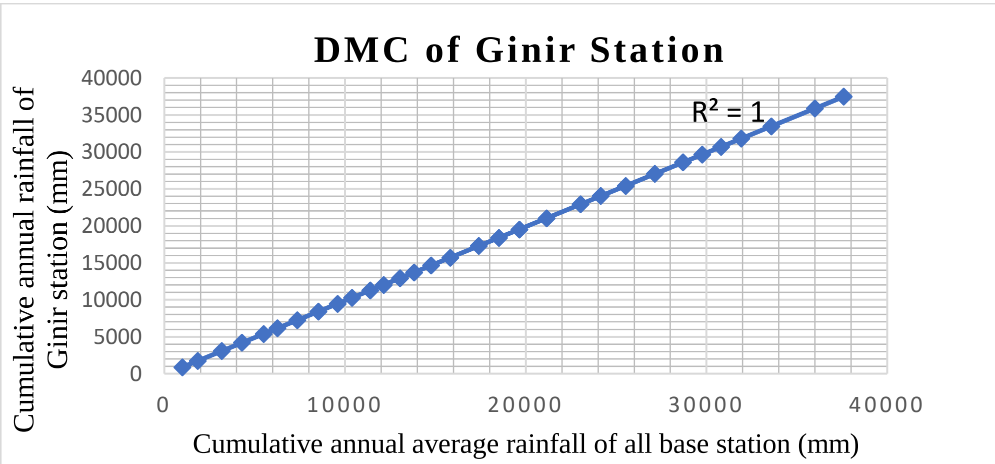
Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
1990	62.8	57.3	63.2	62.1	62.9	61.9	62.8	62.9	61.7	63.0	61.9	63.1	745.7
1991	56.4	53.2	62.5	69.7	66.6	59.2	73.0	70.9	67.8	58.8	58.3	51.7	748.2
1992	59.5	55.2	53.0	62.8	70.5	64.3	67.2	78.8	78.7	78.9	69.6	74.6	813.2
1993	63.0	57.3	63.1	61.5	62.8	61.7	62.7	62.8	61.8	62.9	61.5	63.0	743.9
1994	44.4	39.2	54.0	67.4	71.2	61.8	70.7	72.5	68.1	72.3	68.7	60.4	750.6
1995	51.6	49.5	68.3	72.8	67.8	60.8	74.3	75.5	67.6	73.2	59.9	60.3	781.6
1996	64.2	47.5	68.3	71.3	72.1	72.8	76.6	74.7	67.4	64.6	56.3	50.8	786.6
1997	49.6	28.6	54.8	71.8	67.2	65.9	72.9	70.8	68.7	79.5	75.7	69.7	775.2
1998	70.5	58.3	59.7	64.4	67.6	55.6	74.6	78.2	73.6	79.9	60.4	55.2	797.9
1999	54.6	44.6	71.1	65.1	66.6	62.2	73.8	74.4	69.1	78.5	59.4	52.6	772.0
2000	46.6	35.9	45.8	61.2	65.5	61.6	67.0	76.7	70.3	73.6	66.6	56.9	727.9
2001	52.3	48.8	66.9	65.5	67.3	65.9	72.9	75.7	71.5	76.2	65.4	60.6	788.9
2002	60.1	41.7	66.6	67.7	77.9	68.5	77.8	82.5	81.1	89.5	81.7	72.7	867.8
2003	56.9	43.1	58.3	62.6	62.0	66.7	73.8	77.4	71.6	71.9	64.0	62.7	771.0
2004	63.5	50.8	52.7	71.9	55.1	64.2	72.2	77.7	78.1	71.2	64.2	62.0	783.6
2005	57.0	44.2	60.8	63.4	75.7	70.0	73.4	71.3	69.8	74.2	61.7	48.2	769.7
2006	55.1	51.9	62.5	70.1	70.8	66.0	76.5	79.9	77.2	82.5	70.8	70.8	834.0
2007	61.1	48.0	60.5	70.2	71.0	53.5	76.0	78.3	72.5	73.9	64.0	52.9	782.0
2008	51.6	45.8	46.0	70.2	73.6	70.5	70.9	74.2	68.7	74.0	62.3	48.8	756.6
2009	55.2	43.9	47.5	72.3	66.0	58.7	65.5	75.0	69.6	69.7	55.2	64.8	743.4
2010	58.7	61.8	73.4	72.6	73.7	65.6	73.1	78.5	76.6	76.0	63.7	54.9	828.7
2011	52.5	44.0	50.9	57.5	74.1	65.6	71.8	78.5	77.0	71.7	72.2	54.8	770.6
2012	46.4	40.3	45.3	67.6	66.8	64.0	72.7	76.1	75.5	72.0	67.2	63.1	757.0
2013	62.8	57.5	63.0	61.7	62.8	61.6	63.0	63.2	61.5	62.8	62.1	62.5	744.7
2014	63.2	57.3	63.3	61.6	64.4	61.6	72.0	74.3	76.7	78.4	61.5	63.0	797.1
2015	47.5	48.5	55.2	62.9	70.4	67.6	68.2	75.3	62.0	62.9	61.8	63.2	745.6
2016	63.1	57.3	62.7	61.8	62.8	62.0	62.8	62.9	61.6	63.0	61.7	62.8	744.5
2017	62.9	57.6	63.0	61.5	63.1	61.6	63.1	79.2	78.0	77.5	61.7	63.0	792.4
2018	62.4	57.6	62.7	61.7	63.1	61.6	63.1	76.4	71.2	76.0	70.5	61.6	787.9
2019	45.0	52.5	52.3	64.8	70.7	61.9	62.8	63.0	62.2	62.9	61.7	70.2	729.9
2020	63.1	55.5	63.1	71.3	65.5	68.1	80.3	81.5	77.3	72.6	61.8	62.9	823.0
Mon. aver	56.9	49.5	59.4	66.1	67.7	63.6	70.6	74.2	70.8	72.4	64.3	60.8	



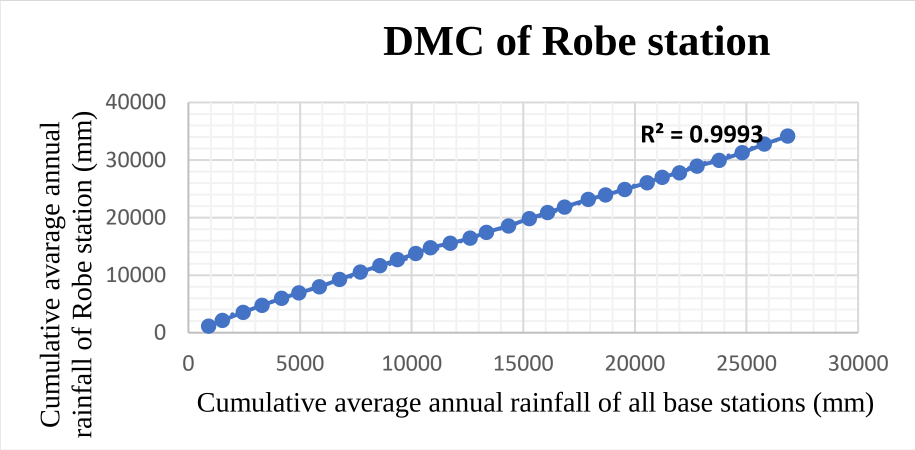
Appendix Figure 1: Double mass curve for Agarfa rain gauge station



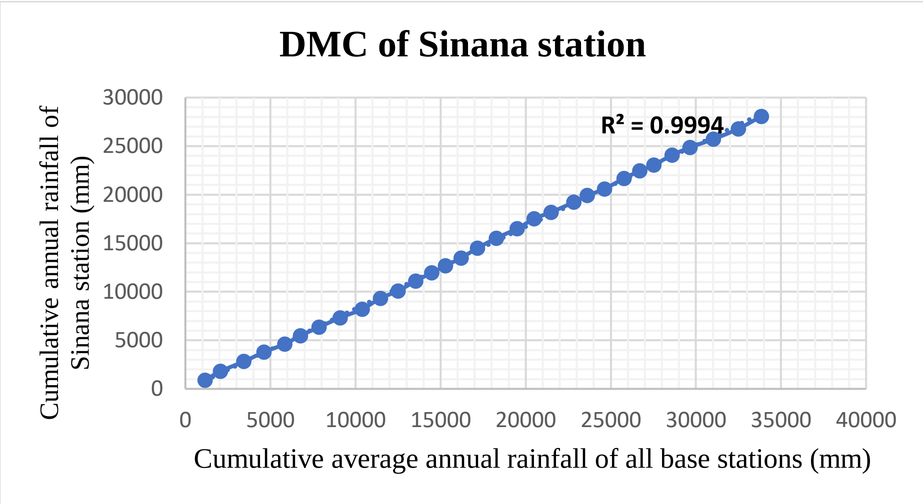
Appendix Figure 2: Double mass curve for Dinsho rain gauge station



Appendix Figure 3: Double mass curve for Ginir rain gauge station



Appendix Figure 4: Double mass curve for Robe rain gauge station



Appendix Figure 5: Double mass curve for Sinana rain gauge station.

Appendix Table 12: Rainfall and Effective rainfall of Robe station

	Rain	Eff rain
	mm	mm
January	17.6	14.1
February	20.7	16.6
March	61.5	49.2
April	118.9	95.1
May	82.3	65.8
June	62.3	49.8
July	96	76.8
August	143.2	114.6
September	112.5	90
October	84	67.2
November	47.6	38.1
December	19.3	15.4
Total	865.9	692.7

Appendix Table 13: ET_O and climate data for Robe meteorological station

Monthly ETo Penman-Monteith - untitled

Country: Ethiopia | Station: Robe

Altitude: 2480 m. | Latitude: 7.13 °N | Longitude: 40.05 °E

Month	Min Temp	Max Temp	Humidity	Wind	Sun	Rad	ETo
	°C	°C	%	km/day	hours	MJ/m²/day	mm/day
January	6.3	22.9	57	130	8.0	19.8	3.79
February	6.5	21.9	50	130	7.6	20.3	3.95
March	8.4	23.4	59	138	7.2	20.5	4.11
April	9.5	21.5	66	130	6.3	19.2	3.72
May	9.8	22.4	68	130	7.0	19.7	3.78
June	9.2	22.1	64	130	7.1	19.3	3.76
July	9.4	22.1	71	138	6.2	18.2	3.53
August	9.4	21.4	74	138	6.2	18.7	3.53
September	9.0	20.4	71	121	5.4	17.6	3.34
October	8.8	20.0	72	112	5.5	17.2	3.19
November	7.0	20.0	64	112	6.8	18.2	3.28
December	6.1	21.6	61	121	7.7	18.9	3.45
Average	**8.3**	**21.6**	**65**	**128**	**6.8**	**19.0**	**3.62**

Appendix Table 14: ET_O and climate data for Ginir meteorological station

Appendix Table 15: Crop Water Requirements for wheat

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.3	0.98	9.8	25.1	0
Oct	2	Init	0.3	0.97	9.7	22.7	0
Oct	3	Deve	0.3	0.98	10.8	19.3	0
Nov	1	Deve	0.49	1.6	16	15.8	0.2
Nov	2	Deve	0.77	2.56	25.6	12.4	13.1
Nov	3	Mid	1.06	3.55	35.5	10	25.5
Dec	1	Mid	1.16	3.96	39.6	7	32.6
Dec	2	Mid	1.16	4.03	40.3	4.2	36.1
Dec	3	Mid	1.16	4.16	45.7	4.4	41.4
Jan	1	Late	1.15	4.26	42.6	4.7	37.8
Jan	2	Late	0.94	3.6	36	4.5	31.5
Jan	3	Late	0.64	2.49	27.4	4.9	22.5
Feb	1	Late	0.39	1.51	10.6	3	6.3
					349.7	138.1	247

Appendix Table 16: Crop Water Requirements for Barley

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Oct	1	Init	0.3	0.98	9.8	25.1	0
Oct	2	Deve	0.35	1.13	11.3	22.7	0
Oct	3	Deve	0.67	2.19	24.1	19.3	4.8
Nov	1	Mid	1.03	3.37	33.7	15.8	17.9
Nov	2	Mid	1.15	3.8	38	12.4	25.6
Nov	3	Mid	1.15	3.86	38.6	10	28.6
Dec	1	Mid	1.15	3.93	39.3	7	32.2
Dec	2	Mid	1.15	3.99	39.9	4.2	35.7
Dec	3	Late	1.14	4.09	45	4.4	40.6
Jan	1	Late	0.92	3.42	34.2	4.7	29.5
Jan	2	Late	0.62	2.38	23.8	4.5	19.3
Jan	3	Late	0.35	1.37	11	3.5	6.1
					348.8	133.7	240.4

Appendix Table 17: Crop Water Requirements for Potato

Month	Decade	Stage	Kc	ETc	ETc	Eff rain	Irr. Req.
			coeff	mm/day	mm/dec	mm/dec	mm/dec
Sep	1	Init	0.5	1.72	17.2	32.7	0
Sep	2	Init	0.5	1.69	16.9	29.9	0
Sep	3	Deve	0.53	1.77	17.7	27.4	0
Oct	1	Deve	0.72	2.37	23.7	25.1	0
Oct	2	Deve	0.94	3.02	30.2	22.7	7.6
Oct	3	Mid	1.12	3.65	40.1	19.3	20.8
Nov	1	Mid	1.14	3.74	37.4	15.8	21.7
Nov	2	Mid	1.14	3.77	37.7	12.4	25.3
Nov	3	Mid	1.14	3.84	38.4	10	28.3
Dec	1	Late	1.14	3.89	38.9	7	31.9
Dec	2	Late	1.06	3.67	36.7	4.2	32.5
Dec	3	Late	0.92	3.31	36.5	4.4	32.1
Jan	1	Late	0.8	2.97	23.8	3.8	19
					395.3	214.8	219.2

Appendix Table 18: Crop Water Requirements for Cabbage

Month	Decade	Stage	Kc coeff	ETc mm/day	ETc mm/dec	Eff rain mm/dec	Irr. Req. mm/dec
Sep	1	Init	0.7	2.41	24.1	32.7	0
Sep	2	Init	0.7	2.37	23.7	29.9	0
Sep	3	Init	0.7	2.33	23.3	27.4	0
Oct	1	Init	0.7	2.29	22.9	25.1	0
Oct	2	Deve	0.73	2.36	23.6	22.7	1
Oct	3	Deve	0.8	2.59	28.5	19.3	9.2
Nov	1	Deve	0.86	2.82	28.2	15.8	12.4
Nov	2	Deve	0.92	3.04	30.4	12.4	18
Nov	3	Deve	0.98	3.29	32.9	10	22.9
Dec	1	Mid	1.04	3.55	35.5	7	28.5
Dec	2	Mid	1.06	3.68	36.8	4.2	32.6
Dec	3	Mid	1.06	3.8	41.8	4.4	37.5
Jan	1	Mid	1.06	3.92	39.2	4.7	34.5
Jan	2	Mid	1.06	4.05	40.5	4.5	35.9
Jan	3	Late	1.06	4.09	45	4.9	40.1
Feb	1	Late	1	3.93	39.3	4.3	35
Feb	2	Late	0.96	3.83	7.7	0.8	7.7
					523.5	**230.3**	**315.2**

Appendix Table 19: CWR and IWR calculation for wheat, barley, potato and cabbage

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Precipitation deficit												
1. Wheat	91.9	6.3	0	0	0	0	0	0	0	0	38.8	110
2. Barley	54.9	0	0	0	0	0	0	0	0	4.8	72.1	108.6
3. Potato	19.2	0	0	0	0	0	0	0	0	29.2	76.8	97.9
4. Cabbage	110.5	42.6	0	0	0	0	0	0	0	10.2	53.3	98.6
Net scheme irr.req.												
in mm/day	2.1	0.3	0	0	0	0	0	0	0	0.3	1.8	3.2
in mm/month	66.3	8.6	0	0	0	0	0	0	0	8.6	55	100
in l/s/h	0.25	0.04	0	0	0	0	0	0	0	0.03	0.21	0.37
Irrigated area (% of total area)	100	50	0	0	0	0	0	0	0	65	100	100
Irr.req. for actual area (l/s/h)	0.26	0.07	0	0	0	0	0	0	0	0.05	0.22	0.39